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This is a quarterly publication presenting articles covering recent developments in Far Eastern (particularly Japanese) scientific research. It is hoped that these reports (which do not constitute part of the scientific literature) will prove to be of value to scientists by providing items of interest well in advance of the usual scientific publications. The articles are written primarily by members of the staff of ONRASIA, with certain reports also being contributed by visiting stateside scientists. Occasionally, a regional scientist will be invited to submit an article covering his own work, considered to be of special interest. This publication is approved for official dissemination of technical and scientific information of interest to the Defense research community and the scientific community at large. It is available free of charge to approved members of the DOD scientific community. Send written request describing DOD affiliation to: Director, Office of Naval Research, Asian Office, Unit 45002, APO AP 96337-0007.

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CONTENTS

Cover: A bird's eye view of the SPring-8 facility, which will be Japan's newest and largest synchrotron-radiation facility. Groundbreaking took place in November 1991 in Harima Science Garden City, located in the mountains west of Kyoto. For more information on SPring-8, see Victor Rehn's article on page 243. Photo courtesy of the JAERI-RIKEN SPring-8 Project Team, Yukio Sato, Deputy Director General.

SIBRIEFS

Scientific Information Briefs

ASIACRYPT '91

The Asiacrypt '91 conference was held in Fujiyoshida, Japan, at the foot of Mt. Fuji, from 11-14 November 1991. It was cosponsored by the International Association for Cryptologic Research (IACR) and the Institute of Electronics, Information, and Communication Engineers [IEICE, a Japanese engineering society similar to the Institute of Electrical and Electronics Engineers (IEEE)] and was devoted to the presentation of the latest research results in cryptology. It attracted about 190 participants, roughly 120 from Japan and the others from over a dozen countries.

The technical program consisted of 4 invited lectures and 39 contributed ones. The proceedings will be published in 1992 by Springer in their *Lecture Notes in Computer Science* series under the title "Advances in Cryptology - ASIACRYPT '91." The editors will be the two program cochairmen, H. Imai of Yokohama National University (imai@imailab.dnj.ynu.ac.jp) and R. Rivest of the Massachusetts Institute of Technology (MIT) (rivest@theory.lcs.mit.edu).

The lectures covered all aspects of modern cryptology, although there was heavier representation than at some of other recent meetings on cryptanalysis and construction of classical private-key cryptosystems.

Sang-Jae Moon of Kyung Pook National University in Korea presented an invited lecture titled "Research Activities on Cryptology in Korea." This lecture turned out to be a survey of cryptologic activities in South Korea, Taiwan, and to some extent Japan. Although some South Korean and Taiwanese cryptologists have been attending Crypto and Eurocrypt meetings for years, and have occasionally contributed papers to those conferences, the recent rapid growth of interest in cryptology in their home countries is not well known. Some of the Korean meetings have attracted more than 100 participants, but it appears that these were more instructional meetings than research conferences. Participants from Taiwan and South Korea attributed the considerably greater level of activity in Korea to the support that country's government has given to cryptology work.

There has been substantial unclassified work on cryptography in China in the last 10 years. Many cryptologists from that country have attended Western conferences and visited European and American universities. Their work was well represented among the papers accepted for the Asiacrypt '91 program, but unfortunately because of visa and financial difficulties few of the authors were able to attend, and most of their lectures were canceled. There does not seem to be any survey of cryptologic research in China similar to that of Prof. Moon for Korea and Taiwan.

Some of the Japanese work in cryptology is well known in the United States, since Japanese scientists have frequently attended meetings in the West, have presented papers, and have published in English language journals. However, the full extent of this work is not appreciated.

There were demonstrations of cryptographic products at Asiacrypt '91, both hardware and software. It appears that the civilian market in Japan for cryptographic products is still undeveloped compared to those in Europe or North America. Fewer products are available, and market demand is small so far. There are some sophisticated products, especially from companies such as NEC and NTT, which have been involved in cryptologic research and development (R&D) work for a long time. However, sales do not appear to be substantial yet. The companies demonstrating their products included most of the large integrated electronics companies, and they appear to be committed to work in this area, as can be seen by the number of people they have working in it. There were no small companies represented that are so common in Europe and North America, consisting of a few people, and often started by a college professor. On the other hand, there were presentations by some companies that in the West would not have been expected to engage in sophisticated R&D.--*Andrew Odlyzko, AT&T Bell Laboratories*

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JAPAN'S PROGRESS ON THE INTEGRATED SERVICES DIGITAL NETWORK (ISDN)

Broad-band ISDN, high speed communication, is coming to Japan. Companies are preparing products for the time when, not if, this will be widely available. The actual date this reaches large numbers of Japan subscribers is less important than the sense that it is moving inexorably forward. (Now there are digital telephone boxes popping up in Tokyo, at least, with ISDN plugs for computer, fax, etc.)

NTT is the major agent, and its monthly *NTT Review* is full of articles about applications.

The current narrow-band integrated services digital network (N-ISDN) went into operation in Japan in April 1988 with the implementation of NTT's INS Net-64, which has a 64-kbit/s transmission capability. In June 1989 NTT introduced INS Net-1500, with a much higher speed of 1.5 Mbit/s. INS Net-1500 allows multimedia communication, including teleconferencing, and it is possible to transmit a document page via fax in only 3 seconds. INS Net started with 29 users and 114 subscriber lines. Total INS Net-64/1500 subscriber lines have now passed the 60,000 mark. NTT claims that the number of ISDN circuits contracted for is expected to have reached 80,000 by April 1992, including about 2,000 areas in Japan.

With a maximum transmission speed of 1.5 Mbit/s, N-ISDN service is limited to the transmission of voice, low- and medium-speed data, still pictures, and simple moving images. Broad-band ISDN (B-ISDN), with transmission speeds as high as 620 Mbit/s, will be able to handle high-density media such as high-definition television (HDTV), cable TV, and videotex. The asynchronous transfer mode (ATM) technique, key to B-ISDN switching, increases both speed and frequency bandwidth by a new transmission protocol. In N-ISDN, telephone, fax, video, and TV signals are divided and passed through several different switching systems and then re-combined just before reaching the receiving terminals. ATM technology integrates these into a single net. The individual ATM transmitting terminal chops the information waves into cells of fixed lengths, assigns labels to them, and sends the "wavelets" to the net. When these cells arrive at the receiving end, the various information signals, grouped by assigned label, are directed to appropriate terminals: telephones, computers, or TV conference terminals.

Although ISDN is still in the fledgling stage, Japanese industry is busy preparing for the second-generation B-ISDN, which is up to 2,000 times faster than the existing ISDN. In 1990, the International Telegraph and Telephone Consultative Committee (CCITT) introduced formal guidelines for B-ISDN. The Japanese telecommunications provider, NTT, plans to have B-ISDN operational for commercial users in 1996 with three distinct features: ATM net, optical-fiber communication, and "opticalization" of components. The new technologies will begin to replace the existing ISDN infrastructure around the year 2000 and is planned to be completed by 2015. It is claimed that optical fiber will reach cost parity with copper by 1995.

New 10-Gbit/s transmitting and receiving equipment is being developed by Toshiba for commercial availability in 1996. This equipment will use one optical fiber to carry 120K telephone lines simultaneously up to 80 km. It will feature several gallium arsenide integrated circuits (ICs) capable of processing information and is claimed to be three to five times faster than conventional silicon ICs. NTT has also successfully carried out a 10-Gbit/s optical transmission experiment using dispersion-shifted single-mode optical fibers with a combined length of 1,260 km that are installed in a commercial route between Tokyo and Hamamatsu (route length 326 km).

NTT's Large-Scale Integration (LSI) Laboratory recently introduced two new types of LSI chips for use with optical communications in B-ISDN. The FIFO (first in, first out) LSI chip is intended for ATM use, and the time-slot-converter LSI chip is designed for use in circuit divisions and multiplexing. The FIFO LSI chip uses 0.8μ BiCMOS technology on a single chip to upgrade processing speeds from the 80 Mbit/s of conventional FIFO to 250 Mbit/s, while reducing power consumption from 20 W to 0.8 W. The NTT system also involves an optical switching system based on VSTEP (vertical-to-surface-transmission electrophotonic device) technology, developed by them. The prototype switching system includes a superhigh-speed 4x4 (four inputs, four outputs) cell-fluting circuit that makes it possible to switch optical signals without converting them to electrical signals and an optical buffer memory that holds input signals until they are placed on the output lines. NTT's experiments, said to be the first of their kind, verified the feasibility of high-speed optical throughput switching, required to achieve 1-Tbit/s ATM switching for B-ISDN. In the area of standardization, NTT has developed a B-ISDN quality standardization system called "SQUARE" (Subjective QUality Assessment REference system) capable of measuring and standardizing both sound and video quality through simulation. NTT is seeking to establish SQUARE as an international standard for B-ISDN quality control through the CCITT.

Fujitsu has developed FLM2400, a synchronous digital hierarchy (SDH) optical telecommunications device for B-ISDN with a transmission speed of 2.4 Gbit/s. NTT also claims to be working in this area. SDH makes it possible to directly multiplex and cross-connect channels that have different capacities, allowing greater freedom and operational flexibility. In the B-ISDN-compatible terminals arena, Fujitsu has developed Monster, a multimedia workstation with an image processing capability, and has also announced a plan to produce an HDTV signal compression system within 2 or 3 years that would be able to vary transmission speeds over a B-ISDN line by 60 Mbit/s to 130 Mbit/s. Since HDTV signals require extremely high transmission rates (approaching 1 Gbit/s), the optical fiber line over which the signals are sent can become too crowded for other data transmissions to take place concurrently. The ability to slow down the HDTV signals could provide an effective means of "time sharing" among various signals while reducing data loss or contamination, a major problem in high-speed ATM transmissions.--*David K. Kahaner, ONRASIA*

* * * * *

SUPERCOMPUTING JAPAN'92 CONFERENCE

Supercomputing Japan'92, held from 23-25 April 1992, is described, with particular emphasis on Hitachi's new 32-GFLOP supercomputer.

by David K. Kahaner

INTRODUCTION

Once each year Supercomputing Japan'xx is held. The two preceding conferences were in central Tokyo. This year's was held in a new conference center at the harbor in Yokohama. At the beginning of this century Yokohama was the center of international business in Japan but has been eclipsed by growth in Tokyo (which is now 30 minutes away by local train). Yokohama is currently trying to regain some of this activity with a major building program and harbor redevelopment. The convention center is spectacularly situated and well equipped, but attendance on the conference's opening day was very low, notwithstanding the presence of U.S. Ambassador Armacost at the opening ceremonies.

This year's conference was organized around 3 days of technical program of which the first was all in English, with speakers almost entirely from the West, and two subsequent days of Japanese speakers. In the past, the technical part of the program has been poorly attended and this year's opening day was no exception, with one estimate of fewer than 100 listeners. Emphasis in all the technical talks is on overview and general applications; the very specialized research papers that are often presented at Western meetings such as Supercomputing'91 (held in November 1991 in Albuquerque) are almost entirely missing. The second and third day's papers covered applications in physics, biology, structures, automobiles, computational fluid dynamics, weather, and electromagnetics, but with only one or two papers in each section. A separate exhibition of vendor products runs for all 3 days. In previous years the exhibition has been thronged, and last year there were almost 9,000 visitors. While I can't speak about the second and third day, on the first day there seemed to be more vendor staff than visitors. This might have been due to bad weather, economy, or some other factors. There were fewer than 60 vendors represented, including publishers, societies, etc.; I assume that this was related to a slowdown in the Japanese computer industry.

I found only a very few items of special interest and almost nothing really new, save for Hitachi's exhibit describing its new supercomputer (announced a few weeks earlier) and Sanyo's new dataflow machine. Overall, one Western visitor commented, "Is this all there is?" I will mention a few Japan-related exhibits but omit any discussion of the U.S. vendors who were present, as expected.

NEC

NEC described its upgraded version of the SX-3, named SX-3R. The major change here is that the clock cycle has been reduced to 2.5 ns (from 2.9 ns), increasing the peak performance of a four-processor system to about 26 GFLOPS. I was told by NEC scientists that the company feels that it has a need to continue to develop a high end vector supercomputer using bipolar large scale integration (LSI) and liquid cooling technologies, although new technologies such as GaAs are being studied. They also feel the need to develop a highly parallel computer using complementary metal oxide semiconductors (CMOS) and BiCMOS. But a key aspect of these plans is that connections between a parallel and vector supercomputer need to be strong; in other words, NEC feels there is a strong need to keep the logical architecture the same for both types of machines. My own discussions with NEC staff working on parallel computing have not suggested that much has been done along these lines yet.

NEC is involved in quite a large amount of research and development (R&D) that was not represented at this conference. For example, they have developed a number of parallel machines for special purpose applications including the following.

- TIP: Dataflow pipeline image processor (ring structured, data-driven processing, pipeline processing, 128 CPUs, connected by hierarchical rings, suitable for image and neuro processing).

- Video signal processor (using 288 custom VLSI chips, broadcast bus, video-rate real time processing, including raster/subregion parallelism).

- HAL, HAL II, HAL III: Logic simulation machines for VLSI (64 CPUs, multistage interconnection network, function level simulation capability, hardware implemented simulation algorithm, subcircuit parallelism).

- Cenju: Circuit simulation (transient circuit analysis) machine (72 CPUs, bus/cluster, multistage interconnection network, quasi-shared memory. Cenju is scheduled to be upgraded this year to Cenju II with faster, custom chips (currently 68000s). I reported on Cenju earlier ["Two Japanese Approaches to Circuit Simulation," *Scientific Information Bulletin* 16(1), 21-26 (1991)]. NEC is now attempting to experiment with this machine on other applications including concurrent fault simulation, line-search router, magnetohydrodynamic (MHD) plasmas, and finite element analysis. Cenju is the closest that NEC has to a general parallel computer.)

- CHI, CHI2: Parallel inference machine (part of the Institute for New Generation Computer Technology (ICOT) Fifth Generation Computer Project, implements a parallel genetic algorithm, with a new object-oriented language A'Um90. Current applications are to DNA sequence searching.)

- VPP: Vector pipeline processor chip (using 0.8-μm BiCMOS, this 64-bit chip runs at 100 MHz and has a peak performance of 200 MFLOPS--addition or subtraction can be done in parallel with multiplication, division, or logs, each at 100 MFLOPS.)

NEC has also collaborated with Hitachi and Fujitsu in the National Supercomputer Project that I have written about earlier. There is also activity on pipelined memory chips.

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- N. Nishi, Y. Seo, R. Nakazaki, and N. Ohno, "A Pipelined Storage for Vector Processors," *Proc. 4th Int. Conf. on Supercomputing and Third World Supercomputer Exhibition* 1, 253-260 (April 1989).

HITACHI

On 31 March 1992, Hitachi Ltd. announced a new series of vector supercomputers, HITAC S-3800 and HITAC S-3600. The S-3800 can be obtained as a multiprocessor system, with a pipeline pitch estimated to be 2 ns using silicon. These are the third generation of HITAC supercomputers, following HITAC S-810 and S-820. For the first time, Hitachi supercomputers support an OSF (Unix) operating system. As I reported earlier, Hitachi has not sold many of their 810/820s in the past year because performance lagged that of NEC and Fujitsu products, so this product has been needed.

Readers should note that I have not yet spoken to anyone who has run on this machine, although delivery is scheduled for the end of this year. As far as I know Hitachi has no plans to market them in the United States.

The S-3800 is water cooled and has six models: 160, 180, 182, 260, 280, and 480. The first digit gives the number of processors, the second relates to the speed, and the last digit '2' in model 182 shows that the system has two scalar units in one processor. The S-3600 is an air-cooled supercomputer with four models: 120, 140, 160, and 180. The specifications for both of these supercomputers are given in the Appendix.

A large number of languages and software products focused on engineering applications have been announced for these machines. One of my favorites is a combination graphical user interface coupled with a powerful scientific programming environment called DEQSOL (Differential Equation Solver Language) that I reported on at length ["DEQSOL and ELLPACK: Problem-Solving Environments for Partial Differential Equations," 16(1), 7-19 (1991)]. ELLPACK is the most similar U.S. software effort that I am aware of, but DEQSOL is designed much more as an engineering tool than as a research environment for algorithms.

The Hitachi exhibit also showed various computer graphics demos, including turbines, tidal waves, flow around a cylinder, molecular dynamics, eddy current for maglev train, etc., all illustrating the power of the supercomputer in modelling applications. One of the most interesting (to me) was almost a perfect copy of a Cray demo showing air flow inside the body of a large commercial airliner; air "particles" vent from the ceiling and could be viewed dispersing throughout the interior. A number of cross sections were also shown. The simulations were done using rational Runge-Kutta integration. What made this fascinating was that Hitachi was modelling air flow inside a Shinkansen (train) body, rather than in an aircraft.

In March 1992 I accompanied Mr. Lloyd M. Thorndyke on a visit to Hitachi. Thorndyke is the founder of ETA Systems in the United States. At that time we were given an overview and explanation of Hitachi packaging technology, some of which is used in these new systems. Both of us were extremely impressed, especially Thorndyke, who has many years of experience in this field. Packaging refers to multichip module construction, boards, cooling, etc. One of the most interesting aspects of Hitachi's work was that the packaging technology looked to us like it was capable of being used cost effectively on products below their highest end machine. Another point to note here is how much life there seems to be left in silicon (2 ns) and that Japanese vendors have clearly demonstrated that they will obtain high performance by capitalizing on their expertise in fast technologies. For example, Hitachi scientists feel that current CMOS technology leads to seemingly high variability in performance, but that this may be related to lithography variability; thus improvements in the latter will translate into performance improvements.

Reducing machine cycle time is a very direct way to increase performance, but doing this requires a substantial number of technological improvements. Machine cycle time is a direct function of the switching time delay or fanout delay per gate for logic or the access time for memory times the number of circuits in the loop. Logic and memory improvements require semiconductor technology, such as developing faster circuit families, or circuits with larger fanout capability. Shortening signal paths, using lower dielectric constant materials, using pins and other conductors with lower inductance, and generally using LSI, modules, boards, and cables with better and more uniform electric characteristics are areas in which to look for improvements. Technologies needed here are design automation, packaging, materials, and componentry. Increasing the number of circuits in the loop requires logic design technology and "smart" logic. Reducing the average number of cycles per instruction is typically done with pipelined (staged) execution leading to shorter execution pitch, parallel execution, and long instruction words.

The Hitachi scientists we spoke to emphasized to us that they feel that their products are competitive with IBM technology and lead in many important areas. (Quite different from the Western view of Hitachi as an IBM follower.) A good overview of the hardware technology used by Hitachi was presented in the paper "Hardware Technology for Hitachi M-880 Processor Group." This was given to us by

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FUJITSU

Fujitsu was showing its VP series machines. The VPX line incorporates some manufacturing cost reductions and the X signifies that it runs Unix. I was shown a number of Fujitsu software products, a crystal structure design system (Crystruct), a computational material design package (COMDEP), as well as various computer-aided design (CAD) packages. While these have English names, they were entirely developed in Japan and looked competitive with Western products. Surprisingly, Fujitsu did not have any exhibit space devoted to its AP1000 parallel computer.

MATSUSHITA

Matsushita (Panasonic, National) had a large exhibit showing off its ADENART. I have reported on this several times in the past, but to repeat, this is a 265-processor parallel machine built on 16 boards. Each board is built with a crossbar switch and communication between boards is designed to make three-dimensional (3D) alternating direction implicit (ADI) computation very efficient. The original design was from Kyoto University (Nogi), but Matsushita is commercializing the product. The current version is based on 68000 chips and has a peak performance of 2.5 GFLOPS. This is a running system, complete with English language user's manual. One ADENART is to be installed at Tokyo University this year. The leader of the project,

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told me that a newer version (based on a custom RISC chip) will have substantially higher performance. I've been told that the internal name for this new machine is either Ohm or Omega.

SANYO

Sanyo displayed an interesting dataflow machine (Cyberflow). This is a 64-processor unit, a high speed display control unit, and an input/output (I/O) interface, packed together in a 0.1 m^3 body. Peak performance is 640 MFLOPS, based on 10 MFLOPS/ 10 MIPS per chip. Each single VLSI dataflow chip (1.2 μ CMOS technology) has 4 MB of memory and 40 MB/s communication capability (total) through four bi-directional ports. The 64 processors are arranged in a torus and the complete unit has two 1280x1024 24-bit frame buffers. Interestingly, Sanyo also produces a line of PC products including a 20-MHz, 386-based notebook. (Note that there are very few Japanese electronics consumer product companies that are not really computer companies, e.g., Sony had a large display of tape storage devices, etc.)

PARALLEL COMPUTING

For the most part Japanese companies are behind those in the United States in parallel computing hardware and Japan is far behind in software and tools development for parallel machines. There are very few general purpose parallel machines and those that exist are all pre-commercial. Until university researchers can easily access parallel machines, there is little likelihood of them producing significant quantities of software tools research, save for some simulation. There are a reasonable number of special purpose parallel machines, and I have mentioned some of these above. Several of these machines implement uniquely Japanese ideas, but there is only a small chance that these systems will get to the United States in the near future. (The Japanese companies are conservative about jumping into the marketing of parallel processing hardware; perhaps they see these as taking sales away from existing products.) I think that it would be extremely useful to give U.S. scientists an opportunity to try these machines in a substantial way. For Fujitsu, good access could be provided at the Australian National University in Canberra. Others would have to be arranged through the vendors or the Japanese universities where they are being installed.

Appendix

SPECIFICATIONS FOR HITACHI'S NEW VECTOR SUPERCOMPUTERS

HITAC S-3800

Model 160

Maximum performance (GFLOPS)	4
No. of scalar units	1
No. of vector units	1
Instruction processor	
No. of vector instructions	99
Buffer memory (KB)	256
No. of add+mult pipes	4
No. of div pipes	1
No. of mask pipes	1
No. of load pipes	2
No. of load/store pipes	2
Main storage	
MB	256/512/1024
Error check	1 bit correction, 2 bits detection
Extended storage	
Maximum (GB)	16
Maximum transfer (GB/s)	2 or 4
Error check	2 bits correction
I/O Processor	0-64/128 optical channels; 32-64/128 metal channels; total channel throughput: max 1.1 GB/s; BLMPX and BYMPX channels
Cooling	water
Facilities	Video output (NTSC and HDTV), HIPPI

Model 180

Maximum performance (GFLOPS)	8
No. of scalar units	1
No. of vector units	1
Instruction processor	
No. of vector instructions	99
Buffer memory (KB)	256
No. of add+mult pipes	8
No. of div pipes	1
No. of mask pipes	1
No. of load pipes	4
No. of load/store pipes	4
Main storage	
MB	512/1024
Error check	1 bit correction, 2 bits detection
Extended storage	
Maximum (GB)	16
Maximum transfer (GB/s)	2 or 4
Error check	2 bits correction

I/O Processor	0-64/128 optical channels; 32-64/128 metal channels; total channel throughput: max 1.1 GB/s; BLMPX and BYMPX channels
Cooling	water
Facilities	Video output (NTSC and HDTV), HIPPI

Model 182

Maximum performance (GFLOPS)	8
No. of scalar units	2
No. of vector units	1
Instruction processor	
No. of vector instructions	99
Buffer memory (KB)	256x2
No. of add+mult pipes	8
No. of div pipes	1
No. of mask pipes	1
No. of load pipes	4
No. of load/store pipes	4
Main storage	
MB	512/1024
Error check	1 bit correction, 2 bits detection
Extended storage	
Maximum (GB)	16
Maximum transfer (GB/s)	2 or 4
Error check	2 bits correction
I/O Processor	0-64/128 optical channels; 32-64/128 metal channels; total channel throughput: max 1.1 GB/s; BLMPX and BYMPX channels
Cooling	water
Facilities	Video output (NTSC and HDTV), HIPPI

Model 260

Maximum performance (GFLOPS)	8
No. of scalar units	2
No. of vector units	2
Instruction processor	
No. of vector instructions	99
Buffer memory (KB)	256x2
No. of add+mult pipes	8
No. of div pipes	2
No. of mask pipes	2
No. of load pipes	4
No. of load/store pipes	4
Main storage	
MB	512/1024
Error check	1 bit correction, 2 bits detection
Extended storage	
Maximum (GB)	32
Maximum transfer (GB/s)	2 or 4
Error check	2 bits correction

I/O Processor	0-64/128 optical channels; 32-64/128 metal channels; total channel throughput: max 1.1 GB/s; BLMPX and BYMPX channels
Cooling	water
Facilities	Video output (NTSC and HDTV), HIPPI

Model 280

Maximum performance (GFLOPS)	16
No. of scalar units	2
No. of vector units	2
Instruction processor	
No. of vector instructions	99
Buffer memory (KB)	256x2
No. of add+mult pipes	16
No. of div pipes	2
No. of mask pipes	2
No. of load pipes	8
No. of load/store pipes	8
Main storage	
MB	1024/2048
Error check	1 bit correction, 2 bits detection
Extended storage	
Maximum (GB)	32
Maximum transfer (GB/s)	2 or 4
Error check	2 bits correction
I/O Processor	0-64/128 optical channels; 32-64/128 metal channels; total channel throughput: max 1.1 GB/s; BLMPX and BYMPX channels
Cooling	water
Facilities	Video output (NTSC and HDTV), HIPPI

Model 480

Maximum performance (GFLOPS)	32
No. of scalar units	4
No. of vector units	4
Instruction processor	
No. of vector instructions	99
Buffer memory (KB)	256x4
No. of add+mult pipes	32
No. of div pipes	4
No. of mask pipes	4
No. of load pipes	16
No. of load/store pipes	16
Main storage	
MB	1024/2048
Error check	1 bit correction, 2 bits detection
Extended storage	
Maximum (GB)	32
Maximum transfer (GB/s)	2 or 4
Error check	2 bits correction

I/O Processor	0-64/128 optical channels; 32-64/128 metal channels; total channel throughput: max 1.1 GB/s; BLMPX and BYMPX channels
Cooling	water
Facilities	Video output (NTSC and HDTV), HIPPI

The technologies of S-3800:

Logic LSI:	25k gates, delay 60 ps and 12k gates, delay 70 ps
Vector register:	9k gates + 18 kbit memory
Memory LSI:	11k gates + 256 kbits and 2k gates + 64 kbits

Two kinds of operating systems:

HI-OSF/1-MJ (Unix) and VOS3/AS (MVS-like)

HITAC S-3600

Model 120

Maximum performance (GFLOPS)	0.25
No. of scalar units	1
No. of vector units	1
Instruction processor	
No. of vector instructions	90
Buffer storage (KB)	256
No. of add pipes	1
No. of add+mult pipes	1
No. of div pipes	1
No. of mask pipes	1
No. of load pipes	0
No. of load/store pipes	1
Main storage	
MB	128/256
Error check	1 bit correction, 2 bits detection
Extended storage	
Maximum (GB)	6
Maximum transfer (GB/s)	1 or 2
Error check	2 bits correction
I/O Processor	0-64 optical channels; 26-64 metal channels; total channel throughput: max 288 MB/s
Cooling	air
Facilities	Video (NTSC), HIPPI

Model 140

Maximum performance (GFLOPS)	0.5
No. of scalar units	1
No. of vector units	1

Instruction processor	
No. of vector instructions	90
Buffer storage (KB)	256
No. of add pipes	1
No. of add+mult pipes	1
No. of div pipes	1
No. of mask pipes	1
No. of load pipes	1
No. of load/store pipes	1
Main storage	
MB	256/512
Error check	1 bit correction, 2 bits detection
Extended storage	
Maximum (GB)	16
Maximum transfer (GB/s)	1 or 2
Error check	2 bits correction
I/O Processor	0-64 optical channels; 26-64 metal channels; total channel throughput: max 288 MB/s
Cooling	air
Facilities	Video (NTSC), HIPPI

Model 160

Maximum performance (GFLOPS)	1
No. of scalar units	1
No. of vector units	1
Instruction processor	
No. of vector instructions	90
Buffer storage (KB)	256
No. of add pipes	2
No. of add+mult pipes	2
No. of div pipes	1
No. of mask pipes	1
No. of load pipes	2
No. of load/store pipes	2
Main storage	
MB	256/512
Error check	1 bit correction, 2 bits detection
Extended storage	
Maximum (GB)	16
Maximum transfer (GB/s)	1 or 2
Error check	2 bits correction
I/O Processor	0-64 optical channels; 26-64 metal channels; total channel throughput: max 288 MB/s
Cooling	air
Facilities	Video (NTSC), HIPPI

Model 180

Maximum performance (GFLOPS)	2
No. of scalar units	1
No. of vector units	1
Instruction processor	
No. of vector instructions	90
Buffer storage (KB)	256
No. of add pipes	4
No. of add+mult pipes	4
No. of div pipes	1
No. of mask pipes	1
No. of load pipes	4
No. of load/store pipes	4
Main storage	
MB	512/1024
Error check	1 bit correction, 2 bits detection
Extended storage	
Maximum (GB)	16
Maximum transfer (GB/s)	1 or 2
Error check	2 bits correction
I/O Processor	0-64 optical channels; 26-64 metal channels; total channel throughput: max 288 MB/s
Cooling	air
Facilities	Video (NTSC), HIPPI

Many thanks to Y. Oyanagi for providing translations from Hitachi catalogs.

AN UPDATE ON COMPUTING ACTIVITIES IN TAIWAN

Visits to the Industrial Technology Research Institute (ITRI), Hsinchu Science Park, and the National Center for High Performance Computing and attendance at the Intelligent Signal Processing and Communication Systems Workshop (ISPACS'92), all in Taiwan, are described.

by David K. Kahaner

INTRODUCTION

My earlier *Scientific Information Bulletin* articles on Taiwan ["Computing in Taiwan," 16(2), 23-29 (1991); "Various Computing Activities in Taiwan," 17(2), 9-14 (1992)] should be referred to for additional background. This visit covered two new sites.

Taiwan, the Republic of China (ROC), has an impressive record of economic growth and now has more than $80B in foreign reserves in its coffers. With all this ready cash the country has been trying to find intelligent opportunities for investments. Some examples of these follow.

One of the most highly publicized is an attempt by Taiwan Aerospace to purchase 40% of the U.S.'s McDonnell Douglas Corporation for $2B. Taiwan Aerospace was created in 1991 with both public and private capital. The deal is not yet final, and there have been hitches both political and financial, but if it goes through it will give Taiwan an important role in the rapidly growing Asian air travel market, as well as giving the country more experience in high technology manufacturing and aerospace technologies.

The Taiwanese Chi Mei Industrial Company is planning to build an acrylonitrile butadiene styrene (ABS) resin plant in Houston, Texas, which will make it one of the largest manufacturers of this product in the United States. It is estimated that the project will cost $300M.

Members of Taiwan's Nationalist Party have offered to lend mainland China (PRC) $10B if an agreement can be reached on various political concessions. Relationships between ROC and PRC are complicated. Governments both in Taiwan and in Beijing claim sovereignty over all of China, including Taiwan, and have vowed to reunify the country one day. In fact, efforts to formally separate the countries have repeatedly been rejected by both governments. Economic ties between the two sides have been growing rapidly since political tensions began to ease in the late 1980s.

As has been repeatedly reported, China is moving to expand its economic base, especially in south China, by setting up various free trade zones. Small businesses in these areas have a rapidly growing trade activity with neighboring countries. For example, a $25B free trade zone is to be built on Hainan Island, modelled on Hong Kong. The 15-year project [Yangpu Economic Development Zone] will get an infusion of $20-25B from a company that is 35% owned by the Japanese construction company Kumagai Gumi. Other foreign investors are being invited to join the project. A free trade zone in China means that there will be no restrictions on remitting foreign currencies in and out of the zone, and foreign investors will be allowed to trade directly with Chinese manufacturers, but will still have to go through state-owned trading companies in other parts of China. PRC government officials hope to make Hainan, whose construction begins this year, the first of 10 Hong Kong like enclaves along its southern coast. Taiwan is especially well poised to take advantage of this because of its common language. Ministry of Economic Affairs tallies show that Taiwan business poured more than $820M into mainland China between 1987 and 1991. In fact, the actual amount would be much higher if illegal investments were included. Further, there are various special economic tax incentives to encourage Taiwanese investment. There are some ups and downs, however. For example, the Formosa Plastics Group (one of the world's largest) was planning to build a multibillion dollar naphtha cracking plant in Haicang. The project is now on hold. There may be some economic reasons, but political questions have entered, too. Some critics charge that such an investment would strengthen mainland China economically and would therefore be inappropriate until Beijing renounces taking

Taiwan by force. Others reply that Taiwanese investors would gain a larger say in bargaining with mainland authorities by forging economic alliances.

The main economic powerhouse in Asia, Japan, has its own problems dealing with China. Although Japan is Beijing's largest foreign aid donor, and relations between the countries are improving, repeated comments from Chinese officials make it clear there are still many subliminal memories on the Chinese side concerning Japanese activities in China during the 1930s and 1940s.

Another examp'; of the use of Taiwan's purchasing power is the participation by Taiwanese firms in a consortium to buy the transmission division of General Motors Corp. In this case, though, the ROC contribution would be very modest, slightly more than $1M. But the fact that the Indianapolis City Council wrote ROC's Ministry of Foreign Affairs asking Taiwan to take part in the consortium to buy the division is indicative of the economic clout available.

At the same time that Taiwan is using its financial muscle to purchase technology, it is also trying to encourage foreign technological investment, which has lagged in the past year. For example, a group of Taiwanese aerospace, computer, and biotech specialists will be in the United States in May 1992 (headed by the Vice Economic Affairs Minister) to help forge alliances between local ROC firms and U.S. high tech companies.

Taiwan's foreign reserves also mean that it has trade conflicts with other countries. There are ongoing talks between Taiwan and the United States about voluntary restraint on export of ROC machine tools. At the same time Taiwan runs almost a $10B trade deficit with Japan and has imposed various discriminatory measures against the importation of Japanese goods.

SCIENCE AND TECHNOLOGY IN TAIWAN

Taiwan's President controls the Executive Yuan (much like a Cabinet department in the United States). The latter has set up the Research Development & Evaluation Commission (RDEC), which plays a key role in defining high technology directions. Another important organization is the National Science Council (see my earlier report). Long range effort in R&D rests with the universities and the National Academia Sinica.

RDEC has a status equal to other ministries under the Executive Yuan, such as the Ministry of Foreign Affairs. RDEC focuses on policy research, planning, control and evaluation of policy implementation, information systems management, and government publications. Each year RDEC reviews country-wide and world-wide developments and selects 15-20 research projects of importance to the country's development. Recommendations are presented to the Premier for final selection and then assigned to an appropriate agency for execution. There is also the National Administrative Information Systems Plan, which includes a department dedicated to the information systems peculiar to science and technology (S&T) development.

The main funding source is the National Science Council of Taiwan (NSC), also part of the Executive Yuan. NSC is charged with planning and coordinating national S&T development. It has a number of divisions, including Natural Sciences, Engineering, Life Sciences, Humanities, Science Education, International Programs, and others. In 1986 NSC drafted a 10-year development plan to run through 1995. The plan added programs in environmental protection, hazard mitigation, synchrotron radiation, and oceanography to eight areas already identified: energy, production automation, information sciences, materials, electrooptics, biotechnology, hepatitis control, and food science. The 1991 budget was $240M, and budget growth has been almost 24% for the past few years. In basic science, the funds are spent mostly on surface physics, superconductivity, trace analysis methodology, biotechnology, science education, and information science. NSC also operates the Hsinchu Science Based Industrial Park (see below).

There are two interconnected educational systems in Taiwan, one for general education and the other for technical and vocational education. Nationally administered examinations allow progress from one level to another, including examinations for prospective college students that determine the curriculum and level at which they will study. While there are some private educational institutions, most students attend public schools.

HSINCHU SCIENCE-BASED INDUSTRIAL PARK (HSIP)

My host at HSIP was

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Ms. Chen gave me a general tour and overview. We did not go into any of the facilities, so my comments below are based on observations and reading.

HSIP is Taiwan's first such industrial park. It is located in the city of Hsinchu in north-central Taiwan, about three-quarters of an hour from Taiwan's international airport and about 1 hour from Taipei. Hsinchu has two universities, National Tsing Hua and National

Chiao Tung, as well as several research institutes, including the Industrial Technology Research Institute (ITRI, see below) and the Food Research Institute. HSIP was established in 1980 to help foster the development of high tech industries in Taiwan. In the past 4 years ROC's Government has invested over $300M, including public utilities, services, residences, schools, etc. Private investment is 30/70% abroad/local, and HSIP companies average about 6% of sales in R&D.

HSIP currently occupies about 400 hectares, with another 120 hectares scheduled to be developed within the next 5 years. There are 135 companies using leased or owned space in the park. Various industry types are represented, as follows.

- Computers & Peripherals (44 companies): Systems, storage devices, input/output (I/O) devices, computer communications, computer-aided design (CAD) equipment, software.
- Semiconductors (35 companies) (fastest growing): Integrated circuit (IC) materials, design, manufacturing, packaging, and testing.
- Telecommunications (23 companies): Telephones, modems, systems, microwave components, optical fiber systems
- Automation (12 companies): Computerized numerical control (CNC) equipment, robots, high-pressure water cutting systems, vacuum generators, casts, surface treatment services
- Optoelectronics (16 companies): Optical disk drives, diodes, optical system components
- Biotechnology (4 companies): Vaccines, diagnostic kits, medical equipment

Taiwanese Companies	92
Foreign	42
U.S.	34
Asian	4
European	4

Taiwan's 1.3-GeV Synchrotron Radiation Research Center is located in HSIP, and construction is underway for the National Center for High Performance Computing (see below, and earlier reports).

Presently, about 23,000 people work at HSIP and of these about 4,000 live in apartments and houses on HSIP property. My host told me that there were about 1,000 Western managers, engineers, and technicians working at HSIP, but I think that this number is very heavily dominated by those of Chinese origin holding Western passports. I had no opportunity to meet with any Westerners, and I think that step would be an essential part of any decision about visiting HSIP for an extended period. In any case there is an attractive and modern public school on the grounds with a bilingual teaching program in English and Mandarin through high school, and this would be an important asset for visiting scientists with families. HSIP is somewhat like a small, self-contained town, with restaurants, banks, post office, tennis and basketball courts, swimming pool, and man-made lake.

There are special incentives to investors of HSIP, including various tax waivers, holidays, access to venture capital, low interest loans, and government grants. In addition, there are attractive capital repatriation opportunities. The park's administration can handle import/export licenses, bonding, warehousing, shipping, etc. An interesting feature of the park is the presence of basic factory buildings that can be set up quickly for manufacturing and laboratory space.

ROC would like to develop HSIP into Taiwan's Silicon Valley. Plans are in print to expand the park to 900 hectares and 50,000 people, as well as annual turnover of 215 billion New Taiwan Dollars, which would be 10% of the country's gross national industrial turnover by 1996. These estimates might be optimistic, but there is no doubt that the park is a success. While some companies have failed, the buildings are mostly full, and there is a long waiting list for vacant space.

INDUSTRIAL TECHNOLOGY RESEARCH INSTITUTE (ITRI)

ITRI is a few minutes drive from HSIP and still within the city of Hsinchu. It is situated on a modern, green, spacious campus. My host was

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ITRI is a 5,400-person facility founded in 1973 as a private institute by funding from the Taiwanese Government. There are about 3,500 scientific staff members, about 350 Ph.D. holders, and 1,750 master's graduates. ITRI is focused on developing innovative technologies for new industries and integrating technologies into existing industries. While its mission includes long term and medium term research, the emphasis is on activities that are seen to be relevant to national needs, with the hope of accelerating development of industrial technology. ITRI receives about two-thirds of its 9.5 billion New Taiwan Dollar revenue from the ROC Government through projects, which are then transferred to the industrial sector. The remaining revenue is from private contracts to work on specific processes or products or to provide technical services. ITRI is also engaged in training as well as pilot production. In 1991 more than 8,500 companies obtained some kind of technical service from ITRI and almost 40,000 people attended various seminars, workshops, or training courses. The staff generated about 350 patent applications, half outside of Taiwan.

R&D activity is in

- Electronics
- Computers & Communications
- Opto-electronics
- Measurement & Standards
- Materials
- Chemicals
- Energy & Resources
- Machinery
- Aerospace
- Industrial Safety & Health
- Industrial Pollution Control

The aerospace activity is new, begun in 1990 when ROC launched the National Initiative for Aerospace Industry Development.

The Computer & Communications Research Laboratories (CCL), where I spent most of my time, run by my host Mr. Wang, is also new, although it was spun off from an older Electronics Research and Services Organization whose job was to foster the IC and PC industries in Taiwan. (Acer is Taiwan's largest PC maker and offers a range of clone products including various high end machines.) Current IC production is just beginning to include the technology to make central processing units (CPUs). CCL and some local private firms are negotiating with MIPS for manufacturing MIPS's R4000 CPUs in Taiwan. There are also discussions between Hewlett-Packard (HP) and several local manufacturers about possible cooperation. CCL's focus is in three general areas.

(1) Workstation and peripherals, multimedia systems, and system software.

(2) Networking, both local area and wide area networks (LAN and WAN), both to take advantage of the trend toward integrated services and data network (ISDN) and for more heterogeneous computing environments that are seen to be common in the 1990s.

(3) Consumer electronics, including improvements to analog devices using digital technology, high definition TV (HDTV), and related audio-visual products.

CCL has almost 1,000 staff members, including 40 with Ph.D. degrees, 440 with M.S. degrees, and 300 with B.S. degrees. The 1991 total budget was about $61M. Some specific projects that I saw include the following.

- A 40-MHz Sparc VME-based workstation, based on a RISC CPU and client/server architecture. A chipset for peripheral devices was also designed. A three-dimensional (3D) color graphics module, an interactive 3D graphics interface, etc. Quite a bit of this chip design was completed but it does not seem as if the actual packaging was completed. In any case the experience is described as the design of a super-mini. Based on this CCL is working on a file server and also, I was told, a multiprocessor and vector processor. I am somewhat skeptical about progress on these later projects, however, as my discussions with Wang did not suggest much interest in really high performance systems. There is substantial work on various open systems software tools.

- Research on Chinese character processing has been in progress since 1985 and includes printed Chinese character recognition, on-line character recognition, etc. CCL wants to expand its recognition work to other languages, especially Japanese and English. There are projects on handwritten address recognition for the post office and form filling for numerous organizations. There is also machine translation research.

- I was shown several demos of multimedia applications. These mostly involved building easy-to-use tools on top of commercial (U.S.) multimedia software.

- There are projects to develop several new products, including at least two notebook PCs, a hand-held (palmtop) PC, an X-terminal, IC card, and a 900-MHz cordless radio frequency (RF) module. (Some of these may have already been completed.) These involve consortia with local companies. Given the state of current technology in these areas there is no reason to think that the projects will not be successful. A few of these projects involve liquid crystal display (LCD) technology, but I had no opportunity to learn about progress on this topic. One of the most interesting and practical of technology dissemination projects was an automated ticketing system for the Taipei railroad system. This has been installed and is in daily operation.

- There is a collection of research projects related to communications, including ISDN applications such as a PC S interface card, a digital telephone for simultaneous voice and data transmission, and ISDN software. Plans are to work on a G4 fax, video phone, etc. There is a great deal of work on digital video processing associated with a 5-year program to develop key HDTV technologies by 1996, i.e., digital video processing and recording, image acquisition, and LCD projection. Prototype products include an HD-camcorder and an HD-video cassette recorder. The HDTV projects are intended to revive what is seen as a declining consumer products industry, as well as to promote defense, medical, and other Taiwanese industries.

My general sense of work at CCL was that projects are not so different from those at some other Asian industrial research institutes. The research is applied and the emphasis is on excellent liaison with industry rather than excellent academic output. With so much emphasis on industry it is not surprising that staff turnover is high, with young scientists and engineers moving from CCL to industrial organizations with which they already have relationships. ITRI management is aware of the issue and is trying to address it by making the work and environment highly attractive. There is a great deal of enthusiasm and energy about working on interesting prototype projects by what appeared to me to be a relatively young staff. CCL seems to be engaged in exactly the kind of R&D that its charter and mission specify. The research activities are not too "far out," so it is possible for the staff to sense where they are going. I did not see (or was not shown) any really unusual directions. As in other laboratories in this part of the world, there is a heavy emphasis on building things and less emphasis on software. Equipment is good, but not as good as at first class research institutes in Japan or the United States; there were many PCs and fewer workstations than I expected. I did not see any work in algorithms or other aspects of computer science; work of this kind would be more likely to occur at a university or the Academia Sinica. CCL did not appear to be much interested in supercomputing either. Also, surprisingly, my host was unaware of the Signal Processing and Communication Systems Workshop that was to be held in the capital the day after my visit. Nevertheless, CCL seemed like an interesting place to work. Concerning cooperation with Western laboratories, Wang pointed out to me that because much of their work is tied to improving industrial activities, some projects might be off limits, but given that this could be handled, I think that there would be opportunities for Western researchers. On the other hand, young CCL staff could provide a welcome additional pair of hands in Western laboratories as medium-term visitors.

NATIONAL CENTER FOR HIGH PERFORMANCE COMPUTING (NCHC)

I have described plans for NCHC in earlier reports and so will not repeat those here. My primary reason for a repeat visit was to see how the construction of the center was progressing and to learn if a decision had been made about a vendor. NCHC is being built just adjacent to the Hsinchu Science Park (see above), but surprisingly, my park administration hosts didn't know about it initially, and even later could not locate the construction activity amidst a great deal of other building projects except to say that it was "somewhere over there." However, I was assured by Prof. San-Cheng Chang, the NCHC Director, that construction is mostly on schedule and that a machine will be installed later this year.

At the moment the sole acceptable vendor is IBM, who proposed a four-processor ES9000/A20 high end machine, each processor equipped with a vector unit. Permission has to be obtained from the Taiwanese Government to allow a sole source procurement and then NCHC staff will begin negotiations about details. The plan is to upgrade this in 1994, and IBM has proposed an SS1 for the upgrade, with NCHC staff being allowed to make quarterly visits to the factory to check that progress on this machine is on schedule. Cray and NEC also made proposals but these did not qualify. Chang told me that Cray's proposal missed because the company made some errors in the paperwork they submitted. NEC's four-processor SX-3 did not run NCHC's seven benchmark programs as well as expected after tuning, and their upgrade, an SX-4, was only to be available in 1995. In fact, NCHC has repeatedly told me that having a strong Taiwan-based support team was an important part of their requirements, and IBM already has a very significant presence there.

While I was visiting NCHC's Taipei office I was introduced to Dr. Jean H. Su [E-mail: ajin@nchc.ntu.edu.tw]. Su is a former student of Prof. Steven Pruess, a well known numerical analyst at the University of New Mexico. During my travels in Asia I have met relatively few scientists with formal training in numerical mathematics and application to high performance computation. Su's presence at NCHC reaffirms my sense that this organization is going to focus on applications and provide professional support to their user community. Also while I was there I observed a course being taught by an American molecular biologist on the use of canned software for molecular modelling. This was tied in with a new visualization laboratory that had several SGI workstations and had just been opened.

INTELLIGENT SIGNAL PROCESSING AND COMMUNICATION SYSTEMS WORKSHOP (ISPACS'92)

This 1992 IEEE International Workshop, held from 19-21 March 1922 in Taipei, brought together about 150 people, including 35 from outside of Taiwan (half from Japan) and 45 students. The meeting organizers were

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The motivation for this workshop was that the organizers (mostly coming from the hardware side of signal processing) felt that more computer science ideas need to be injected into the field of signal processing and that bringing members of both communities together would be a small step in that direction. Nevertheless, most of the participants were still heavily focused on hardware, so it was clear that a great deal more needs to be done to move these groups together.

Typically, this field has been heavily oriented toward digital signal processing (DSP) applications and especially techniques to increase the information content of signals by increasing the bit rate by using new physical medium, reducing the bits needed to be transmitted by compressing techniques, improvement of the output signal by echo cancellation, adaptive filters, signal transmission/equalization and finally speech, text, and character recognition/synthesis, etc. (Signals can be speech, data, or video.) More interesting to me were the very different world views expressed by the two keynote speakers,

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The titles of their talks speak volumes: Messerschmitt, "Telecommunications and Signal Processing: The Evolving Relationship"; Nishitani, "Hardware Approaches to Signal Processing on Communication Systems."

Messerschmitt emphasized that telecommunications, signal processing, and computing are merging, even though he saw a polarization into wireless and optical transmission technologies with almost opposite bandwidth and reliability problems. He felt that in the future a proliferation of services with smaller interest groups will mean that abstraction, complexity management, system design, and structured design methodologies will become increasingly important. He concluded that he was anxious to learn more about object oriented programming, which he felt will be a key to future developments. Everyone agreed that his presentation was brilliant and exactly what was called for by the meeting organizers.

Nishitani emphasized that the community should concentrate not on abstraction but rather on building domain-specific digital signal processors and that this would enable DSPs to be developed that were small, required low power, and were low cost. (The speaker is a recognized expert in the field of programmable DSP and was responsible for the very early development of a single chip DSP for NEC.) Build it, try it, and learn from it might be his motto. Nishitani repeatedly described the possibilities for realizable hardware such as a domain specific video signal processor that can realize motion compensation in contrast to a mesh-parallel computer that he felt was too general and hence both too expensive and not powerful enough. Other examples included real-time computer graphics, high-resolution video, 3D video, a 128-module video signal processor for HDTV, and finally a video compression chipset that is available now, implementable because it was specific rather than general. Nishitani is also very interested in picture coding algorithms using wavelet transforms but gave no specific details of his work in this area.

To me, these papers were perfect metaphors for the different approaches to research as practiced in Japan and in the United States.

In addition to invited and presented talks, there was a full afternoon session devoted to posters. An English language Proceedings contains all the presented papers, not including the keynotes, unfortunately. There were several papers on the "hot" topic of digital communication. These centered on methods to code speech signals. Traditionally speech coders (the conversion of speech signals into digital data streams) have been judged on three major performance criteria: speech quality, rate (number of bits per second necessary to transmit after compression), and complexity (equivalent to cost). In efforts to bring coding rate down to the required international standard of 8 kbit/s [Consultative Committee on International Telephony and Telegraphy (CCITT) standard], coding algorithms become more complex and hence take more time. Consequently a fourth criterion, communications delay, has become increasingly important for speech encoding. In a complex network, the delays of many encoders add together, transforming the delay into a significant impairment even after echo cancellation has been performed. The international CCITT standard specifies an algorithmic delay lower than 16 ms (with an objective of 5 ms) and a total coder-decoder delay of 32 ms (with an objective of 10 ms). The CCITT 16-kbit/s standard specifies a total delay lower than 2 ms. In mobile telephony, there are related objectives to get a frequency use efficiency in the range of 2-3 bps/Hz.

I found three other papers particularly interesting.

"Realization of Array Architectures for Hierarchical Block Matching Algorithms"

Yeu-Shen Jehng, Liang-Gee Chen, Tzi-Dar Chiueh, Thou-Ho Chen
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The basic problem being looked at in this paper (Jehng's thesis) is how to extract information from a two-dimensional sequence of images in order to predict movement. For digital transmission of image data, it is much more efficient to transmit "motion vectors" rather than the primitive images, and there are many algorithms that attempt to do this. Jehng has studied one particular method, the three-step hierarchical search algorithm (3HSA), which is very efficient in terms of operation count but is difficult to implement in hardware. In his paper he considers a technique due to H.T. Kung for a systolic array implementation of the algorithm. It is a nice piece of work but needs hardware implementation and testing to determine if it will be practical.

"Determination of IFS Codes Using Scale-Space Correlation Functions"

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IFS (iterated function systems) have been very heavily studied in the context of image compression (M. Barnsley is one of its earliest and most active proponents, and of course work by B. Mandelbrot was seminal) for natural images. Kanbara's work involves the systemic analysis of fractal images and the development of an algorithm to determine the IFS codes using digital signal processing techniques. What makes this approach interesting is that while many clever people have been working on the topic of IFS, Kanbara's group is unique in their use of DSP thinking. In particular he proves an important theorem relating the maximum value (with respect to a parameter) of a one-parameter spatial correlation function to the IFS codes (when applied to binary images). Finally, his paper provides an algorithm implementing how the theorem can be applied.

"Application of High-Speed Analog Neural Networks to Optical Communication Systems"

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The main idea is to develop a neural net, optical WDM (wavelength demultiplexer). Typical optical WDM are difficult to fabricate and are not flexible. A single-mode transmission fiber allows multichannel signals to propagate through a multimode waveguide and couple to a detector array. When the optical signals are coherent the result is an inhomogeneous optical power distribution (speckle pattern) at the output caused by the interference among propagating modes. If this is input to a neural net (through a detector array) it might be possible to separate the signals as the output of the net. The advantages of this approach are that the optical components are easy to build and the demultiplexing characteristics can be changed by changing the neural net parameters, i.e., without changing the optical components. Matsumoto says it better, "In a fabrication sense, the burden which is imposed on the optics side in a conventional WDM demultiplexer is moved to the electronics side." His paper describes the experiments and an analog learning method [called multifrequency oscillation (MFO)]. The main problem with the approach is that more than 1K synapses/chip and a speed of over 1G input patterns per second are beyond the ability of current large scale integration (LSI) fabrication technology. Nevertheless, the technique is a very unusual one.

ELECTRONIC DICTIONARY RESEARCH INSTITUTE (EDR)

The Electronic Dictionary Research Institute is described and a potential new project on knowledge archives is discussed.

by David K. Kahaner

INTRODUCTION

Machine translation (MT) is a major activity in Japan. It is considered an investment in the future to develop and enhance Japan's national information capacity. Most Japanese electronics companies are involved in the development of MT systems; some are already in use and many others are almost ready. Many users of MT systems consider them to be extremely valuable in limited fields such as technical manual translation. The Japanese also believe that MT will promote standardization of technical writing and glossary development and increase the use of electronic media for document transmission. There is no question that MT is being more actively pursued in Japan than in any other country.

From the U.S. side, there have been numerous studies on Japanese MT. The most definitive was conducted by the Japan Technical Evaluation Center (JTEC), with a workshop on MT conducted in March 1991, and a comprehensive report issued shortly after that. See

Machine Translation in Japan
(January 1992)
Jamie Carbonell, Chair
Japanese Technology Evaluation Center
Loyola College in Maryland
4501 North Charles Street
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The basic conclusions of this study, in addition to the comments above, centered on the fact that fairly conventional approaches are being employed, a great deal of pre-editing is still in use, and more native English speakers are needed during the development stages of the projects.

The purpose of this report is not to focus on MT directly but to describe one important research activity, the Japan Electronic Dictionary Research Institute (EDR). EDR's functions are as follows:

(1) To produce computer software (programs and a database that can be used as a dictionary) and to perform research into systems utilizing such a dictionary.

(2) To license industrial ownership of the products of (1) and to license "know-how," including the copyright for the computer programs.

Thus EDR's work can be viewed as a major underpinning to MT systems.

EDR is a private company that is supported by the Japan Key Technology Center (JKTC), as well as a collection of Japanese companies: Fujitsu, NEC, Hitachi, Sharp, Toshiba, Oki, Mitsubishi, and Matsushita. JKTC is run both by the Ministries of International Trade and Industry (MITI) and Posts and Telecommunications (MPT). Funding arrangements are complex [see, for example, my article "Advanced Telecommunication Research Institute (ATR)," *Scientific Information Bulletin* 17(2), 19-23 (1992)], but in the case of EDR, its funding by JKTC is through MITI. EDR was set up to run as a 9-year project, ending in 1994. EDR's total budget from JKTC is ¥14B, plus about 30% from the participating companies. There is no comparable size project in the United States.

EDR has a laboratory in central Tokyo [adjacent to the Institute for New Generation Computer Technology (ICOT)] with 50-70 people, including three or four computer scientists. In addition, there are distributed laboratories at each of the industrial firms associated with the project. The total work force has been as high as 300, although it is normally about 100. Workers are often employed from commercial dictionary companies, and the central laboratory has many "company" employees, too. On my visit, I met

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The current status of the project is as follows. Four major dictionaries exist: Word, Concept, Co-occurrence, and Bilingual.

Word dictionary
- General dictionary
  - Japanese: 200K words
  - English: 200K words
- Specialized information processing terminology dictionary
  - Japanese: 100K words
  - English: 100K words
- Corpus
  - Japanese: 500K sentences
  - English: 500K sentences

Concept dictionary
- Classifications: 400K concepts
- Descriptions: 400K concepts

Co-occurrence dictionary
- Japanese: 300K words
- English: 300K words

Bilingual dictionary
- Japanese-English: 300K words
- English-Japanese: 300K words

A schedule for access has also been published.

01/91 Dictionary interface published (1st ed.)
12/91 External evaluation group established
  Word, Concept, Co-occurrence dictionaries given to six universities for evaluation
03/92 Word dictionary complete (1st ed., Japanese and English) for commercial use
  Dictionary interface published (2nd ed.)
03/93 Complete for commercial use
  Word dictionary (2nd ed.)
  Concept dictionary (1st ed.)
  Bilingual dictionaries (1st ed.)
  Co-occurrence dictionaries (1st ed.)
  Dictionary interface (3rd ed.)

The EDR project has only modest interaction with ICOT, although it is just next door. ICOT's work is seen as fairly theoretical when viewed from EDR's perspective. It is hoped that in time bridges will be built between MT work at Japanese companies through EDR to ICOT. Some early EDR work was done with Prolog, although now most of the programming is in C on standard Unix workstations. (Generally, in Japan, there is much reduced interest in LISP-based artificial intelligence (AI) related work; most successful projects are now being written in C.)

EDR researchers see themselves as providing the key technologies for MT. They freely admit that their data structures are relatively flat, but believe that successful MT over general fields cannot occur without a very large dictionary and associated software tools to access it. They believe that research on small-scale dictionaries can help to improve electronic dictionary technology, but that the minimal requirement of an electronic dictionary is that it should be of large scale. Consequently, language accumulation cannot be done manually, even with the best efforts. A large dictionary requires the development of computer, natural language, and knowledge-processing technology. For example, different language dictionaries interact through so-called head concepts, i.e., word dictionaries are connected through concepts, in a way that EDR believes will make it relatively easy to add new languages. In addition, EDR chose the information processing field as a prototype technical application field. They estimate that 30-50 million words exist in the fields of mechanics, chemistry, biology, medicine, economics, law, etc. EDR thinks of itself as providing a knowledge base, rather than a database, in the sense that each dictionary item in the EDR dictionaries is created and described by linguistic specialists. These data are verified, evaluated, and corrected in connection with text databases with computer tools. (This is not to say that EDR content is perfect; the JTEC panel found opportunities to criticize some individual entries.)

USE OF EDR DICTIONARIES AND A POTENTIAL NEW PROJECT

EDR staff members want to encourage international cooperation in the use and further development of the dictionaries. All the results of the EDR project will be sold at reasonable prices I was told. The same conditions regarding the use of the EDR electronic dictionaries are to be applied to all users, no matter whether they are domestic (Japanese) or overseas. EDR plans to set its prices much lower than those of machine readable dictionaries currently on sale. Further, for academic users, such as universities and public research institutions, special measures are being planned, including very low prices. Details are being formulated now and should be available some time this spring.

EDR's view of the role of the electronic dictionary as a primary tool for knowledge acquisition leads naturally to an extension in order to study the accumulation of other knowledge. The EDR project formally ends in 1994, although sales or licenses of the dictionaries may provide funding for maintenance and other research. Hence project planners are investigating what to do next. We were given a careful description of one potential project, proposed by EDR's General Manager Toshio Yokoi, under the general heading of Knowledge Archives. He explained to us that at the moment this is simply an idea, and there are no firm commitments from the Japanese Government. The project may not be implemented, or it might be rearranged in a significant way. Nevertheless, Yokoi's idea is to push forward in the area of very large-scale knowledge bases and to develop "knowledge archives." He wants to perform research and development of various technologies in the following areas.

- The technology to acquire and collect in an automated way vast amounts of knowledge.
- The technology in which knowledge bases are self-organized so that substantial amounts of knowledge can be systematically stored.
- The technology that supports the creation of new knowledge by using vast amounts of existing knowledge.
- The development of appropriate and applicable knowledge bases that fulfill the need for various knowledge usage.
- The technology that translates and transmits knowledge to promote the interchange and common use of knowledge.
- The development of a basic knowledge base that can be shared by all applications.

A fuller description of Yokoi's proposal is given by him in the paper "Knowledge Archives--Very Large-Scale Knowledge Bases Forming the Basis of Knowledge Processing Technology," available from him at the address above.

NEURAL NETWORK RESEARCH AND DEVELOPMENT IN ASIA

The 1991 International Joint Conference on Neural Networks, held on 18-21 November 1991 at Singapore, is summarized and assessed.

by Clifford Lau

INTRODUCTION

In the past decade, there have been significant increases in research and development (R&D) in the area of neural networks in the United States, Europe, and Asia. In the United States, much of the research activity is supported by the Office of Naval Research (ONR) and the Defense Advanced Research Projects Agency (DARPA). The impetus is provided by the work of P. Werbos on the backpropagation algorithm, the work of J. Hopfield on neural modeling, and the work of S. Grossberg on the adaptive resonance theory. In Europe, funding increases have also been seen in the European Community (EC). There the impetus is provided by the work of T. Kohonen in Finland on self-organizing maps and the work of R. Eckmiller in Germany on neural control. In Japan, neural network research is seen as the natural follow-on to the fifth generation computer program. The New Information Processing Technology (NIPT) program, also called the Real World Computing program, is a multimillion dollar, long-term program that is still in the planning stage [see the article by D. Kahaner, "First New Information Processing Technology Workshop '91," *Scientific Information Bulletin* 17(1), 51-60 (1992)]. The impetus in Japan is provided by the work of S. Amari on the mathematics of neural computing and by the work of K. Fukushima on the neocognitron. Together with the increases in R&D activities, there have been many conferences on the subject of neural networks.

The 1991 International Joint Conference on Neural Networks was held on 18-21 November 1991 at the Westin Stamford and Westin Plaza in Singapore. At the conference, which was attended by about 530 people from all over the world, 440 papers were presented. A breakdown of the authors and attendees as well as their countries is given in Table 1. To no one's surprise, many papers were from the United States (slightly over 100) and from Japan (slightly under 100). However, there were a significant number of papers from Australia, China, Korea, Taiwan, and Singapore.

This report summarizes the research and development work in neural networks in these and other Asian countries. The research in the United States is not included in this report because the state of the art in neural network research is probably familiar to those who follow this field in the United States. The research in Europe is also not included here because the papers, even though many were presented, are not representative of the large amount of effort in Europe.

AUSTRALIA

In Australia, neural network research is spread out in many universities and industrial research laboratories such as the University of Western Australia, the University of Melbourne, the University of New South Wales, Royal Melbourne Institute of Technology, Queensland University of Technology, Monash University, and Telecom Australia Research Laboratory. Much of the work is in applying neural network technology to various problems. Table 2 lists the research topics and locations.

As can be seen from Table 2, the research interest in neural network technology in Australia is very broad. Of particular interest to the Navy is the work of Mathew J. Boek at the Royal Melbourne Institute of Technology on the application of neural networks to rotating machine fault diagnosis. A backpropagation network is used to classify the condition of an operating desk fan based on its vibration signature. Data from a set of experiments are used to train the network. The trained network is then used to detect and classify faults commonly occurring in industrial fans, such as impeller unbalance and cracked impeller blades. The results of these experiments show that the network is quite successful at distinguishing between the two types of faults when no examples of both faults occurring together are included in the training set. The main conclusion is that the spectral representation provides the best recognition performance and that the primary discriminatory information for distinguishing the two types of faults (impeller unbalance and cracked impeller) is contained in the first three harmonics. This work is relevant to the Navy's research program on helicopter gearbox fault diagnosis.

CHINA

The neural network research in China is also spread out in many universities. The work is very much application oriented, as can be seen by the list of topics and locations in Table 3.

Of particular interest to the Navy is the work of Jungang Xu, Zhong Wang, and Youan Ke at the Beijing Institute of Technology on optimum frequency selection for radar target classification by a neural network. The radar cross sections at multiple frequencies are used as the inputs to a backpropagation neural network for radar target classification. The frequencies corresponding to the input nodes that have maximum sensitivities are selected as optimum frequencies needed for classification. The method is applied successfully in classifying simple radar targets in an Anechoic Chamber. Obviously this result has significance in automatic radar target classifications for the Navy.

HONG KONG

Research is concentrated in the three big universities in Hong Kong. At the Hong Kong University of Science and Technology, there is work on the automatic determination of multilayer feedforward network size for supervised learning and work on using the Householder encoding algorithm for discrete bidirectional associative memory (BAM). The original BAM as proposed by Bart Kosko of the University of Southern California (USC) uses Hebbian type of correlation for memory storage. However, by using Householder encoding, the memory capacity of the BAM is greatly improved over the conventional BAM. Also at the Hong Kong University of Science and Technology, there is work on networks whose processing elements are quadratic functions and work on mapping multilayer attributed graphs onto a neocognitron network.

Table 1. Breakdown of Authors and Delegates by Country

Country	Authors	Delegates
Australia	25	33
Austria	2	2
Belgium	6	6
Brazil	2	2
Bulgaria		1
Canada	16	14
Chile	1	1
China	27	16
Czechoslovakia		1
Finland	4	5
France	12	11
Germany	20	16
Greece		1
Hong Kong	10	11
India	11	4
Indonesia		1
Ireland		1
Israel	2	
Italy	11	11
Japan	97	125
Korea	17	19
Mexico	1	
Malaysia		1
Netherlands	4	4
New Zealand	3	2
Norway		1
Singapore	26	103
South Africa		1
Spain	2	2
Sweden		1
Switzerland	2	2
Taiwan	13	11
Thailand	1	1
Turkey	1	1
United Arab Emirate	1	1
United Kingdom	28	19
U.S.A.	107	91
U.S.S.R.	4	1
Yugoslavia	2	2

Table 2. Research Topics and Locations in Australia

Topic	Location
On-line identification of nonlinear systems	Univ. of Western Australia
Time series analysis	Univ. of Melbourne
Hybrid systems	Swinburne Inst. of Tech.
Higher order neural nets	Telecom Research Labs
Rotating machine fault diagnosis	Royal Melbourne Inst. of Tech.
Learning in feedforward networks	Univ. of Queensland
Texture segmentation	Monash Univ.
Dynamic channel assignment	Univ. of Melbourne
Classification of intracardiac electrocardiograms	Univ. of Sydney
Probabilistic neural network	Univ. of Western Australia
Reinforcement learning	Univ. of Western Australia
Object recognition for robots	BHP Research, Melbourne Lab
Kohonen algorithm on transputers	Univ. of Western Australia
Information retrieval	Univ. of New South Wales
Visual reconstruction networks	Telecom Research Labs
Adaptive quadratic neural net	Univ. of Western Australia
Autoassociative network	Griffith Univ.
Network of exponential neurons	Queensland Univ. of Tech.
Robust networks	Univ. of New South Wales
Self-organizing network for object recognition	Univ. of Melbourne
Genetic algorithms	Univ. of Western Australia
Unsupervised learning for neural trees	Telecom Research Labs
Kolmogorov representation theorem	Telecom Research Labs

At the Chinese University of Hong Kong, the neural network research efforts are spearheaded by Professor Lai-Wan Chan, who is a graduate of the Imperial College in London. They have developed a novel learning algorithm for a recurrent backpropagation network and a system for detecting three-dimensional (3-D) motion from a sequence of image frames. At the Chinese University, BAM is studied from the viewpoint of match filtering. Sufficient conditions are found for stability and attractivity for BAM networks. Also there is work on neural networks that learn the decision boundaries with nonlinear clustering, similar to the Reduced Coulomb Energy (RCE) model of Leon Cooper and the Radial Basis Function (RBF) classifier of Thomas Poggio.

At City Polytechnic of Hong Kong, a new Hopfield type of training algorithm has been developed whereby the orthogonally coded memories are obtained iteratively. Also a structured backpropagation network has been developed that adapts to the problem. Clearly these are initial efforts in applying neural network technology.

INDIA

Research appears to be centered at the Indian Institute of Science and the Center for Artificial Intelligence and Robotics. It seems that there should be a lot more work going on in India because traditionally they have been very strong in learning automatons, but only a small number of papers were presented at this conference.

At the Indian Institute of Science, a great deal of work is devoted to the study of bidirectional associative memories (BAM). The extended hypercube, as well as the INMOS transputer-based computer system, is used to simulate the parallelism in BAM. The Fokker-Planck equation is also used to study the dynamics of associative memories. The Hopfield-based model for distributed representation of objects and for use as content addressable memory is also investigated. There is also research work on genetic algorithms and learning automata for pattern recognition.

Table 3. Research Topics and Locations in China

Topic	Location
Associative memory	Tsinghua Univ.
Self-improving associative network	Zhejiang Univ.
Adaptive pattern recognition	Nanjing Aeronautical Inst.
Transform domain backpropagation algorithm	Jiao Tong Univ.
Laterally inhibitory neural network	Tsinghua Univ.
Multilayer network with dynamic neurons	South China Univ. of Tech.
Recall in multilayer perceptron network	Inst. of Electronics
New neural network architecture	Inst. of Electronics
Radar target classification	Beijing Inst. of Tech.
Character recognition using holographic memory	South China Univ. of Tech.
Local minima in backpropagation error surface	Southeast Univ.
Job-shop scheduling	Tsinghua Univ.
Object oriented neural network language	Changsha Inst. of Tech.
Unstructured economic decision process	Inst. of Auto. Academia Sinica
Adaptive predictor for nonlinear dynamics	Univ. of Sci. & Tech. of China
Speaker independent syllable recognition	Beijing Inst. of Tech.
Absolute stability of Hopfield nets	Beijing Univ. of Aeronautics
Short time speech recognition	South China Univ.
Bounds on the approximation capacity	South China Univ. of Tech.
Hopfield-Tank model for solving TSP	Beijing Univ. of Post & Telecom.
Weighted associative memory	Zhejiang Univ.
Fault tolerance in self-organizing nets	Southeast Univ.
Complexity of learning algorithms	Tsinghua Univ.
Speaker recognition	Peking Univ.

Of particular interest to the Navy is the work of P.Y. Mundkur and U.B. Desai at the Indian Institute of Technology on automatic target recognition. A sequence of images taken from high altitude reconnaissance flights is used as input to the network. The network consists of two cascaded modules, a multilayer perceptron network followed by a modified Maxnet, to provide translation-invariant recognition of the targets in clutter. The network is partitioned into subnets and a backpropagation algorithm is used to train the subnets. Preliminary results show promise, but a lot more research needs to be done yet.

JAPAN

Japan clearly is the most technologically advanced country in Asia. The number of researchers involved in neural networks is close to a thousand. The papers, close to a hundred, presented at this conference are but a small portion of the neural network work that is going on in Japan. Table 4 is a list of the topics of research at various universities and industry.

KOREA

Most of the neural network research is centered at the Korea Advanced Institute of Science and Technology, although there are a few efforts at the other universities and industry. Of particular interest to the Navy is the work of Dae-Young Yim, Sung-Il Chien, and Hyun Son at Kyungpook National University on multiclass 3-D identification and orientation estimation using multilayer feedforward neural networks. Top-down views of three different aircraft (DC-10, Phantom, and MiG21) at different azimuth and roll angles are used for training the network. The training set consists of 216 images (72 images per aircraft at 10° roll and azimuth angles). Two multilayer feedforward neural nets are used, one for classifying the type of aircraft and another for estimating the orientation angle. Out of the three aircraft types, correct classification approaches the 98.6% level, and the accuracy of estimating the orientation is at 89.4%. Of course, these performance levels are extremely good for such a small number of different aircraft types. This work has implications in military automatic target recognition as well as in commercial aviation. Table 5 is a listing of the location of different neural network research in Korea.

Table 4. Research Topics and Locations in Japan

Topic	Location
Hebbian type associative memory	Keio Univ.
Multilayer network for character recognition	Nagoya Univ.
Adaptive input field neural network	NEC Corp.
Hybrid neuromorphic and symbolic control	Kisarazu National Tech. College
Hybrid control of robotic manipulator	Kisarazu National Tech. College
Sequential network for speech recognition	Kyoto Inst. of Tech.
Fuzzy logic neural network	Hosei Univ.
Neuron with a center	NTT Commun. Switching Lab
Error correction learning in three-layer network	Kyushu Inst. of Tech.
Inverted pendulum problem	Kyushu Inst. of Tech.
Adaptive decision feedback equalization	ATR Research Lab
Optimal control with recurrent network	Toshiba Corp.
Three-layer backpropagation for pattern recognition	Nagoya Univ.
Hierarchical Markov Random Field model	ATR Auditory & Vision Lab
Finite size multilayer net for polynomials	Toyohashi Univ. of Tech.
Models of the cerebellum	ATR Auditory & Vision Lab
Fuzziness in 3-D surface depth perception	Inst. of Physical & Chem. Res.
Recognition of facial expressions	Sci. Univ. of Tokyo
Network model for color blindness	Toyohashi Univ. of Tech.
Model for conscious and unconscious processing	Matsushita Res. Inst. of Tokyo
Time delay discrete neural network	Nagoya Univ.
Multilayer network with quantizer neurons	Matsushita Electric
Inverse modeling of dynamical systems	Fujitsu Lab
Fuzzy training algorithm for phoneme recognition	NTT Human Interface Lab
Memory based artificial neural network	Hiroshima Univ.
Learning rule using difference approximation	Kansai Univ.
Spatial inhibition and local association	Tokyo Univ. of Agric. & Tech.
Pattern classification for remote sensing	Univ. of Tokushima
Moment invariants for katakana recognition	Tokyo Inst. of Tech.
Road segment extraction from maps	Univ. of Tsukuba
Rule evaluating neural networks	Toshiba ULSI Res. Center
Feature selection for recognition	Yokogawa Electric Corp.
Piecewise linear higher order network	Univ. of Tokyo
Learning process of recurrent networks	Nagoya Univ.
Automatic determination of association units	Fukui Univ.
Estimation of a posteriori probability	Toyohashi Univ. of Tech.
Asymptotic behavior of simulated annealing	Hitachi Ltd.
Global suppression of spurious states	Hitachi Ltd.
Automatic gray level adjustments	Toshiba Corp.
Multiply descent cost competitive learning	Ibaraki Univ.
Regularization vision chips	Yokogawa Electric Corp.
CombNET-II for written digit classification	Nagoya Inst. of Tech.
Rotation invariant neural pattern recognition	Univ. of Tokushima
Hierarchical intelligent control	National Kisarazu Tech. College
Feedforward network for robot motion control	Nippon Steel Corp.
Visual tracking of robot manipulator	Univ. of Tokyo
Finite times of search in multilayer networks	Tokyo Inst. of Tech.
Synthesizing networks for pattern recognition	Hitachi Ltd.
Elimination of local minima in backpropagation	Kyushu Inst. of Tech.
Neural sequential associator for prediction	Hitachi Ltd.
Speaker independent 1000 word recognition	Nagoya Inst. of Tech.
Car detection system using neocognitrons	Chiba Inst. of Tech.
Limb function discrimination using EMG signals	Nagoya Univ.
Feedforward control based on inverse systems	Mitsubishi Heavy Industries Ltd.
Learning scheme to improve speed of convergence	Tokyo Inst. of Tech.
Quasi-symmetric logic networks	Ryukoku Univ.
Ultrasonic 3-D visual sensor	Ricoh Co. Ltd.
Space perception model	Univ. of Tokyo
Human hard position control learning	Univ. of Tokyo
	(continued)

Table 4. Continued

Topic	Location
Receptive field network for kanji recognition	Sharp Corp.
Extension of backpropagation algorithm	Univ. of Osaka Prefecture
Regression analysis with inverse model	Univ. of Osaka Prefecture
Face graph method for fuzzy neural networks	Nippondenso Co. Ltd.
Bidirectional optical neural net	NTT Transmission System Lab
Basin size in autoassociative memory	Kyoto Univ.
Learning algorithm based on information theory	NTT Human Interface Lab
Recursive neural system in a tree like structure	Univ. of Tokyo
Reduction of precision in learning	Matsushita Electric
Neural network based adaptive control system	Yokohama National Univ.
Wafer scale LSIs with 1152 digital neurons	Hitachi VLSI Engineering Corp.
Low-bit learning algorithm for pattern recognition	Kanazawa Univ.
Cross-coupled Hopfield network	Kobe Univ.
Neuromorphic sensing and control	National Kisarazu Tech. College
Controller for autonomous underwater robot	Univ. of Tokyo
Trajectory generation for biped robot	Kobe Univ.
Inverse kinematic calculations	Hitachi Ltd.
Self-learning robot vision system	Waseda Univ.
NN/II network for pattern recognition	Kyoto Univ.
Time warping network for phoneme recognition	NTT Human Interface Lab
Adaptive neural model reference structure	Univ. of Tokushima
Structure detection by neural sequence associator	Hitachi Ltd.
Neural searchlight processor	Fukui Univ.
Cluster formation in random neural network	Kinki Univ.
Parallel ASIC VLSI neurocomputer	Toshiba Corp.
Inducing algorithm for LTP in hippocampus	Tamagawa Univ.
Temporal association in symmetric networks	Tokyo Univ. of Agric. & Tech.
Dynamics in chaotic neural networks	Tokyo Denki Univ.
T-model neural network with learning ability	Telecom Systems, Inc.
Capabilities of three-layer network	Sony Co., Ltd.
Parallel algorithm for simulated annealing	Univ. of Osaka Prefecture
Solving the four color mapping problem	Toyota Tech. Inst.
Solving the dynamic traveling salesman problem	NTT Human Interface Lab
Broadcasting in multihop packet radio network	Keio Univ.

Table 5. Research Topics and Locations in Korea

Topic	Location
Iterative autoassociative memory	Kyungpook National Univ.
ARMA model time series modeling	Korea Adv. Inst. of Sci. & Tech.
Parallel Boltzmann machine	Korea Adv. Inst. of Sci. & Tech.
Benchmarks for learning algorithms	Pohang Inst. of Sci. & Tech.
3-D aircraft orientation identification	Kyungpook National Univ.
Image parameter estimation by error propagation	Korea Adv. Inst. of Sci. & Tech.
Hopfield network for self-tuning control	Yonsei Univ.
Functional approximation	Korea Adv. Inst. of Sci. & Tech.
Hopfield network for obstacle avoidance	Kwangwoon Univ.
Optical implementation for BAM	Korea Adv. Inst. of Sci. & Tech.
Perceptrons for image recognition	Pohang Inst. of Sci. & Tech.
Hidden node reduction techniques	Electronics & Telecomm Res. Inst.
Distributed memory multiprocessors	Korea Adv. Inst. of Sci. & Tech.
Neural network for systolic design	Korea Adv. Inst. of Sci. & Tech.
Nearest neighbor classifier	POSTECH
Weight value initializations	Korea Adv. Inst. of Sci. & Tech.

NEW ZEALAND

Only research by Professor G.G. Coghill and his students at the University of Auckland was presented at this conference. There a multilayer perceptron network is trained using error backpropagation to recognize the angle and length representations of various shapes in robotic systems. A competitive learning network is used to estimate the centroid of clusters of patterns. Also, a method has been developed for selecting the optimum operating point for a network consisting of hardlimiting neurons, for use in content addressable memories.

SINGAPORE

Due to the fact that the conference was held in Singapore, a fair number of papers were presented. Research is concentrated mostly at the National University of Singapore, as shown in Table 6.

Of particular interest to the Navy is the work of Leonard Chin at Nanyang Technical University on a neural network approach in multiple target tracking. Conventional multitarget tracking uses either Kalman filtering or the Dempster/Shafer method. These methods try to find the maximum probability solution to search all possible solutions exhaustively. The computation requires n! search paths, where n is the number of tracks. Even with pruning methods, the multitarget tracking problem is extremely computation intensive. Using a Hopfield network operating in the optimization mode to solve the traveling salesman problem, he is able to show that the Hopfield net can be used to solve the multitarget tracking problem in a short time. Furthermore, he suggests that with the rapid pace of development in neural network hardware VLSI technology, real-time multitarget tracking is soon to become a reality.

Table 6. Research Topics and Locations in Singapore

Topic	Location
Parallel implementation on transputers	National Univ. of Singapore
Processing of medical images	Acoustical Services Pte Ltd.
Character recognition	National Univ. of Singapore
Forward generating neural network	National Univ. of Singapore
Competitive unsupervised learning	National Univ. of Singapore
Neural network expert system	National Univ. of Singapore
Nearest neighbor learning	National Univ. of Singapore
Neural net control system	National Univ. of Singapore
Robot motion control	National Univ. of Singapore
Electrical load forecasting	National Univ. of Singapore
Multiple target tracking	Nanyang Tech. Univ.
Cause associator network	Human Interface Engin. Pte Ltd.
Forecasting of electricity consumption	National Univ. of Singapore
Backpropagation for prediction	Information Tech. Inst.
Controller in the presence of disturbances	National Univ. of Singapore
Fuzzy feature extraction	National Univ. of Singapore
Fuzzy neural system for decision making	National Univ. of Singapore
Dual network expert system	National Computer Board
Case-based diagnostic expert system	National Univ. of Singapore
Forward kinematic problem	National Univ. of Singapore
Robust stability of analog VLSI	Nanyang Tech. Univ.
Training algorithm for fast error propagation	National Univ. of Singapore
Inverse nonlinear control	National Univ. of Singapore
Rotation invariant neocognitron	National Univ. of Singapore
Unlearning in BAM	National Univ. of Singapore
Occluded object recognition	National Univ. of Singapore

TAIWAN

In Taiwan, much of the neural network work is centered at National Taiwan University and National Chiao Tung University. There is also a great deal of academic-industrial collaboration, such as between National Chiao Tung University and the Telecommunications Laboratory and the Industrial Technology Research Institute.

A very theoretical piece of work on fuzzy activation functions was presented by Chi-Cheng Jou of National Chiao Tung University. The fuzzy activation function generalized the two-value activation function in conventional perceptrons. The work was a mathematical analysis of the fuzzy neural networks started by Prof. B. Kosko at USC. Another theoretical work was that of Fu-Chuang Chen on the convergence properties of a modified backpropagation learning algorithm. The modification was in introducing a deadzone around the origin. He showed that the norm of the parameter error will converge to a constant provided the initial errors were sufficiently small. Also at National Chiao Tung University, neural network algorithms were used on a multistage network to solve the traffic control problem.

At National Taiwan University, Hopfield nets with time-varying energy functions were used to solve the traveling salesman problem. The time-varying function was similar to the concept of system entropy. They did not, however, prove and guarantee the stability and convergence of the solution. Also at National Taiwan University, time-varying gains in the weight update laws were used to insure terminal attractions in the backpropagation learning algorithm. Lipschitz conditions were used to guarantee convergence and stability. An algorithm has also been developed to determine the appropriate number of hidden units in a multilayer perceptron network.

THAILAND

The only work reported here from Thailand was that of Andreas Weigend at Chulalongkorn University on the dimension of the space of hidden units. The work was in collaboration with David Rumelhart while Weigend was at Stanford University. They showed that the effective number of parameters was changed during backpropagation training. The eigenvalue spectra of the covariance matrix of hidden units were analyzed to determine the ranks of the matrix. The technique was applied to the problem of prediction in the sun-spot time series. This work appeared to be quite advanced for a country like Thailand.

SUMMARY

As can be seen from this report, there is a great deal of research and development work in the area of neural networks in Asia. Much of the work is in applying neural network technology to various problems. The applications are very diverse, but mostly in the area of pattern recognition. The most common neural network is the multilayer perceptron network with backpropagation learning algorithm. There is also a great deal of work in merging neural network technology with fuzzy logic. Many of the researchers are educated in the United States or Great Britain. Clearly Japan is the most technologically advanced country in Asia. The number of researchers in the area of neural networks is large. With the start of the New Information Processing Technology program this year, the amount of effort is certain to increase dramatically. However, my impression is that much of the work is in applying neural network technology and that these Asian countries will continue to depend on the United States for theoretical results and basic research in neural networks.

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SCIENCE STRUCTURE OF JAPANESE GOVERNMENT AND EXCHANGE POSSIBILITIES

This article provides an overview of organizations within the Japanese Government that support science and describes the sources of support for international exchanges.

by Iqbal Ahmad and David K. Kahaner

ORGANIZATIONAL STRUCTURE OF SCIENCE AND TECHNOLOGY (S&T) IN JAPAN

The Government of Japan (GOJ) is organized around the Prime Minister, who heads the government. He is assisted by a Cabinet, composed of Ministers (Education, Justice, Foreign Affairs, etc.). Each of the ministries has its own budget. However, two ministries are especially important, the Ministry of International Trade and Industry (MITI) and the Ministry of Education (Monbusho). Both of these support significant scientific activities by a variety of mechanisms including grants for research and development (R&D), tax incentives, loans, and others. These organizations have subunits that also provide support. Monbusho supports the national universities and gives research grants, the latter somewhat like the National Science Foundation. Examples include the National Institute for Education Research, the National Education Center, and the National Women's Education Center. Monbusho also administers the National Center for Science Information System (NACSIS). MITI runs the Patent Office, which is highly automated. Some projects are supported by joint programs. To a lesser degree the Ministry of Post and Telecommunications (MPT) is also important.

In addition to the ministries, directly under the Prime Minister's office is the Science and Technology Agency (STA), which operates much like a ministry. STA, in addition to having research programs, also supports the Japan Information Center of Science and Technology (JICST).

The GOJ also includes its legislative arm, the Diet, which supports the National Diet Library (NDL), similar to the Library of Congress, in which all unclassified publications (including grey literature) published in Japan are deposited.

Within the Government, the highest policy making body for S&T is the Office of the Prime Minister, who is advised by the Science and Technology Council and the Science Council. These two councils establish national goals and provide broad directions for S&T and in general decide S&T issues of national importance. The membership of these councils consists of eminent scientists and outspoken science policy experts. These councils have a strong say in Japan's Federal S&T budget and have been responsible for the increase from ¥10,627B ($80B) in 1988 to more than ¥13T ($100B) in 1990.

MITI and Monbusho, along with STA, share the responsibility of planning, funding, and overseeing the government-sponsored S&T programs. The Federal Trade Commission governs the legality of the business practices and rules on the MITI plans and activities. The Ministry of Finance approves all the budget and justification for new programs and requirements of additional funds.

Science and Technology Agency (STA)

The agency is located in the Prime Minister's Office and receives about 25% of the government S&T funds for major programs such as space and nuclear reactor projects. The agency also has the responsibility for promoting basic research in industry through the Japan R&D Development Corporation (JRDC) and supporting new initiatives such as the Exploratory Research on Advanced Technology (ERATO) program. Attached to STA are six research institutes:

- National Institute for Research in Inorganic Materials (NIRIM)
- National Research Institute for Metals (NRIM)

- National Aerospace Research Laboratories
- National Institute for Radiological Sciences
- National Research Center for the Disaster Prevention
- National Institute of Resources

Another function of this agency is to administer programs of research fellowships and a number of large national and international research programs. It is also responsible for managing research fellowships and grants. Of these the most well known is the Japan Society for the Promotion of Sciences (JSPS) fellowships. This is discussed in more detail in a later section.

Ministry of International Trade and Industry (MITI)

MITI receives about 13% of government S&T funds and has the responsibility for formulating industrial technology plans, providing subsidies and/or funding, and selecting/persuading/organizing participating industrial R&D groups/associations to work in collaboration with one or more of the 16 MITI national laboratories. These national laboratories are administered by the Agency of Industrial Science and Technology (AIST), which in 1985 had a budget of approximately $1B. A sister agency, called the Japan Industrial Technology Association (JITA), functions as a licensing agency of AIST and provides regular information on foreign technology developments. MITI relies on cooperative mechanisms with industry to leverage much more R&D than could be expected of the 13% Federal S&T funds allocated to it. The 16 national research laboratories managed by AIST are as follows:

- National Research Laboratory for Metrology
- Mechanical Engineering Laboratory
- National Chemical Laboratory for Industry
- Government Industrial Research Institute, Osaka
- Government Industrial Research Institute, Nagoya
- Government Industrial Research Institute, Kyushu
- Government Industrial Research Institute, Tohoku
- Government Industrial Research Institute, Shikoku
- Government Industrial Research Institute, Chukoku
- Fermentation Research Institute
- Research Institute for Polymers and Textiles
- Geological Survey of Japan
- Electrotechnical Laboratory
- Industrial Products Research Institute
- National Research Institute of Pollution and Resources
- Government Industrial Development Laboratory, Hokkaido

AIST is one of the most important elements of MITI. It implements its basic policy of promoting techno-globalism to stimulate scientific and technological creativity as well as distribution and transfer of the results of these activities. AIST is responsible for providing funds for the international research programs such as the Human Frontier Science Program, international fellowships, subsidies and invitations for foreign scientists, etc. The execution and management of these research programs are shared by STA, MITI, and an agency called the New Energy and Industrial Technology Development Organization (NEDO).

NEDO is a quasi-government body that was established in 1980 to promote coordinated development and commercialization of alternative energy sources for oil to reduce the dependency of the Japanese economy on imported oil. But as of 1988, its functions have been expanded to include MITI's R&D projects at the national laboratories, large scale projects, development of advanced research facilities, and initiation of international joint research grant projects.

Ministry of Education, Science, and Culture (Monbusho)

This ministry manages 47% of the government research funds, which are distributed amongst the universities and national centers for scientific research. University research is exclusively supported out of these funds. There is very little university-industry interaction. Therefore, industry does not support much research in the universities. This is one of the often quoted reasons for the poor state of university facilities and research laboratories.

Key Technology Center (KTC)

Its primary objective is to promote research and development through industrial consortia composed of more than one corporation by providing investment funds. KTC also makes loans to individual corporations to conduct research on key basic technologies needed by various regions of the country. It is a financing body and does not have R&D facilities of its own. The center, with a budget of $186M, is jointly supported by MITI, industry, and the local prefectures.

Technopolis/Research Parks

The concept of "technopolis" materialized in Japan in the form of Tsukuba Science City. Recently, the Kansai district has decided to develop a science city in the Kansai area in the middle of the triangle made by the cities of Kyoto, Nara, and Osaka. In all, 26 such projects are planned throughout Japan. Also, there is a movement towards establishing research parks. One of these is being developed in the Kansai district. At this time both the technopolis and the research park concepts are getting a lukewarm response from industry. The main reasons are the large investment required to establish these research centers and the fact that the corporations are favoring centralizing their research activities in their own corporate laboratories ("Japan as Scientific and Technological Superpower 1990," by Justin Bloom, Department of Commerce Report PB90234923).

Industrial Research Laboratories

As is well known, most of the high tech research is conducted by industry in Japan. Unlike the United States, where the industrial contribution to R&D investment is about 50% or less, in Japan industry's share is more than 80%. The attitude of industry towards accepting foreign researchers is also changing. The Tokyo office of the National Science Foundation has prepared a survey report in which the names of the companies willing to accept foreign research workers and the specified fields are summarized (*Directory of Japanese Company Laboratories Willing to Receive American Researchers*, 1 March 1991). According to a recent survey, in 1991, there were approximately 750 foreign research personnel employed by private corporations in Japan; 189 of them are from the United States.

Other Ministries

In addition to MITI, other ministries also have R&D activities, but at a smaller scale. They also have programs of science and technology exchange involving scientists from the developed countries.

Japan Defense Agency (JDA)

There are four major research institutes engaged in defense-related projects in Japan. These institutes employ a total of 1,000 persons. Compared with U.S. Department of Defense (DOD) R&D laboratories, the JDA activity is very small. At the same time there is no formal Memorandum of Understanding (MOU) between the United States and Japan to establish a scientist/engineer (S&E) exchange. Examples of some U.S. DOD scientists working for a short period at the Technical Research and Development Institute (TRDI) of JDA or a Japanese scientist working in the United States are few and far between. Recently there has been a considerable updating of the research facilities at these institutions and some mutually agreeable high tech research projects could be undertaken at these laboratories. However, that will be possible only if a formal MOU is established between DOD and JDA.

R&D Activities of Private Corporations

Over 14% of Japanese corporations have R&D facilities outside Japan. A majority of these R&D facilities have been established for product development matched to local needs. Reportedly 71 companies from the United States have R&D facilities in Japan, mainly for developing products specifically to meet the needs of Japan.

National Science Foundation

In the context of U.S.-Japan S&E exchange, the most important body involved is the National Science Foundation (Japan office). This office not only manages the program under which U.S. scientists and students visit Japan, both for short and long periods, but also supports JSPS programs of Monbusho and some international programs operated by both STA and AIST.

INTERNATIONAL COOPERATION IN R&D AND OPPORTUNITIES FOR U.S. SCIENTISTS

Discussions with responsible officials in MITI and NSF indicated that there is no reliable source of information on the overall international cooperative R&D activities including data about the number of foreign scientists in Japan versus the number of Japanese scientists abroad. A MITI official stated that MITI was conducting a survey on this issue. The report will be ready by the end of March 1992. The data summarized in the following were obtained from discussions and brochures available on some of the programs.

AIST/NEDO

The following programs are managed by NEDO.

Foreign Researcher Invitation Program. Under the program established in 1988, AIST invites foreign scientists for 6-12 months to conduct research at the 16 AIST laboratories. In 1989, AIST assigned NEDO to administer this program. In 1990, of the 30 scientists invited, 3 were from the United States. In 1992, this number may increase to 50. NEDO provides the expenses for air transportation to and from Japan, per diem, housing and family assistance, and other contingencies including travel within the country. In the category of exchange with a duration of stay of more than 6 months, according to the director of the program, in 1990 27 Japanese went to the United States and 13 U.S. scientists came to Japan.

International Joint Research Grant Program. This was established in 1988 to promote creative research and to contribute to the advancement of international exchange in the field of industrial technology. Under this program grants up to ¥30M per year are awarded to international joint research teams that fulfill the following conditions:

(1) Each team must consist of four or more researchers.

(2) Each team must consist of researchers of two or more nationalities.

(3) The research organizations where the researchers' major activities take place must be located in two or more countries.

The grant duration is for 3 years. The fields of research suggested are: investigation and elucidation of material functions and practical use of material functions. In 1991, 59 teams consisting of 299 participants of various nationalities, which included 78 from the United States, applied. Six teams were selected.

Research Training Program. This program is only for young Japanese researchers.

International Research Cooperation Program. NEDO also promotes R&D projects supported jointly by Japanese domestic industries in cooperation with organizations of scientific and industrial research abroad. In 1991 there were five such projects, of which one is a ¥90M program with the U.S. Environmental Protection Agency.

Science and Technology Agency

The STA Fellowships Program was established in 1988 to offer opportunities to young foreign researchers to conduct research at Japan's national laboratories and public research corporations (excluding universities and university-affiliated institutes). The host institutes include 84 government laboratories, 10 private corporations, and 17 nonprofit institutes. The program is managed by JRDC in cooperation with the Japan International Science and Technology Exchange Center. This program is for researchers who are 35 years old or younger and have a Ph.D. degree or equivalent qualifications. The tenure of the fellowship is from 6 months to 2 years. The field of research is decided through negotiation between the candidate and the host institution. The fellowship provides a round-trip airline ticket; monthly living, family, and settling allowances; local travel expenses; etc. Also, STA pays ¥149,000 per year to the host institution to cover research expenses. In 1991, 180 fellowships were granted. The number may increase in 1992. The National Science Foundation in Tokyo (Dr. L. Weber) is the coordinating agency for applicants from the United States.

Monbusho

The Japan Society for the Promotion of Sciences (JSPS) or Gakushin is a quasi-governmental organization under the auspices of the Ministry of Education, Science, and Culture. JSPS plays a key role in the administration of various scientific and academic programs of Monbusho. It was established in 1932 as a nonprofit foundation through an endowment granted by Emperor Showa. In recognition of the importance of international cooperation in promoting scientific research, JSPS administers the following programs.

(1) Inviting foreign scientists to Japan, including foreign scientists in general and postdoctoral fellowships for foreign researchers.

(2) International joint research programs and scientific meetings.

(3) Bilateral programs with foreign academic institutions (currently with 42 institutions in 30 countries). It includes scientist exchange and joint research and seminars.

(4) Cooperative programs with Southeast Asia and other countries. In fiscal year 1990 over 1,500 foreign scientists were invited and at the same time 1,700 Japanese scientists were sent to foreign countries.

The program for the foreign scientists in general is designed to enable Japanese scientists to invite foreign colleagues to Japan to participate in cooperative research and other academic activities. There are 240 short (14-90 days) and 40 long term (6-10 months) programs.

Postdoctoral fellowships for foreign scientists are awarded to promising, highly qualified foreign researchers who have obtained a doctoral degree. It is designed to provide opportunities to conduct cooperative research with leading research groups in Japanese universities and research institutions. In 1990 405 fellowships were awarded to postdoctoral researchers from 30 countries; 115 came from the United States.

JSPS provides 143 fellowships to Japanese scientists to conduct joint research with their counterparts in other countries. JSPS also has a number of bilateral programs for scientific cooperation and exchange, under MOUs between itself and various foreign academic institutions. Under this program more than 350 foreign scientists were invited to Japan, and 540 Japanese scientists were sent to various foreign institutions during fiscal year 1990.

Fellowships are available for Japanese postdoctoral researchers for conducting research at foreign institutions for a period of 2 years. In 1990, 118 such fellowships were awarded. Of these 61% went to the United States.

Fellowships involving U.S. researchers are coordinated through the National Science Foundation in Tokyo. Table 1 shows the number of JSPS scientists participating in exchange program from 1988-1990.

National Science Foundation (NSF)

Like JSPS, NSF also has long term and short term fellowships for U.S. researchers in Japan. NSF is also involved in the bilateral U.S.-Japan seminars, state-of-the art reviews, Japanese language study, and summer institute for graduate students in science and engineering. Four arrangements were initiated in 1988 to increase the number of U.S. researchers who go to Japanese laboratories for 6-24 months. With money from the Government of Japan, NSF formed the U.S.-Japan Fellowship Fund to support U.S. researchers at Japanese university, government, and corporate laboratories. An MOU between NSF and AIST established terms under which AIST provides access to its research institutes to 30 U.S. scientists and engineers each year. NSF also serves as the nominating agent for young scientists from the United States to award 12-month fellowships to carry out research in Japanese university laboratories. Under a similar program NSF nominates researchers to the Science and Technology Agency to stay in Japan for 6-24 months at government laboratories. According to Dr. Weber, the NSF chief at the Tokyo Office, since the inception of the JSPS Fellowship Program and the Japan-U.S. Science Fellowship Fund in 1988, the number of Americans sent or selected to go to Japan for 6 to 24 months has reached over 200. There are presently 75-80 Americans conducting research in Japan under the NSF programs. Also, the summer institute brought 25 and 49 American graduate students to Japan for 2 months in 1990 and 1991, respectively. These NSF fellowships for research in Japan are open to all qualified researchers from the United States, including scientists from DOD organizations.

Table 1. Number of JSPS Scientists Exchanged with the U.S.

Type of Exchange	1988	1989	1990
U.S. Scientists to Japan			
Fellowships for foreign scientists			
Short term	82	73	71
Long term	11	14	7
Postdoctoral fellowships	15	50	77
Bilateral programs	12	20	11
Total	120	157	166
Japanese Scientists to U.S.			
Fellowships for research abroad	20	18	22
International joint research projects	28	12	13
Bilateral programs	378	424	393
Total	426	454	428

Industry and Technology Management Program

Under a Congressional act, the Industry and Technology Management Program was initiated in 1991 to provide U.S. scientists and engineers with an increased understanding of Japanese technology management methods, training in the Japanese language, and understanding of Japanese business and culture. The program is also expected to promote the participation of DOD scientists in R&D projects at Japanese government and industrial laboratories. Included in the scope of activities is extending fellowships and travel grants to Japanese scientists to visit the United States. The management of this program is assigned to the Air Force Office of Scientific Research.

Iqbal Ahmad is the director of the Army Research Office (ARO) Far East. He has a Ph.D. degree in physical chemistry from Imperial College, London, and is a Fellow of the Royal Society of Chemistry, London. Prior to his present position, Dr. Ahmad was a program manager in the area of materials science at ARO, Research Triangle Park, North Carolina.

David K. Kahaner is a senior scientist at the Office of Naval Research Asian Office. He obtained his Ph.D. in applied mathematics from Stevens Institute of Technology in 1968. From 1978 until 1989 Dr. Kahaner was a group leader in the Center for Computing and Applied Mathematics at the National Institute of Standards and Technology, formerly the National Bureau of Standards, responsible for scientific software development on both large and small computers. From 1968 until 1979 he was in the Computing Division at Los Alamos National Laboratory. Dr. Kahaner is the author of two books and more than 50 research papers. He also edits a column on scientific applications of computers for the Society of Industrial and Applied Mathematics. His major research interests are in the development of algorithms and associated software. His programs for solution of differential equations, evaluation of integrals, random numbers, and others are used worldwide in many scientific computing laboratories. Dr. Kahaner's electronic mail address is: kahaner@xroads.cc.u-tokyo.ac.jp.

KOREAN SCIENCE INSTITUTIONS

A high level description of a half dozen Korean science institutions is given.

by David K. Kahaner, Victor Rehn, Iqbal Ahmad, and Pat Wilde

INTRODUCTION

From 4-6 March 1992, three members of the Office of Naval Research Asian Office (ONRASIA) and the director of the Army Research Office Far East (AROFE) visited Korea at the invitation of

Mr. Kenneth D. Cohen
Counselor for Scientific and
Technological Affairs
U.S. Embassy
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Seoul, Korea
Tel: +82-2-732-2601 x4159
Fax: +82-2-738-8845

Participants were

Dr. David K. Kahaner (ONRASIA)
Dr. Victor Rehn (ONRASIA)
Dr. Pat Wilde (ONRASIA)
Dr. Iqbal Ahmad (AROFE)

Cohen's motivation for the invitation was to introduce the scientists to Korean science. He hoped that this would generate further contacts and perhaps collaborative activities. Consequently, the visit was almost entirely limited to meetings with heads of organizations or their delegates and there was very little time to make detailed examinations of laboratories or have substantial discussions with working scientists. This made sense also in that the four scientists are interested in quite different activities: Ahmad (materials), Kahaner (computing), Rehn (physics), and Wilde (marine geology). At each stop they gave a short overview of ONRASIA's or AROFE's role (assessment, fostering contacts and collaborations, etc.). But most of the time was spent listening to descriptions of current and future programs at the sites visited.

Below is a brief sense of what the scientists learned in their areas and a description of the programs at each institute visited. The Appendix contains a list of the hosts and a few key contacts. The sites included public and private universities, government laboratories, and "not for profit" laboratories. Korean industrial laboratories were not included because of lack of time.

BACKGROUND

Korea's business environment has deteriorated recently; wage rates and per capita gross national product (GNP) growth are worse than in other countries in the region; trade deficits, especially with China, are growing; and there is labor unrest. A bright spot might be improved relations with North Korea; there are hopes that it will be possible to harness the low cost labor available there, and overtures are already being made. For example, the Chairman of Daewoo has just reported plans to build several light industrial plants in the North. But at the moment, research money is getting tighter than in the recent past because of Korea's worsening economic situation, although funding is still attractive.

Korean scientists are exceptionally well linked to colleagues in the West, especially the United States, where many, perhaps as many as 90%, have had advanced education. For this reason language is not a serious problem, much less so than in Japan. There is a very large reservoir of good will between Korea and the United States, and the Korean scientists were exceptionally open and frank about their work, problems, needs, etc. They are very willing to collaborate. Kahaner feels that what they mostly need are collaborations with senior scientists who can help shape directions. They seem to have ample numbers of young researchers, and as mentioned already, good facilities. However, at this point he does not see very strong technical reasons for senior Western scientists to consider spending substantial time at Korean laboratories, in as much as they have little to offer that is not already available in the West; younger researchers might feel differently. Kahaner's assessment of the best form of collaboration is for Western laboratories to offer research opportunities to Koreans. Younger Korean scientists are well trained and have good communication skills in English. These people could be important research associates and postdoctoral candidates for ongoing or new research projects. Further, their experiences will be brought back to Korea where further collaboration might ensue. Thus a short term benefit to laboratories in the West may result in long term benefits later on.

THE HIGHLY ADVANCED NATIONAL PROJECT (HANP)

The most interesting new project is the Highly Advanced National Project (HANP), for the period 1993-2006. The premise is that Korea is still a third-world country with recent problems of stagnating economy, high inflation, and distorted national income distribution. Combined with rising labor costs and international competition, the economic environment is seen as being very unfavorable unless steps are taken to advance the state of the country's high technology research and development (R&D) capability. The Government realizes that it will be nearly impossible for Korea to catch up with advanced countries in all technological fields. Thus the strategy is to emphasize "technology" rather than "science" and to concentrate limited national resources in some critical technologies.

In Korea, national R&D programs are basically controlled by the Ministry of Science and Technology (MOST) and the Ministry of Trade and Industry (MTI). MOST is mainly responsible for basic and fundamental technology developments, while MTI is in charge of industrial technology development. Other related ministries such as the Ministry of Energy and Resources and the Ministry of Communications (MOC) also participate in R&D programs. But the Korean Government recognizes that there has been some unnecessary overlap and that better coordination is necessary in order to leverage modest investments.

HANP is planned to be interministerial and is to include universities, industry, and government-supported institutes. Naturally funding for HANP will be lower than desired, but the other obstacle is seen to be manpower. To aid this, involvement of foreign experts is strongly recommended by the Government, even in the planning stages and for evaluating plans. Specifically, MOST is going to invest 5% to 20% of HANP budgets for international R&D activities. Active international exchange programs for researchers will be actively promoted. The Korean Government is going to amend certain laws to better permit participation of foreign researchers and experts in the country's R&D projects, supported at government-supported research institutes. HANP is scaled at about 200-300 man-years per year. During the research stages funding will be close to 2:1 government-to-industry funding; funding during the development stage will be in the reverse ratio. Major Korean industries are participating (at least in the planning phase) and include Samsung, Goldstar, Hyundai, Daewoo, PosData, SanYong, Hyosung, Korea Telecom, TriGem, Korea Computer, Qnix, and Dacom. There is also participation from the leading universities and national laboratories.

Two distinct categories of projects have been selected. One group, Products Technology Development Project (HANP-I), focuses on technologies for very specific products that may have large industrial world market share and which Korea has the capability to compete in the 21st century. The second category, Fundamental Technology Development Project (HANP-II), concerns more core technologies that are seen as essential to society but for which it may be impossible to manufacture products by 2001. Within each of these two categories seven projects have been selected. There is still some internal discussion about the projects and a certain amount of modifications are likely, but the general framework is now in place. These projects are listed below.

HANP-I: Products Technology Development

A. Industrial fields which will be supported to keep and advance Korea's present technological level and competitive advantages.

1. Semiconductor Industry: Development of highly integrated semiconductor
   - Development and production of 256M dynamic random access memory (DRAM) by 1996
   - Development of 1G DRAM by 2000
2. Communication Industry: Development of integrated services and data network (ISDN)
   - Development of ATM (asynchronous transfer mode) by 1996
   - Development of ISDN by 2000
3. Home Appliance Industry: Development of high definition TV (HDTV)
   - Establishment of HDTV monitor technology by 1993
   - Development of transmission and broadcasting technology by 1994
   - Development of flatpanel display by 1997
4. Automobile Industry: Development of electric vehicle-- Commercialized by 1996

B. Industrial fields in which Korea will be able to compete with advanced countries or will be forced to challenge to acquire competitive capability in 21st century.

5. Computer Industry: Development of intelligent computer
   - Development of multimedia computer by 1994

- Development of intelligent and neuro-computer by 1997
- Development of direct interpreting computer by 2000

6. Fine Chemical Industry: Development of new medicine and new agricultural-medicine--Development of new antibiotic and germicidal agent by 1997
7. Mechatronics: Development of advanced production systems
    - Development of computer integrated manufacturing (CIM) by 1996
    - Development of intelligent manufacturing system (IMS) by 2000

HANP-II: Fundamental Technology Development

1. New Materials: Development of new advanced materials in information services, electronic and energy industry--Critically important in information and highly developed industrial society
2. Machinery: Development of next generation transportation systems including machines and parts--Management of current social transportation problems and its schematic control techniques
3. Biotechnology: Development of new functional biomaterials--Expected to be more important in future industries in the 21st century but is not at early stage
4. Environmental Technology: Technology development in environmental engineering--Provision of better human and social environment and cooperation for global environmental protection and conservation
5. New Energy: Development of new energy resources
    - Development of clean energy with high efficiency
    - Contribution to highly developed industry and society
6. Atomic Power: Design of new atomic reactor and verification--Securing stable energy resources in preparation for the exhaustion of fossil energy
7. Human Factors: Human interface technology associated with electronics and robotics--Provide better human life with more pleasure, comfort, and convenience in highly developed industrial society

A set of technology guideposts have been established, extracted from the HANP plans.

1993:

- Development of 64M DRAM
- Development of HDTV monitor technology
- Opening of Taejon EXPO (Taejon is Korea's science city. A science and technology (S&T) EXPO is to be held beginning next spring.)
- Test operation of Maglev vehicle

1994:

- Commercialization of multimedia computer
- Development of super-precision fabrication system
- Development of transmission and broadcasting technology for HDTV

1995:

- Launch of communications satellite (Mugunghwaho)

1996:

- Development of 256M DRAM
- Development of ATM switching systems
- Commercialization of electric vehicle
- Realization of CIM

1997:

- Development of flatpanel display
- Generation of new antibiotic and germicidal agent
- Development of intelligent and neuro-computer
- Development of advanced fabrication machines

2000:

- Development of 1G DRAM
- Development of broad-band ISDN
- Development of direct interpreting computer
- Generation of new medicine and new agricultural-medicine
- Development of IMS
- Enhancement of environmental technology
- Development of mini-robot for medical use

2006:

- Construction of new atomic reactor

Remark: Of the HAN projects mentioned, the one most directly linked to Kahaner's background is the Intelligent Computer Project. The project's organizers see this as related to many other projects, such as CIM, materials, B-ISDN, HDTV, DRAMs, human interface, multiprocessors, and electric car. Major technology required will be flat-panel display, wireless communication, high speed networks, large scale databases, Korean language processing, object-oriented technology, application-specific integrated circuits (ASICs), virtual reality, etc. The intelligent computer planning team's road map for this project contains the banner "One Computer Per Person" and divides the major subprojects into three parts, associated with neural computer, knowledge processing, and multi media. Other subprojects include a voice typewriter and a personal assistant server. As most aspects of this project are still in the planning stage, it is too early to make an assessment; however, it looks like an excellent opportunity for enhanced international cooperation.

Computer researchers should make note of the following meetings to be held in Korea.

15-18 September 1992, Seoul, Korea

Second Pacific Rim International Conference on Artificial Intelligence

For information:

PRICAI Conference Secretariat
Center for AI Research
KAIST
373-1 Kusong-dong
Yusung-gu, Taejon 305-701, Korea
Tel: +82-42-829-2711, -2712
Fax: +82-42-829-8700
E-mail: pricai92@cair.kaist.ac.kr

4-9 July 1993, Seoul, Korea

Fifth International Fuzzy Systems Association World Congress

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VISITS OF THE ONRASIA-AROFE TEAM

Systems Engineering Research Institute (SERI)

Keeping Korean science organization names straight is difficult, especially so as some of their affiliations have changed over time. SERI began as the Computation Research Laboratory in the Korea Institute of Science and Technology (KIST), then became affiliated with the Korean Advanced Institute of Science and Technology (KAIST), and in 1989 moved back (organizationally) to KIST. It is located in the Taeduk Science Town, about 90 minutes by train from Seoul. Taeduk is the sight of several Korean science agencies as well as industrial laboratories. It differs from Japan's Tsukuba in that it was already a "real" small city when the scientists began moving in. At the moment a large EXPO is being constructed that will focus attention on Korean science and Taeduk in particular. SERI has 472 staff, 22 with Ph.D. degrees.

The main interest here is the Cray-2, which was discussed in an earlier report. Its Cray-2 was installed almost 4 years ago and was the first supercomputer in Korea. It has a very rich application software base; this is due not only to the largess of the Korean Government but also to the connections Korean scientists have with the United States, which makes them familiar with Western software products. Application fields are represented quite uniformly, with physics, electrical engineering, and chemistry each covering about 20% of the users. During the machine's first year in operation it was free to users. Currently a charging algorithm is in place. The scientists at Seoul National University are not heavily on this machine because of the high cost and also because until now a high-speed link was not available.

In addition to the supercomputer center, SERI also has divisions of Artificial Intelligence, System and Application Software, and Software Engineering. Very few of the actual research activities were shown, although some that looked interesting to Kahaner were automatic license plate recognition, automatic personal identification via image analysis of fingerprints, and remote sensing/image processing work. The facilities at SERI are among the very best in Korea; essentially any kind of advanced workstation-type equipment is installed. The Cray is heavily used but not completely flooded. Parallel computing is centered around a transputer-based system. To the best of Kahaner's knowledge there is no commercial parallel system available, and this could be a serious weakness for anyone wanting to do work on applications, but might be a challenge for systems researchers.

SERI is the central information center for a collection of databases and on-line services jointly called KRISTAL (Korea Research Information on Science and Technology Access Line). Databases include the Union catalog for monographs, bibliographic information compiled by specialized information centers, scientific equipment, software registration, scientific specialists, as well as other specialized databases for specific scientific disciplines.

Information moves to/from industry, government agencies, libraries, etc. and is available via public networks and a new backbone network, KREONET (Korea Research Environment Open Network). KREONET includes a 56-kbps line to the United States through the San Diego Supercomputer Center, a T1 line to SERI's Seoul facility, and a number of 56-kbps lines from SERI in Taeduk to other Korean cities including Pohang, Kwangju, Pusan, Chanwon, etc. KREONET provides the usual network services such as file transfer protocol (FTP), mail, rlogin, etc.

Korea Advanced Institute of Science and Technology (KAIST)

KAIST is a research oriented graduate school with 1,000 Ph.D. students (70% full time) administratively supported under MOST (all other federal universities are administered by the Ministry of Education). Associated with KAIST is the Korea Institute of Technology (KIT), which is an undergraduate school with 3,000 students. Since KAIST's inception in 1971 it has awarded over 1,000 Ph.D. and 6,000 M.S. degrees. A new KAIST campus is mostly complete in Taeduk (the analogy with Tsukuba University is very strong). KAIST has departments in virtually all standard fields of science and engineering as well as in management science, humanities, and social sciences. As a federal university, KAIST and KIT provide various kinds of financial support; in practice it seems that most full time students are fully supported. In the area of computing, there is a large Computer Science Department with more than 100 Ph.D. and 100 master's students that has already conferred more than 40 Ph.D. degrees.

The mainstay of the research activities in computing appears to be in the Center for Artificial Intelligence Research (CAIR), which is subdivided into six laboratories (Database and Knowledge Engineering, Language Engineering, Visual Information Processing, Speech Information Processing, Computer Systems, and Human Computer Interaction). There are plans to install a 64-transputer parallel system, but the research projects Kahaner read about are all nonnumerical. The facilities appeared to be excellent.

In the physics area, one laboratory is conducting research in subpicosecond transient behavior of semiconductor optical devices. Samples are prepared by the Electronics and Telecommunications Research Institute and measurements are made at KAIST, using lasers with pulse widths as short as 60 fs.

Korea Research Institute of Standards and Science (KRISS)

This was recently renamed from the Korea Standards Research Institute (KSRI) by incorporating the Korea Basic Science Center (KBSC) and the Institute of Space Science and Astronomy (ISSA). KBSC's main function was to provide research facilities and information on basic sciences to universities in Korea. ISSA was responsible for optical and radio observation and research in positional astronomy, astrophysics, and space science.

KRISS is essentially a standards organization that also conducts some R&D in precision measurement technology and supports industry with training in measurement technologies as well as development and repair of high-precision instruments. It has divisions of Mechanical Metrology, Electromagnetic Metrology, Quantum Metrology, Analytical Chemistry, Precision Instrumentation, and a Materials Evaluation Center. In the physics area, research is carried out on the quantum Hall effect, direct current superconducting quantum interference devices (DC SQUIDs), laser spectroscopy, and other solid-state phenomena of interest for standards.

The staff of almost 500 (about 100 with Ph.D. degrees) is located on a campus setting in the Taeduk Science Town. Most of KRISS' scientists have degrees in physics or engineering and there are no Ph.D. holders in computer science among the staff. KRISS' 1992 budget is about $30M. As with other international standards organizations, KRISS has a large number of international cooperative agreements and joint research projects with similar organizations in the United States, Japan, the United Kingdom, Italy, Canada, Germany, the Commonwealth of Independent States, and Australia.

Electronics and Telecommunications Research Institute (ETRI)

Also located in Taeduk Science Town, ETRI is the R&D arm of the Ministry of Science and Technology (MST), focusing on information technology, telecommunications, computers, automation, and semiconductors. It has a staff of about 1,700 of which about 1,400 are technical and/or professional. Only about 5% of ETRI's work is viewed as basic science (60-70 man-years per year), although the plan is to grow this to about 15% during the next decade. The current budget is about $130M, which is planned to grow to $175M by 2001. By that time ETRI hopes to have a total staff of about 2,350, of which 30% will be Ph.D. holders.

Most of the R&D work is clearly oriented toward telecommunications such as digital switches, ISDN, transmission technology, and networks. Semiconductor design and development such as ultra large scale integration (ULSI), HDTV, etc. is next. Other computer work is much more narrowly based and supports the HANP Intelligent Computer Project mentioned above.

ETRI has a small office in San Jose to support the dozen or more staff that are in the United States at any given time and also to act as a base for obtaining information about advanced technology. This year they will open a liaison office in Europe to support information exchange, joint research, etc.

In electronics research, ETRI has developed a 4-Mbit DRAM memory using 0.8-micron technology. Work is underway currently to develop 16- and 64-Mbit DRAMs using 0.5-micron technology. In applied optoelectronics research, ETRI has developed a prototype 155-Mbps optical transmitter and receiver using InGaAs/InP materials at a 1.3-micron wavelength. Current work is directed toward 565-Mbps optical transmission for use in cable television networks. More advanced systems envisioned will use InGaAs/InP positive-intrinsic-negative field effect transistor (PIN-FET) optoelectronic integrated circuits, fiber amplifiers, and distributed feedback lasers for coherent transmission at 2 or 10 Gbps. Other notable research includes the development of quantum devices, based on heterostructure materials grown by organometallic chemical vapor epitaxy and liquid phase epitaxy. These heterostructural materials and devices are the subject of the subpicosecond optical response research conducted jointly with KAIST (see above). Semiconductor device research is directed toward emitter-controlled logic (ECL) and complementary metal oxide semiconductor (CMOS) arrays. Device delay times in ECL devices as low as 51 ps have been achieved using 1.0-micron bipolar process technology.

The President of ETRI, Dr. Kyong, emphasized his interest in international collaboration (see Summary).

Korea Science and Engineering Foundation (KOSEF)

KOSEF is essentially equivalent to the U.S. National Science Foundation. A brief conversation with KOSEF's Director, Dr. Kang, revealed that, unfortunately, there are very few programs to support visiting Western researchers to Korea.

Pohang Institute of Science and Technology (POSTECH)

POSTECH is Korea's newest private university, established by the Pohang Iron and Steel Company (POSCO) in the city of the same name, slightly more than 200 miles southeast of Seoul. Its first entering class was 1987. POSTECH was discussed at length in an earlier report, so that information will not be repeated here except to say that the goal is to make POSTECH Korea's equivalent of Cal Tech. Even after just a few years there is now agreement that it is one of three most important science universities in Korea (KAIST and Seoul National University being the other two), although there is friendly disagreement about its ranking between the three.

Dr. Kim, the President of POSTECH, explained that they are very satisfied with the level of students they have enrolled. By 1995, when the university will be operating at its full capacity, there will be about 1,200 undergraduates, 1,000 graduate students, and 300 faculty. Support from POSCO is generous, but Kim is hoping to reduce the university's dependence on the company as their endowment builds up. He would also like to get additional government support that is now going to other national (nonprivate) universities.

On the topic of visitors, Kim explained that international collaboration is considered very important and that more than a dozen Nobel Prize winners have already lectured at POSTECH. There are a few Western visiting professors who are able to work in English, but lecturing in Korean is an unofficial requirement for any permanent position. POSTECH provides an attractive research situation for visitors, but there might be some lifestyle difficulties. Pohang is definitely not Seoul and access to Seoul is only fair. While English is widely spoken at POSTECH, it is unlikely to be understood outside in the city of Pohang. Further, there are no schooling facilities in the area for non-Korean speaking children.

One of the most important projects at POSTECH is the construction of a 2-GeV synchrotron-radiation source, the first in Korea. POSTECH serves as the host organization for the Pohang Light Source (PLS), Korea's entry into the synchrotron-radiation research arena. Starting from a planning task force in 1988, PLS will be a 2-GeV electron storage ring, similar in design to the Advanced Light Source currently under construction at Berkeley, CA. The injection system is very different, however. The PLS injector will be a full-energy linear accelerator (linac) designed by the High Energy Laboratory of Beijing, China. The initial section of the linac was built in Beijing and installed at Pohang by the Chinese. Subsequent sections are being built in Korea to the Chinese design, which is closely related to the design of the 2-mile-long Stanford Linear Accelerator but reduced to 2 GeV instead of 50 GeV. When finished, PLS will serve as a "user facility" for all qualified Korean scientists. Of the capability for 12 beam lines, only two are currently funded, and one of those will be for machine monitoring. Hence, the ambitious plans for research in materials science, surface science, molecular biology, chemical engineering, atomic and molecular physics, x-ray lithography, etc. will develop later as additional beam lines are added.

Research Institute of Industrial Science and Technology (RIST)

RIST is the research arm of Pohang Iron and Steel Company. It is located in Pohang within the complex of the POSTECH campus. Nearly 900 staff are supported by a budget of about $80M; there are also about 100 POSTECH faculty that have a research appointment at RIST, and many of their students are working on research projects there. Approximately half of RIST's work is concerned with steelmaking, although Kahaner did meet two students working on Bezier curve and related computer graphics applications. In the materials area, large programs are in progress in the area of advanced materials including metal matrix composites, polymers, and semiconducting materials and devices.

Facilities look very good, and the team was told that RIST is very interested in international cooperation, especially in the areas of optical fibers and infrared (IR) sensors. However, potential visitors will want to clarify to what extent they will have access to potentially proprietary information and technology.

According to Kahaner, the visit to RIST was too brief to get an accurate reading about the place. However, he came away feeling that the organization did not have its own clear vision of where it wanted to go and depended on POSCO for spirit and direction as well as for funding. By other names, POSCO has had an affiliated laboratory since 1977; it is only very recently that the organization has moved close to a university, so it is probably natural that it will take time for it to evolve into a real research institution. RIST's goal to become a world-class hi-tech research center by the year 2000 will mean that it will have to establish its own identity, independent of faculty advisors from POSTECH.

Korea Institute of Science and Technology (KIST)

KIST is Korea's first science research institute, formed in 1966. It was merged with KAIST (essentially a science and technology university) during the 1980s but was separated again in 1989. Its main facility is in Seoul, although there are two affiliated institutes, SERI (see above) and the Genetic Engineering Research Institute (GERI), both located in Taeduk Science Town. Total Seoul staff is almost 900, with more than 500 researchers. KIST's total budget last year was about $260M, of which almost 80% is from the Korean Government.

In Seoul there are divisions of Fine Chemicals, Process Technology, Mechano-Electronics, Metals, Ceramics, Polymers, and Semiconductors. The ceramics laboratories were well equipped and were engaged in research on ceramics for turbine engines, composites, sol gel processes for ceramics, etc. There is a doping control center (used to test athletes during the 1987 Seoul Olympic Games), an optics and electronics technology center, an environment research center (focused on pollution and waste control), and a fluorocarbons alternatives center. Kahaner saw no significant work relating to computing except to assist in physical laboratory experiments. The link to the SERI's Crav is new and is not used much. Kahaner didn't get a sense that much modeling was going on, but admittedly the visit was very brief. There is a remote sensing and image processing group, but he did not get to see any of their work.

International cooperation is an important ingredient of KIST's programs and, in fact, there is a Korea-Soviet Scientific and Technical Cooperation Center (KSSTCC), established in 1991.

Rehn observed that KIST's Semiconductor Materials Laboratory is one of the most advanced electronic materials research groups in Korea. Among the key research activities are:

- Growth of high quality bulk GaAs crystals by the vertical-gradient freeze method, as well as other, more standard methods.
- Heteroepitaxial growth of III-V compounds by molecular beam epitaxy, organometallic chemical vapor epitaxy, and hydride vapor phase epitaxy.
- Deposition of low resistivity W and W_2N layers by plasma-enhanced chemical vapor deposition.
- Recrystallization of Si-on-insulator structures with application to three-dimensional semiconductor devices.
- Electrical and optical characterization: Hall effect, x-ray analysis, C-V, deep level transient spectroscopy (DLTS), PICTS, photoluminescence (PL), photoluminescence excitation (PLE), and other techniques.
- Device fabrication and characterization: double heterostructure laser diode, two-dimensional electron gas devices, resonant tunneling diode, and multiple quantum well devices.

Seoul National University (SNU)

SNU is the largest, oldest, and one of the most prestigious institutions in Korea. The team's visit to SNU was only at night, to have dinner with their host, Dr. Sang Joo Kim, Vice President. Kim commented that there is competition between SNU, KAIST, and POSTECH for government support. He admitted that recently POSTECH had been very successful, but he felt that over time the advantages of Seoul would swing the pendulum back to SNU. There is not much interest in either supercomputing or practical parallel computing at SNU. Perhaps faculty in the engineering departments are able to do all their necessary computations on workstations. Interests in electronics-related research are wide and varied, including research in semiconductors and superconductors. Epitaxial semiconductor structures are grown by both molecular beam and organometallic methods under the direction of U.S.-trained scientists such as Prof. Jung-Chun Woo.

Korea Ocean Research and Development Institute (KORDI)

The visit to KORDI, located in Ansan on the west coast, was very brief. Their new ship, the ONNURI, was just arriving from its construction in Norway, and they will be getting another ship, the EARDO, which will be the support ship for their submersible. The capacity of KORDI to participate in international programs is growing. Wilde's impression was of great potential capabilities but with facilities just coming on-line for other than just coastal work.

SUMMARY

Korean computing research is behind that in the United States in most of the areas Kahaner was told about and this corresponds to earlier experiences he has reported in previous *Scientific Information Bulletin* articles [see, for example, "Snapshot of Computing Activities in Korea," 16(2), 7-13 (1991); and "First Korea-Japan Conference on Computer Vision," 17(1), 37-49 (1992)]. Koreans are aware of all the main thrusts in computing science and often are working up to their own approaches to finding solutions to problems being pursued widely. Parallel computing research is highly oriented around transputers. Supercomputing is concentrated at one laboratory (ETRI) along with some industrial applications at Kia Motors, but the field is not thriving, nor did I hear about much research in numerical computation. Networking is improving, with the soon-to-be-opened T1 link between Seoul and Taeduk and other 54-kbit lines in operation or soon to be and enhanced Internet access. Facilities at the research laboratories are good to very good and include a variety of advanced workstations and graphics terminals.

Korean work in ocean science and engineering shows great promise after a period of heavy investment. They have the equipment, buildings, governmental support, and well-trained staffs. Right now, they are in the pre-active research phase, advancing on the learning curve by doing routine survey work in coastal areas, mainly as service to government agencies and industry. Their fisheries-marine biology work is close to par with Western nations, but as expected it's far smaller than the effort in Japan. On the international level, Korea is actively cooperating in Antarctica with many nations. KORDI is involved in several global oceanographic experiments with components in near Korean waters. Once they have people familiar with the equipment, they have the potential of developing active basic research programs. Right now, much of the research is applied, which may be suitable for a country as small and emerging as Korea. Korea might benefit from a more active exchange program with the United States. They do have a relatively small program with Japan. However, because of historical reasons, Korean-Japanese cooperation may be expected to be limited and less valuable to the Koreans than with Western nations. Due to the lack of research funds in the United States, any Korean exchange would have to be supported by Korean money both ways. A Korean scientist, already paid for, would be more likely to get a welcome reception at a U.S. facility. On the other hand, even with good facilities, the culture shock may be an inhibiting factor in any U.S.-to-Korea exchange. A Korean equivalent to the Humboldt Prize, where the German Government thanked the United States for the Marshall Plan, might be required to attract senior U.S. scientists. From the U.S. side, presently there is little active research going on of other than regional interest to U.S. scientists. The potential is there, and there would be opportunities for young researchers struggling for funds and space in the United States. Some of their active research programs such as the Ocean Thermal Energy Conversion (OTEC) program and Ocean Mining are essentially defunct in the United States. It may be in the interest of the United States to maintain some times to these programs as insurance on potential emerging technologies.

Korean research groups have emphasized electronic materials and semiconductor heterostructure studies for their obvious commercial potentialities. Korea is determined to earn a share of the HDTV market, which requires development of very sophisticated digital and analog IC production capacity. Both silicon-based and GaAs-based ICs are being developed at ETRI, KIST, RIST, and SNU, especially among the laboratories visited. In addition, there are strong industrial research programs in laboratories of Samsung, Goldstar, and Hyundai Electronics, which Rehn will attempt to assess later. From this bird's eye view of Korean government-sponsored research in electronic materials and semiconductor heterostructures, we heard about research on quantum heterostructures and superlattices in III-V and in Si-Ge materials. We heard about organometallic vapor phase epitaxy and molecular beam epitaxy growth facilities at ETRI, KIST, and SNU. We saw application of Josephson junction technology in standards research at KRISS and femtosecond laser spectroscopy studies at KAIST on optoelectronic devices grown at ETRI. We also saw the beginnings of the Pohang Light Source (PLS), a 2-GeV synchrotron-radiation (SR) facility under construction at POSTECH. Plans for PLS beam lines are not yet available, but a committee has convened in Seoul to study effective application of SR in electronics-oriented research programs.

Korean scientists and research managers are eager for international collaboration. They realize, however, that they do not now have as much to offer as to receive in such exchanges. Hence, they are willing to provide the greater share of the funding and make other contributions. For example, Korean research scientists may be sent, fully paid, to the United States for extended (6-12 months) visits in U.S. laboratories, where they can contribute to U.S. research activities while learning U.S. research techniques. Exchanges the other way are more problematic, however. Although the Korean laboratories are eager to host U.S. scientists for extended visits, and to pay much of the cost, they recognize that the benefits to the U.S. scientists may not be so great.

The depth and breadth of Korean electronics-oriented research was not apparent from this brief overview. In the near future, Rehn will report in greater depth on electronics-oriented research in Korea and on the opportunities for international cooperation.

ERATO AND JAPAN'S DREAMS OF FUTURE TECHNOLOGY

The 10-year-old ERATO program is one of Japan's most innovative programs for moving the frontiers of science toward advanced technology. Covering a broad scope from the biological and life sciences to the chemical sciences and new areas of nanoscience, ERATO is a highly visible program of 17 individual projects, currently, involving 576 researchers (24 foreign) in 145 laboratories, with a total funding of about $51M per year. The impact of these multidisciplinary, time-limited, exploratory research projects is beginning to be felt in several areas of science and technology, both within and outside Japan.

by Victor Rehn

INTRODUCTION TO ERATO

ERATO is a high-visibility, highly political research program spanning a wide range of research from genetics and biological sciences to surface and semiconductor physics and chemistry. Considering the long tenure in office of Japan's Liberal Democratic Party, as well as the Japanese cultural concern for continuity and harmony, the continuity of ERATO in the foreseeable future seems assured.

ERATO (Exploratory Research for Advanced Technology) is a 10-year-old program of the Research and Development Corporation of Japan (JRDC). JRDC, in turn, was founded by the Science and Technology Agency (STA) in 1961. STA is an element of the Prime Minister's office, along with the Council for Science and Technology (see Figure 1).

There seems to be no program in the United States similar to ERATO. It differs from National Science Foundation (NSF) programs in the scale, tenure, and organization of the projects: total funding for each project is typically $15M over a 5-year period, sometimes to be followed by a post-project project. Each project is selected by the JRDC with the coordination of the Research and Development Council.

Projects are organized around a research theme by a single Project Director (PD), who may be associated with a university, a national research institution, a public research corporation, or an industrial research laboratory. Typically, the PD utilizes three research groups comprising researchers from any type of research laboratory, including overseas laboratories. (There are currently 89 overseas researchers from 24 countries in the ERATO program.) Each group is given a specific subgoal and coordinates its work with the PD via a group leader. PDs are not encouraged to build permanent laboratory facilities but rather to rent temporary facilities as needed. Usually these facilities are separate from the PD's organization.

ERATO research is carried out at the interface between science and technology. However, project themes are considered starting points only and are not restrictive. One ERATO PD told me that they are encouraged to "play around" with new research ideas, even lying outside the original scope of the project. A wide variety of disciplines can be included in any project. Younger Ph.D. investigators in their early thirties form the majority of researchers, thereby providing a training ground for the professional, innovative leadership of the next generation. Note that ERATO (i.e., JRDC) is independent of the Ministry for International Trade and Industry (MITI) and the Ministry of Education, both ministries with extensive research programs of their own.

ERATO PROJECTS

Three or four new ERATO projects are announced annually. With the 1991 announcement of four new projects beginning 1 October 1991, there are currently 17 in all, and 12 others have been completed (see Appendixes A and B). ERATO projects are reviewed publicly annually in the ERATO Symposia given in Tokyo. Although these reviews are presented in Japanese, English translations are published later. Several English translations of the 1990 ERATO reviews were reproduced in the *JPRS Report on Science and Technology*, Japan, JPRS-JST-91-022, 12 August 1991. They can be thought of as progress reports on the realization of the dreams of future science and technology dreamt by some Japanese researchers.

In the next sections brief descriptions are presented of some of the projects. Most of this material comes from the English abstracts of the presentations made at the ERATO Symposia '91, Tokyo, November and December 1991. Additional material was gathered from JRDC publications.

The order of projects below corresponds to that given in Appendixes A and B. Further information concerning any of the ERATO projects may be obtained from the appropriate project director, whose mailing address and telephone and telefax numbers are given in Appendix B.

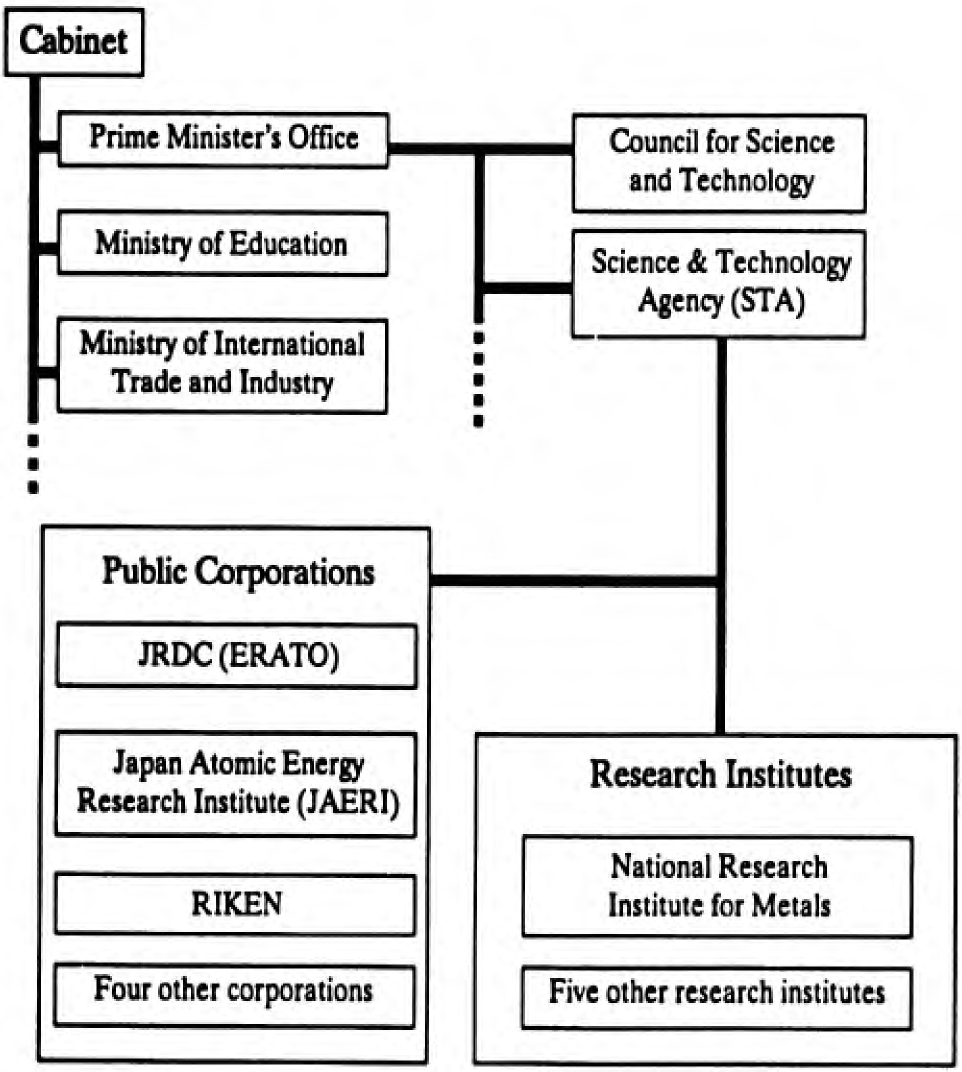

Figure 1. Organization relationship of the JRDC ERATO program within the Science and Technology Agency under the Prime Minister's Office.

QUANTUM MAGNETO FLUX LOGIC PROJECT: SUPERCOMPUTER THROUGH SUPERCONDUCTOR

Project Director: Eiichi Goto

The advancements of supercomputers have made it possible to simulate many complicated natural and artificial phenomena, such as meteorology, large-scale integration (LSI) design, and even protein structures. However, more than several hundreds of times faster computers should be required to accurately analyze these large and complicated systems, including long-term weather forecast, accurate ultra LSI (ULSI) design, and DNA simulations. The silicon LSIs, which are mainly utilized in today's supercomputers, should face such limitations as power consumption and propagation delay in these very large and fast computer systems. Therefore, very fast operation and low power consumption devices should be necessary for the future high performance computer systems.

A quantum flux parametron (QFP) device was first reported in 1984 (Ref 1) and was named after the parametron device (Ref 2) invented about 30 years before. QFP is a very promising candidate for future supercomputers because of its very low power dissipation (10^{-9} W/gate) and fast switching speed (10^{-12} s/gate), with its capability of three-dimensional (3D) packaging through magnetic coupling. These characteristics should make it possible to integrate the whole system in a very small volume. Thus, a TFLOPS (10^{12} floating operations per second) computer should be made possible by QFP circuits. The Quantum Magneto Flux Logic (QMFL) project aims to demonstrate (1) multi GHz operation of QFP circuits; (2) highly functional QFP logic circuits; (3) a suitable operation system for fast QFP computers; (4) a reliable refrigerator; and (5) removal of trapped magnetic flux from superconductors, as the first step toward a TFLOPS QFP computer. The QMFL project consists of three groups, Fundamental Property, Computer Architecture, and Magnetic Shielding. The former two were at Hitachi's Central Research Laboratory and the third one was with ULVAC Corp.

The detailed achievements of this project are listed in References 3 and 4 and a brief summary is stated here. The Fundamental Property Group aimed to clarify the physics of QFP devices to investigate the QFP logic circuit design, to demonstrate very fast operation of QFP circuits, and to verify 3D integration. A highly functional logic gate, D-gate, was proposed and was shown to be twice as powerful as compared with semiconductor logic gates. The operation of D-gate was successfully demonstrated by experiment. A shift register circuit, fabricated by 5-μm Pb alloy technology, operated at 16 GHz and was simulated to operate at 100 GHz if 2.5-μm Nb technology was utilized. Other circuits, such as analog-to-digital converters, were also demonstrated to operate at more than 18 GHz. Three-dimensional signal transfer via magnetic coupling was also successfully demonstrated. These results suggest that QFP is a very promising candidate for the future high performance computers.

The Computer Architecture Group looked into the cyclic pipeline architecture (CPC), which is suitable for the very fast latching circuits, such as QFPs. Compilers and several application software were designed, and the performance of CPC was verified. Along with these simulation studies, a CPC computer, made of silicon emitter-controlled logic (ECL) integrated circuits, was designed and fabricated, and the performance was evaluated using standard supercomputer benchmarks. It was made clear that CPC architecture accelerates the performance by a factor of 10, if 12 jobs are processed in parallel, while conventional pipeline accelerates only a factor of 3 using the same hardware.

The Magnetic Shielding Group aimed for the verification of a high performance refrigerator and establishment of trapped flux detection and removal technology. The characteristics of a bellows type refrigerator were examined first, and it was found that multilayering eases the maximum stress. The fatigue strength of bellows was also made clear. The new pulse-tube type refrigerator, which has no moving parts in the low temperature region, was investigated and high efficiency and reliability were ascertained. The trapped flux in the superconductor film was detected by superconducting quantum interference device (SQUID), with a spatial resolution of 100 μm and a magnetic field resolution of less than 0.1 flux quanta. The trapped flux was successfully removed by irradiating a laser beam to the superconductor film and heating it up to the normal state (micro heat flushing).

These achievements of the QMFL project, which came to an end in September 1991 and has already reached the applied research level, will be succeeded by a high-tech consortium, with Hitachi and ULVAC, supported by JRDC. The other achievements, in a relatively basic research level, will be further pursued by the Goto Research Laboratory at RIKEN.

KUNITAKE MOLECULAR ARCHITECTURE PROJECT: NOVEL FUNCTIONS THROUGH SELF-ORGANIZATION OF MOLECULAR MATERIALS

Project Director: Toyoki Kunitake

The biomembrane is formed by self-organization of component molecules (lipids and proteins) that are derived from their unique steric structures. The preparation of synthetic bilayer membranes has been successfully achieved in Japan and other countries by using a large variety of novel organic compounds. These compounds are composed of hydrophilic head groups and hydrophobic hydrocarbon chains in an analogy to biolipid molecules. This new molecular system provides an exciting possibility to produce artificial organization and to lead to a new field of chemical science.

In our ERATO project, the major emphasis is placed on self-organization of the above-mentioned types of organic molecules in the form of surface monolayers, Langmuir-Blodgett (LB) films, aqueous bilayers, and cast films. We aim at construction of molecular organizations that would possess particular electronic, magnetic, and chemical functions. Improvements of these functions will be attained by means of chemical modifications of simple assemblage and formation of multiply composed organizations. These studies should provide clues for the development of novel industrial materials that are equipped with sophisticated functions analogous to those of the biological organization and yet are characterized by stability and processability of synthetic materials.

Our laboratories are set up at Kurume Research Park on Kyushu Island. The total staff is 21, as of 1 October 1991, including project director, administrative staff, researchers, and technicians. The whole research team is divided into three groups. The current activities of each group are described below.

Fundamental Design Group. We have prepared a series of surface monolayers that possess hydrogen bonding functionalities such as phenolic hydroxyl, carboxylic acid, 2,6-diaminotriazine, diphenyl-urea, and guanidinium. These monolayers bind biologically important compounds (sugars, amino acids, nucleotides, ATP) in specific manners. The strong binding behavior observed in exposure to bulk water at the air-water surface is surprising.

Surface force measurements provided the evidence for a strong attractive force between two hydrophobic surfaces at an unprecedented distance of 300 nm. Any theory to explain this effect has not been proposed yet. The subsequent measurement of repulsion between two polyelectrolyte-modified surfaces produced data that could be discussed in the conventional theoretical framework.

Scanning tunneling microscopy (STM) showed that azobenzenecarboxylic acids were regularly aligned on highly oriented poly graphite (HOPG). The liquid crystalline nature of the azobenzene derivatives was closely related to complete wetting of graphite.

Functional Architecture Group. The self-assembling property of synthetic bilayer membranes was used to produce regular organization of metal ions (transition metals and lanthanides) on a two-dimensional molecular surface. Multilayered films of ultrathin silicate and aluminosilicate layers were prepared by using cast films of synthetic bilayer membranes as molecular templates. The morphology of the highly porous silicate was replicas of aqueous bilayer dispersions and showed surprising variations depending on the composition and the preparative conditions. An ion exchange technique applied to cast multilayer films provided an additional template procedure. These methods were also used to obtain metal oxide multilayers from ultra-fine particles of metal oxides.

A series of novel oligo (phenylene-vinylene) amphiphiles formed stable monolayers on water. Some of these wholly pi-conjugated monolayers produced Z-type LB films with nonlinear optical properties.

Composite Architecture Group. Regular multilayer films were obtainable from aqueous mixtures of bilayers and polar bifunctional monomers. Photoirradiation and removal of the template produced multilayered two-dimensional (2D) polymer networks. When allylammonium monomers were used, multilayered ultrathin ion exchange films were formed. A similar technique was realized in nonaqueous media by the use of polyfluorinated amphiphiles, which formed ordered dispersions in some organic solvents. These fluorocarbon amphiphiles also gave uniform, stable monolayers.

Molecularly thin 2D networks were prepared by covalent bonding of ion complexes of oppositely charged polymers formed at the air-water interface. Defect-free films of a few molecular layers were thus formed by proper combination of the starting polymers.

Direct Observation of Molecular Assembly by Scanning Tunneling Microscopy

Masahito Sano, Fundamental Design Group

Azobenzene derivatives, self-assembled on the graphite surface, were imaged directly by STM in air (Ref 5). The images confirmed the model previously proposed for layered aggregates and compared well with the bulk correlation length. The methyl terminated compounds frequently showed bimolecular packings, while the brominated derivatives indicated a monomolecular structure. The difference in the distance between the carbon-hydrogen and the carbon-bromine atoms is an important factor contributing to these different packing styles.

In the course of sample preparation, it has been found that the liquid crystalline molecules with a sufficiently long alkyl chain in the nematic phase wet the basal plane of graphite completely. Also, alkylated compounds that are not liquid crystalline can be made to wet the graphite completely by forming a mixture with other compounds. These observations, together with STM images of these compounds, allow us to argue a mechanism of wetting on a molecular scale.

Synthesis of Multilayered Inorganic Ultrathin Films by Using Cast Multi-Bilayer Films as Molecular Templates

Munetoshi Isayamagi, Functional Architecture Group

Cu^{2+} ion was incorporated into a multi-bilayer cast film of a phosphate amphiphile by an ion exchange process. The Cu^{2+} ion showed different electron spin resonance (ESR) patterns depending on the angle of the cast film surface against the magnetic field.

Silicate and silica-alumina ions can be also inserted into the cast film of an ammonium amphiphile in stoichiometric quantities by the same technique. Ultrathin films of silicate and silica-alumina could be obtained after extraction of the amphiphile.

The high regularity and the ion exchange ability of a multi-bilayer cast film that was prepared from a self-assembling amphiphile enable orientation control of inorganic structure units and synthesis of molecularly thin inorganic materials.

Preparation of Ultrathin Fluorocarbon Film and Its Application

Kenji Fukuta, Composite Architecture Group

Novel double-chain ammonium amphiphiles, whose alkyl tails are composed of fluorocarbon and hydrocarbon segments, are synthesized. They can form self-supporting, multi-bilayer films by casting from water or from appropriate organic solvents. Especially, those amphiphiles that have olefinic or ether units in the tail exhibit higher solubilities (dispersibilities) in many organic solvents and produce well-ordered films rather readily.

These fluorocarbon amphiphiles can be used as molecular templates to prepare multilayered poly(stearyl acrylate). The thickness of the individual layer is determined to be 500 Å or less by scanning electron microscopy (SEM). The formation of multi-bilayer cast films even from organic solvents enlarges the usefulness of the casting technique.

NISHIZAWA TERAHERTZ PROJECT: EXPLORATION FOR TERAHERTZ SEMICONDUCTOR DEVICES

Project Director: Jun'ichi Nishizawa

Background

The last several decades has witnessed a tremendous growth in the understanding and development of solid-state materials, resulting in a proliferation of semiconductor devices. These can be applied to ever-increasing regions of the electromagnetic spectrum.

In the electromagnetic wave region the usable frequency band has been extended to 10^{11} Hz (3-mm wavelength) owing to technological advancements of microscopic semiconductor elements (less than 0.1 micron). Further, the near-infrared region (near 1-micron wavelength) is now usable owing to progress in quantum electronics. Jun'ichi Nishizawa is presently following up his very successful Perfect Crystal project (described in post-project-phase ERATO projects) with a study of the manipulation and use of the hitherto unexplored terahertz region (10^{12} Hz or 300-micron wavelength).

This research will hopefully lead to the fabrication of semiconductor elements at the level of molecular layers, giving birth to a new engineering field that might well be called Molecular Electronics. It should also contribute to a sharp increase in not only the measuring techniques of lattice and molecular oscillations but also the future speed and volume of communication devices.

Research Strategy

This project is investigating compound semiconductors of the size of molecular ultrathin layers fabricated by carefully controlled photo-stimulated molecular layer epitaxial growth. Since it is not certain whether knowledge concerning electron behavior in conventional element structures is applicable to devices operating in the terahertz frequency region, crystal technology at the molecular-layer level is being studied.

Circuits that can operate as a mixer, detector, harmonic generator, and traveling-wave type optical modulator are also being investigated. New devices that are very thin, less than several hundred molecular layers, must be achieved not only for devices used to amplify signals but also for detectors and receivers that can also convert optical waves into lower frequencies.

Research Progress

A buried heterostructure Raman laser has been investigated in which an intermediate layer is formed for pump power introduction, while Stokes radiation is confined within the active region without any disturbance from the entrance window. Lasing has been demonstrated and the pump power improved to as low as 0.5 W. The fabrication method is based on liquid-phase epitaxy by a temperature-difference method under controlled vapor pressure, which can maintain a very low nonstoichiometric defect concentration. For the first time very perfect control of the crystal thickness in single crystals has been achieved.

In molecular-layer epitaxy the carrier concentration in a film strongly depends on the injection period of impurity gas, as well as substrate surface orientation. From studying the doping efficiency of Si using Si_2H_6, it could be doped on a Ga-compound substrate surface. Sites may be influenced by the AsH_3 pressure. Moreover, Si can be incorporated as a donor on the (111)B or (100) surfaces and as an acceptor on the (111)A surface.

Films have been made that are thinner than the carrier mean free path, resulting in the absence of both collisions and scattering by lattice vibration, enabling a mesoscopic static induction transistor (SIT) to be fabricated with an operation speed greater than 1 THz.

Progress has also been made towards an SIT device with a very thin base layer, thus limiting the frequency. Eventually, both Tunnett and SIT preparation will be combined.

A fabrication procedure for Pt/GaAs diodes (used for low-noise mixers with low conversion loss in the THz region) has been developed. Reactive ion etching and surface treatment of GaAs wafer surfaces have been improved and the diode diameter reduced to obtain a higher cutoff frequency: 0.8-micron-diameter diodes have been fabricated with a 11,600-K mixer noise temperature and a 19.1-dB conversion loss at a signal frequency of 1.4 THz. Further, an antenna pattern suitable for imaging optics and antenna impedance of a good Schottky diode by tuning the director element of a Yagi-Uda antenna has been achieved. A new-type traveling-wave optical modulator is being developed and analyzed in which the optical wave and modulating wave phase velocity are matched. Three-dimensional fine processing is necessary to fabricate steps of a few microns height and vertical, smooth sidewalls. The etching of the dielectrics and semiconductors used for optical waveguides and metals for electrodes has progressed.

There are three subgroups in our project located in Sendai: Basic Analysis, Functional Device, and Circuit Configuration. In the Basic Analysis Group, the photo-stimulated molecular layer epitaxy (MLE) technique is used to obtain the very thin epitaxial layers for the very high speed transistors and diodes. Several kinds of devices such as the SIT, the Tunnett diode, the semiconductor Raman laser, etc. have been developed. The circuits that operate as the mixer, detector, harmonic generator, travelling-wave-type optical modulator, etc. are also being investigated.

Ideal Static Induction Transistor (ISIT)

Piotr Plotka, Functional Device Research Laboratory

Yutaka Oyama, Basic Analysis Research Laboratory

The ISIT transistor may be looked at as composed of some "building blocks": $n^+n^-p^+n^-n^+$ sandwich, extrinsic gate, and nonalloyed contacts. To develop a fabrication process, methods for fabrication of these blocks should be developed first.

Nearly ballistic operation of the ISIT can be obtained if the distance between highly doped n^+ regions of drain and source is on the order of 100 nm (Ref 6). To induce a potential barrier, we applied a very thin, fully depleted p^+ layer inside an n^- layer, an idea taken from high power SIT devices and planar doped barrier devices.

Such $n^+n^-p^+n^-n^+$ sandwiches have bean fabricated with MLE on GaAs(100) n^+ wafers. The fabrication process started with a 20-nm-thick n^+ buffer followed by subsequent growths of a 200-nm-thick n^- layer, thin p^+ layer, 50-nm-thick n^- layer, 20-nm-thick n^+ source layer, and finally a 10-nm-thick n^{++} layer for contact. The potential barrier value is a very sensitive function of the Zn doping of the p^+ layer.

So far, selective fabrication of semiconductor regions of one conduction type, surrounded by regions of opposite type, was characteristic for silicon rather than for III-V device technology. We applied MLE for selective growth of GaAs pn structures in grooves, similar to those required for gates of ISIT devices. A GaAs substrate with an n^- Si doped metal organic chemical vapor deposited (MOCVD) layer was covered by photo-excited chemical vapor deposited (PECVD) silicon nitride. The SiN was patterned to form square openings. This served as a mask for subsequent wet etching of grooves in GaAs and as a mask for epitaxy. Two different MLE processes were checked: one doped with Zn and the second doped with carbon.

Current-voltage measurements were performed to evaluate quality of the regrown pn junctions. Characteristics of diodes containing MLE layers on (100) bottom and sidewalls parallel to the {01-1} direction of the groove and terminated at overhanging SiN are not worse than characteristics of diodes with MLE layers on (100) bottoms only. However, the performance of regrown pn junctions fabricated with Zn as dopant is better than for C as dopant. The ideality factor of forward characteristics for Zn-doped junctions is n=1.3, whereas in the case of C doping n=1.6.

The technique developed for selective growth of pn junctions with MLE can find application not only for fabrication of gates on ISITs but also for many other devices. It is attractive especially because of the low temperature required to grow MLE layers.

To exploit fully the advantages of very thin layers that can be grown with MLE, we are working on development of nonalloyed contacts to both n and p type GaAs.

Contacts to n-type GaAs were formed by lift-off on MLE layers heavily doped with selenium. The specific contact resistance, evaluated with the transmission line method, was in the range of low 10^{-6} Ω-cm^2. This is the best reported result for homogeneously doped n-type GaAs.

The specific contact resistance for p-type GaAs MLE layers heavily doped with Zn is 2×10^{-6} Ω-cm^2. Although other methods enable obtaining even lower values of contact resistance, and are selective as well, the advantage of this method is the possibility of fabricating high quality pn junctions with excellent coverage of sidewalls of complicated shapes. This makes the method suitable for contacts to thin, buried layers or two-dimensional hole-gas layers.

Tunnett Diode

Toshifumi Suzuki, Functional Device Research Laboratory

The tunneling-electron transit-time diode, the Tunnett diode, is considered the most important semiconductor device in the submillimeter-wave region. We have made Tunnett diodes using MLE, controlling layer thickness with an accuracy on the order of one molecular layer (Ref 7).

The Tunnett diodes we have made utilize a $p^+n^+i(n^-)n^+$ structure. Tunnel current is injected from the p^+n^+ region into the $i(n^-)$ region. The oscillation frequency depends on the running time of these carriers in the $i(n^-)$ running region. Therefore, to obtain a higher frequency, it is desirable to reduce the thickness of the running region.

In conventional impact avalanche transit-time (IMPATT) diodes, reducing the device dimensions causes an increase of the electric field intensity in the injection region. Eventually, tunneling replaces avalanching as the high frequency carrier injection mechanism. Therefore, it can be said that the Tunnett diode is necessary to obtain higher frequencies.

A field intensity in the injection region of about 106 V/cm is needed to get tunnel injection. On the other hand, in the running region a field intensity of about 104 V/cm is sufficient to obtain the saturation velocity of carriers. To achieve such field intensities in these two regions, it is necessary to control thickness and doping concentration of each layer precisely. MLE is a promising method to realize the necessary precision. It is considered that submillimeter oscillation of the Tunnett diode with optimized potential distribution will be realized with an applied voltage of about 1 V. We are now making Tunnett diodes to oscillate in the terahertz region.

We are also researching resonators for the submillimeter region. One type is a waveguide cavity resonator and another is an open resonator. We cannot analyze the behavior of resonators in the submillimeter region directly because no network analyzer for this region exists. So we made a W-band resonator (75 to 110 GHz) and measured network characteristics with good results. In the submillimeter region, the electromagnetic wavelength is very small, so it is very difficult to make waveguide cavity resonators for this region. Therefore, it is expected that the larger dimensions of the open resonator will make it easier to fabricate.

We have used a Fourier-transform infrared (FTIR) system to measure the oscillation frequency of Tunnett diodes. The Michelson interferometer in this system has a Mylar film as a half mirror. We have measured a wavenumber of 4.5 cm^{-1} (135 GHz). With this system, we have the basic technology for frequency measurements from the far infrared to infrared.

The Tunnett diode oscillation system is very convenient because of its small size and power requirements. It is considered that submillimeter oscillation from the Tunnett diode will be very important for the development of devices in this frequency region. Further, it will make a significant contribution to the study of the interaction between submillimeter waves and matter.

Photoexcited Etching of GaAs

Kenji Yamamoto, Functional Device Research Laboratory

To fabricate a superlattice structure or a quantum effect device, atomic scale controllability of processing is demanded. In recent years, there have been many reports on the use of the alternate operation of gas feeding, which has atomic scale controllability in thin-film growth, but few such reports in etching. In conventional etching, the etchant and the energetic particles (ion, electron, photon) are introduced onto the substrate simultaneously. On the other hand, in digital photoexcited etching (DPE), the etchant and ultraviolet (UV) irradiation are applied alternately (Ref 8,9). The basic concept is as follows: (1) The etchant is introduced into the chamber and is adsorbed on the substrate (the etchant should not etch the substrate spontaneously at this moment). (2) Excess etchant is evacuated. (3) UV light irradiates the surface to initiate the photochemical reaction between adsorbed etchant and the surface atoms and to promote the photodesorption of products.

In the present study, DPE of GaAs (100) and (111) has been demonstrated with a Xe/Hg lamp/Cl_2 system. Dependence of etching rate per cycle on UV irradiation time, Cl_2 evacuation time, and Cl_2 gas pressure are investigated. Etching profiles and surface morphology are also observed. Xe/Hg lamp power, etchant supply time, and substrate temperature are fixed through all experiments at 0.19 W/cm^2, 1 second, and 10 °C, respectively.

(1) UV irradiation time dependence: The Cl_2 gas pressure was 1 x 10^{-4} Torr and evacuation time was 12 seconds. Etching rate is saturated for an irradiation time of more than 20 seconds. This means that 20 seconds of irradiation is enough to promote surface reaction of adsorbed etchant and desorption of etching products.

(2) Cl gas evacuation time dependence: The Cl gas pressure was 1 x 10^{-4} Torr and UV irradiation time was 20 seconds. The etching rate has a plateau region with the etchant evacuation time from 3 to 12 seconds. This indicates that the amount of adsorbed etchant is constant during this time. In the region less than 3 seconds, the residual etchant probably contributes to the etching. In the region more than 12 seconds, the etchant doesn't seem to adsorb in the same amount any more and probably desorbs from the substrate gradually.

(3) Cl_2 pressure dependence: The UV irradiation time was 6 seconds and the etchant evacuation time was 6 seconds. For these conditions, no saturated region is obtained. This means that there is no self-limiting of adsorption. Therefore, the etchant gas pressure must be controlled precisely in order to control the etching rate. The gas injection time and substrate temperature, however, should be considered for the probability of the self-limiting process.

(4) Etching profile and surface morphology: DPE exhibits crystallographic etching because no etching of GaAs(111)A occurs. Surface morphology is better than that of conventional etching in which etchant and UV light irradiation are supplied simultaneously.

Although no self-limiting process was obtained in the current DPE system, the etched depth can be controlled by sequence time alone if the etchant pressure is controlled precisely. Crystallographic atomic-layer-controlled etching like DPE is expected to play an important role in the fabrication of ISIT or quantum effect devices.

MASUHARA MICROPHOTOCONVERSION PROJECT: MICROCHEMISTRY BY PHOTON TECHNIQUES

Project Director: Hiroshi Masuhara

Microtechnology is now recognized as a general trend and affords various possibilities in science, as microelectronics, microoptics, microsurgery, micromachine, and so on. When a reaction vessel is reduced to a micrometer-order dimension, the contribution of surface and interface to the chemical and physical properties of solution increases. As an example, the viscosity of a liquid increases and intermolecular interactions in solution could be influenced to a greater extent by reducing the size of a reaction vessel. Clearly, chemistry in micrometer dimensions is extremely important and worthy to be studied. Nevertheless, microchemistry and chemical microengineering have never been discussed as one of the microtechnologies. We expect exploratory research on chemical and materials conversion in micrometer size dimensions to be promising as a new science and technology.

To realize the idea, a variety of methods to prepare minute reaction sites as well as to measure and control reactions should be developed. Recent progress in laser and microfabrication techniques contribute to the problem. Laser light is monochromatic and intense, interferes with each other, and can be pulsed and focused to a wavelength order spot. Furthermore, it is possible to follow molecular energy-relaxation processes and chemical reactions in small dimensions with picosecond time resolution. This means we have an "eye" for observing chemistry micrometer dimensions. By utilizing the optical pressure of a laser beam, we can choose a single particle in a dispersed solution and manipulate and fix the particle at a certain spacial position. The surface of an individual particle is photochemically modified, and a small area of the surface is fabricated. We can say we have a potential "hand" for microchemistry.

In general, a reaction field is intrinsically important to control chemical reactions; therefore, it is strongly suggested to prepare a micrometer size small reaction field. This is now possible by introducing various microfabrication techniques: laser ablation, microlithography, scanning electrochemical microscope, chemical vapor deposition, and microelectrochemistry. The surface of semiconductors, metals, polymeric materials, etc. is physically and chemically modified. Spatial micropatterns can be arbitrarily introduced onto a small area of the material's surface. This means we have a "field" for microchemistry.

Thus, chemical reactions and materials conversion in micrometer dimensions are made possible by photon techniques and very wide research fields have been opened. Scientific and technological products are classified into the following three subjects. The first concerns the development of space- and time-resolved spectroscopy and elucidation of micrometer size effects upon physical and chemical dynamics, which can be revealed by microspectroscopy. Although molecular relaxation phenomena and chemical reactions in micrometer small volumes have never been explored, such studies are an extremely interesting subject.

Secondly, we will study the physical and chemical properties of a single individual particle that is trapped by optical pressure, elucidate mechanics of particle motions and intraparticle interactions, and construct micrometer structures by photochemical adhesion of particles. This is a novel subject and is called the chemistry of a single microparticle.

The third is microfabrication and microfunctionalization of polymeric materials by laser and microfabrication techniques. Preparation of a series of micrometer reaction sites with different chemical and physical functions and their spatial arrangement will afford a new dynamic function. Toward our final goal, we are exploring a prototype of integrated microchemical systems, utilizing our original techniques of microchemistry: "eye," "hand," and "field."

The project consists of three groups dealing with laser spectroscopy, microfabrication techniques, and reaction control. During these 3 years we have presented 57 and 30 papers to domestic and international symposia, respectively, and presented a lot of reviews and invited lectures. Now 14 researchers including 3 foreign scientists are working.

1. Dynamic Microspectroscopy Group (Kyoto Research Park Co. Ltd., Kyoto). A new class of spectroscopy for elucidating picosecond chemical processes in micrometer small dimensions is being developed. A laser trapping technique of microparticles is combined with time-resolved spectroscopy, photochemical reaction, and laser fabrication, which is now constructed as a laser manipulation-spectroscopy-reaction system. The results will open a new way to control chemical reactions arbitrarily in three-dimensional space.

We previously reported a variable angle, time-resolved, total-internal-reflection fluorescence spectroscopy for elucidating structure and dynamics in the surface/interface layers of solids and liquids (Ref 10). It has been clarified that the properties in the surface/interface layers with thickness of 0.1 micron were different from those in the bulk (Ref 11). Analogous results were obtained for photophysical properties of molecules in alcohols and water.

To measure transient absorption spectra and their rise/decay dynamics, we have developed two types of new spectroscopic techniques where a subpicosecond (ps) white continuum was used as the monitoring light (Ref 12). One is to introduce sub-ps excitation and monitoring pulses into microscope optics, which enables us to obtain absorption spectra of a single microcrystal, a liquid droplet, and molecules in porous glasses. The other is a new technique called sub-ps transient grating spectroscopy. The excitation pulse forms a transient grating that diffracts the probing continuum. The diffraction efficiency as a function of wavelength of the probing continuum is related to transient absorption spectra in the excited states of chemical intermediates. The high sensitivity of the novel spectroscopic technique promises future applications to study chemical reactions in micrometer small dimensions.

In addition to these methods, a laser manipulation-spectroscopy-reaction system has been developed.

2. Microchemical Function Group (Central Research Laboratories, Idemitsu Co. Ltd., Sodegaura). Using various fabrication techniques, micrometer sites with chemical functions are created on the surface of polymers, metals, and semiconductors. Furthermore, arrays of reaction sites with different functions are fabricated as a prototype of an integrated chemical system.

With a scanning electrochemical microscope (SECM), we have achieved in situ observation and fabrication of a material's surface in solution. A fluorescence micropattern is produced on an ionic conducting polymer film. The film contains a fluorescent dye and a quencher, and the latter was decomposed electrochemically along a locus of an SECM tip. Therefore, the scanned area emits the letter "M." This indicates that the SECM can act as a new method for electrochemical modification of a small area on a material's surface.

Microelectrodes were fabricated by microlithographic techniques and used for pH sensing and photoelectrochemical reactions (Ref 13). Photodecomposition of water was performed on microarray electrodes of Pt and TiO_2 under a microscope. Spectral measurements also have been performed to elucidate the photoelectrochemical mechanism.

Micrometer patterns of polymerized phthalocyanine derivatives were prepared by developing a new technique called area-selective chemical vapor deposition.

3. Microconversion System Group (Research Institute for Production Development, Kyoto). Characteristic micrometer size effects upon chemical reactions are studied, and new methods for controlling chemical reactions in small dimensions are developed. Furthermore, the laser manipulation-spectroscopy-reaction system is applied to reveal and control chemical reactions and to construct microstructures for creating a prototype of a microchemical factory.

Micrometer size effects have been studied for oil droplets fixed in gelatin films as well as for photoresponsiveness of microgels. A change in the excited-state dimer formation efficiency of a dye suggests that the droplet becomes viscous and/or the effective concentration of the solute becomes lower as the diameter of the droplet is reduced. The rate of photoinduced volume expansion of the microgels is now examined in detail by simultaneous measurements of volume and absorption spectral changes (Ref 14). This makes it possible to interpret the unique behavior of the photoinduced volume expansion reaction of the gels in terms of the diffusion theory of gels.

We have succeeded in controlling a photochromic reaction by albumins. The thermal back reaction of merocyanine to spiropyran was analyzed by assuming an enzymatic-like reaction between the molecule and albumins, and the reaction rate was confirmed to be accelerated by two orders of magnitude in the presence of albumins. This suggests a new way of photochemical control of reactions in a micrometer field.

Chemical applications of the laser manipulation-spectroscopy-reaction system are very fruitful.

Dynamic Functions of a Lasing Microsphere

Keiji Sasaki, Dynamic Spectroscopy Group

The interaction between laser light and a microsphere such as a liquid droplet, a polymer latex particle, or a microcapsule leads to two interesting phenomena. One concerns optical trapping of a microsphere induced by optical momentum changes. The other is optical resonance within a microsphere, in which light propagates in a circumferential manner to create a standing wave field similar to that in a laser cavity. We have applied these phenomena to realize spatial, dynamical, and chemical manipulation of individual microspheres and for fabricating minute reaction fields (Ref 15,16).

We developed a laser scanning micromanipulation system, in which two trapping laser beams were independently scanned by computer-controlled galvano mirrors (Ref 17-19). Laser trapping and manipulation of a metal particle or a low refractive index droplet in solution, which cannot be achieved by the conventional manipulation technique, were successfully accomplished using an "optical caging" method with our laser system. Furthermore, simultaneous trapping of multiple particles was made possible by scanning laser beams, producing micrometer-size spatial patterns as well as driving particles along the locus of the laser beams (Ref 20,21). This system was extended and combined with a pulsed Nd^{3+}:YAG laser that induces photochemical reactions. The system is called a laser manipulation-spectroscopy-reaction system (Ref 22). As an example, photopolymerization was employed for adhesion of polymer particles, by which integrated structures of polymer particles were assembled with two trapping laser beams.

We have succeeded, for the first time, in simultaneous optical trapping and losing of a dye-doped polymer particle suspended in water. Laser oscillation was confirmed by the appearance of sharp resonance peaks in the emission spectrum. Photon tunneling from a lasing microspherical cavity to the other particle was also demonstrated by using the two-beam trapping technique. Optically manipulated lasing microspheres are promising in surface profiling, and microspectroscopic measurements, and act as a novel light source for photochemical reactions in small geometries.

Micrometer Selective Deposition of Polymers

Atsushi Sekiguchi, Microchemical Function Group

Organic thin films have received much attention because of their new chemical/physical properties and functions that are not expected for inorganic materials. In order to prepare functional chemical reaction sites based on organic compounds, fabrication of films with micrometer spatial resolution is required. In this work, we first developed an area-selective chemical vapor deposition (CVD) method and then demonstrated that it could produce micrometer size patterns of copper phthalocyanine derivatives from 1,2,4,5-tetracyanobenzene (TCNB) (Ref 23,24).

Copper films were patterned on silicon wafers by photolithography and wet etching techniques. The silicon-copper substrate was sealed in a glass tube with TCNB and heated at different temperatures. Over a narrow temperature range, selective CVD was achieved to produce copper phthalocyanine thin films on the copper patterns. By thermal annealing the films were converted to a polymer of the copper phthalocyanines, and their chemical/physical properties were greatly improved. Indeed, the conductivity of the copper phthalocyanine films proved to be higher than that prior to thermal annealing (Ref 25).

In order to apply the technique to fabricate microchemical functional sites, an area-selective CVD of copper phthalocyanines was also performed on insulating and optically transparent materials (Ref 26).

Since copper phthalocyanine and its polymers are expected to be photoactive materials, sensing materials, and catalysts, the present technique has enormous promise. Further applications of the selective CVD method to other organic compounds and fabrication of materials surfaces should eventually allow one to prepare microphotoconversion systems.

SAKAKI QUANTUM WAVE PROJECT: MANIPULATION OF ELECTRON WAVES IN A QUANTUM MICROSTRUCTURE

Project Director: Hiroyuki Sakaki

The aims of this project are threefold: (1) exploration of the design methodology and the fabrication technology of materials at an atomic scale to control electron waves within a solid, (2) analyses and predictive syntheses of new quantum phenomena in semiconductor microstructures having future sizes comparable with electron wavelength (100 Å), and (3) clarification of the advantages and limits of electronic and optical devices using such new phenomena and/or new materials.

For these purposes, we are studying (1) material and process technologies at an atomic scale to fabricate quantum microstructures, (2) the physics of electron wave phenomena in quantum microstructures and their application to devices, and (3) the formation of quantum hybrid materials using novel components such as organic materials to expand the controllability of quantum waves.

We have successfully set up and now fully exploit the fabrication and characterization facilities for quantum microstructures. Though most of the fabrication efforts are devoted to clarifying various elementary processes such as microscopic processes of growth, deposition, and etching at present, we will combine them in order to build quantum microstructures in the near future and will make an effort to investigate their properties. In the field of theoretical studies, we have been and will be continually pursuing to propose novel ideas based on quantum waves and to deepen these understandings.

Fabrication of Microstructures by Atomic-Layer-Controlled Growth System

Akira Usui, Quantum Hyperstructure Group (Electrotechnical Laboratory, Tsukuba)

It is desired to develop growth technologies with a self-limiting growth mechanism for the fabrication of microstructures such as quantum wires (QW) and quantum boxes (QB). Atomic layer epitaxy (ALE) is one of the promising technologies to realize these structures because of the digital nature of monolayer/cycle growth. This characteristic is due to the chemical interaction saturation between a substrate surface and a reactant source gas. In this report, the growth study of microstructures by chloride ALE is presented (Ref 27). First, the growth kinetics study of chloride ALE using in situ optical reflection measurements during ALE growth is described. Clear reflection intensity saturation was observed, corresponding to self-limiting growth. The nature of the surface that causes the self-limiting growth was also discussed. Second, T-shaped QW structures were grown by sidewall epitaxy of ALE. Two kinds of structures were tried. One was fabricated by the overgrowth of GaAs/InGaP by ALE on the cleaved edge of quantum wells. The other was formed by sidewall epitaxy on the (111)B planes, which appeared by in situ selective gas arching of quantum wells. Conditions for obtaining mirror-like and smooth surfaces by gas etching for InGaP/GaAs heterostructures are also presented. Finally, band discontinuity between InGaP and GaAs was evaluated by photoluminescence (PL) and PL excitation spectroscopy of InGaP/GaAs quantum wells grown by ALE (Ref 28,29). The discontinuity of conduction bands was found to be approximately 0.06 eV. This result will be used to design the T-shaped quantum wire structures.

Making Quantum Wire Structures by Molecular Beam Epitaxy

A. Shimizu, Exploratory Device and Physics Group

Molecular beam epitaxy (MBE), in which crystal growth occurs in ultra-high vacuum conditions, is one of the most promising techniques for fabrication of quantum microstructures. A newly designed ultra-high vacuum system has been established in order to fabricate inversion-type quantum wires (QWIs) by etching the sample of quantum wells into V-shaped grooves and by subsequent regrowth on the etched sidewalls (Ref 30). The formation of the V-grooves has been achieved by in situ microlithography of GaAs using electron beam assisted gas etching. A second method to make QWIs by MBE, growth on a reverse-mesa shaped GaAs substrate, is now in progress (Ref 31). This method takes advantage of the appearance of (111)B facets on the grown layer, which is due to the fact that the mobility of Ga atoms on the surface greatly depends on the crystallographic orientations. A 1-micron-wide modulation-doped structure formed on the (111)B facet has proven to be good enough to have a two-dimensional electron gas by observing the Shubnikov-de Haas oscillation in magnetoresistance.

In order to characterize quantum microstructures, a measurement system using ultra-short-pulse lasers, a superconducting magnet, and an FTIR spectrometer has been installed.

In the field of theoretical analysis, we estimated some properties of QWIs and designed several novel quantum devices (Ref 32-35).

Electronic and Optical Properties of Organic Quantum Structures

Hitoshi Akimichi, Quantum Hybrid Materials Group

Novel quantum structure devices using organic materials are expected to show interesting properties. Conjugated pi-electron materials such as oligothiophenes and oligoacenes can be excellent candidates for these devices. To investigate the structural, electronic, and optical properties of these materials, we fabricated pure and well-ordered thin films of the materials using an ultra-high vacuum evaporation chamber.

In this report, we show the field effect transistor (FET) characteristics of the alkyloligothiophenes (degree of polymerization: 3-6), oligoacenes, and other pi-electron materials (Ref 36). As a result, we have found that the materials with smaller ionization potential have larger mobility. Structural control of oligoacene (pentacene, tetracene) thin films under various evaporation conditions is currently under investigation by optical absorption spectroscopy and x-ray diffraction (Ref 37,38). The results for layered structure with two different species of oligoacenes are also reported.

IKEDA GENOSPHERE PROJECT: HOW DO WE ACCESS HUMAN GENOME ORGANIZATION?

Project Director: Joh-E Ikeda

All of the characteristics of every organism depend on genetic information. It is the DNA molecule, the genetic instructions inscribed in every cell, that tells a body how to grow, survive, and reproduce. The DNA molecule, a densely packed configuration with nuclear proteins in the cell, is constructed of an unbroken string of billions of nucleotides. These genetic sequences are commands for protein subunits, enzymes, and hormones; commands for turning genes on and off; the recipe for how the configuration of the chromosomes can change during the cell cycle; and the recipe for how the cells can divide and differentiate. All genetic material harbored in a cell's nucleus is called the genome. The genome also governs behavior related to various activities, including neural.

For many years it has been generally considered that the genome is a biolinguistics composed of four nucleotides. We are exploring the idea that equally important for the expression and regulation of the genomic information are the geometry of the genome and the positional orientation of the chromosomes within the cell. From this perspective we prefer not to sequence all of the human genome. Instead, we are taking the view that the many DNA sequences without any known biological functions at the moment may have significance in the geometry of the genome.

Our current studies are to identify the genes, chromosome domains, and DNA sequences that are responsible for the mental faculties and genomic behavior related to chromosome pairing. To this end, specific regions of human chromosomes are being laser microdissected and then segmented according to chromosome maps and the generated regional chromosome DNA clones are studied. New instruments are also being developed that will allow such a real-time monitoring of human chromosomes within a cell as to their relative positions and orientations within a nucleus. These new devices will result in a real-time, three-dimensional human genome atlas.

Molecular Studies of the Functional Domains of the Human Genome

Haruhiko Yokoi, Research Group of Gene Function

New methodologies need to be developed to study the genomes of higher organisms such as humans because they have far larger quantities of information and more complex functions than those of bacteria. We have established methods to dissect specific domains of chromosomes and analyze the information or functional units within them. By these means, it will be possible to investigate the higher phenomena of life such as mental activity in humans.

Three-Dimensional Reconstruction of Chromosomes in a Cell

Yoshitaro Nakano and Kouichi Kojima, Research Group of Chromosome Dynamics

Little is known about the structure of nuclei, but it is thought that chromosomes occupy a discrete territory in the interphase nucleus and specific chromatin arrangements reflect processes of cellular differentiation and cell specific gene expression. To investigate the three-dimensional organization of chromosomes in nuclei and its possible functional significance, we are constructing equipment with which we can visualize intranuclear three-dimensional chromosome topography.

Though any optical microscopic image of the specimen is contaminated with out-of-focus information, the digital image processing method can remove its contribution. At first we obtained characteristic three-dimensional frequency response of the optical system by direct experimental measurement using fluorescent microbeads. Then we used the frequency response to obtain the true image by the Fourier transform of the observed image.

AONO ATOMCRAFT PROJECT: OPENING OF "ATOMCRAFT"

Project Director: Masakazu Aono

"Atomcraft," which is our newly coined word, expresses a new world of possibilities where we may manipulate an atom or a group of atoms at will to create artificial micromaterials with novel atomic arrangement and electronic properties, nanometer micropatterns exhibiting a novel electronic or optical function and for huge memories, etc. Although this was only a dream a decade ago, the dream has come truer to some extent by the invention of the scanning tunneling microscope (STM). The STM was invented as a tool to observe atoms, but it is also useful to manipulate atoms. In fact, several amazing demonstrations have been made of the manipulation of an atom or several atoms by using the STM. However, in most cases, the mechanisms of the manipulation have not been clarified and the reproducibility of it is insufficient. Namely, many scientific and technical hurdles remain in order to master this new technology.

Our Atomcraft project has been organized to make systematic studies to overcome such scientific and technical hurdles and apply the results to the various fields mentioned above. For these purposes, our project has three research groups, i.e., the Basic Analysis, Structure Control, and Surface Measurement Groups.

We attach importance to the close cooperation between experimentalists and theorists, so that we have three theorists in the Basic Analysis Group. The theorists are making calculations of electronic structure, atomic structure, atomic motion, atom transfer by a field, etc. by using a supercomputer. An interesting fact has been found recently. It is usually believed that protrusions in an observed STM image correspond to individual atoms, but this is actually wrong. According to the theoretical calculations of the STM image of the Si(111)rt3xrt3-Ag surface, which agree well with a corresponding observed STM image, each protrusion in the STM image does not correspond to any atom but corresponds to the center of three Ag atoms. That is, observed STM images do not always represent the arrangement of atoms. The experimentalists in this group are constructing a novel apparatus to obtain information on the species and number of atoms transferred by a field.

In the Structure Control Group, they are studying various techniques to manipulate an atom or a group of atoms by using the STM. For this purpose, they have developed hardware and software that can control the motion of an STM tip, the mode of application of the voltage to the tip, etc. in a sophisticated manner. In order to directly measure the electric properties of micromaterials and micropatterns created by the technique, a novel apparatus, which consists of an STM and a low-temperature measurement chamber connected with a sample transfer rod, is now under construction. Such a measurement has already been done with another STM for a double tunneling junction with a liquid crystal molecule as the intermediate electrode, the two outer electrodes being an STM tip and a Pt substrate, and a series of single-electron tunneling events have been observed at room temperature. In addition to these, a molecular beam epitaxy apparatus equipped with a novel ion scattering spectrometer has been constructed to control the composition of the growing outermost atomic layer at will.

As already mentioned, the key to manipulate an atom or a group of atoms by using the STM is to clarify the mechanisms of the manipulation. The Surface Measurement Group has been studying the mechanisms in cooperation with the Structure Control Group. For example, if we apply an appropriate positive or negative voltage to an STM tip (Ag, W, Au, or Pt) and scan the tip parallel to a Si(111) surface, we can create a desired nanometer etching pattern on the Si(111) surface. On the basis of detailed experiments done by changing various parameters widely, it has been found that the nanometer etching is caused by the field evaporation of surface Si atoms as positive or negative ions depending on the polarity of the voltage applied to the tip.

Atomic-Scale Observation of Material Structures: An Important Role of Theory

Satoshi Watanabe, Basic Analysis Group

Rapid development of experimental techniques in these days such as the invention of scanning tunneling microscopy (STM) has made it possible to observe material structures on the atomic scale. However, the interpretation of obtained experimental results, such as STM images, is not necessarily straightforward. First-principle theoretical calculations are often very helpful to derive a reliable conclusion from such experimental results. In this paper, we would like to demonstrate it by taking the structure analysis of the Si(111)rt3xrt3-Ag surface, which has been a pending problem in surface science for more than 20 years, as an example.

Aono, the director of this project, and coworkers (Ref 39) have recently proposed a new structural model, or the modified honeycomb-chained-trimer model, for this surface. This model is consistent with most of the reported experimental results regarding atomic geometry, but it has not been determined if this model is consistent with those experimental results that are related to electronic properties. In particular, this model appears to be inconsistent with reported STM images (Ref 40) at first sight; bright spots in the STM images, which correspond to protrusions, are arranged in a honeycomb structure, while the Ag atoms forming the top layer of the model have no honeycomb arrangement at all. We have theoretically calculated (Ref 40 and 41) the electronic structure and the STM image of this model from first principles using the local density functional method. The calculated electronic structure agrees very well with reported experimental results on electronic properties such as photoemission (Ref 42) and inverse photoemission (Ref 43,44) spectra. The calculated STM images also agree very well with the reported STM images (Ref 40); it has been found that each bright spot in the observed STM images represents neither Ag nor Si atom but corresponds to the center of three Ag atoms.

In this way, we have been able to understand the atomic and electronic structures of the Si(111)rt3xrt3-Ag surface very well by combining the experimental results with the theoretical calculations.

Atomic-Scale Control of Electron Movement

Hitoshi Nejoh, Group Leader, Structure Control Group

Although many liquid crystal (LC) molecules have been imaged using scanning tunneling microscopy (STM), little has been done on their scanning tunneling spectroscopy (STS). On the other hand, many people have observed the incremental charging of a fine metal particle on a thin insulated layer formed on a metal substrate by using STS. However, the incremental charging, which is due to Coulomb blockade (Ref 45), has been observed only at temperatures as low as 4 K, since the charging energy associated with the incremental charging is smaller than the thermal fluctuation at room temperature. In the present study, we have measured the tunneling current via one of the LC molecules on a Pt(111) substrate by using STS and have succeeded in observing the incremental charging at room temperature (Ref 46). This is interpreted as follows. Since the size of the molecule is very small, the capacitance values between the STS tip and the molecule and that between the molecule and the substrate are so small that the charging energy is larger than the thermal fluctuation at room temperature.

As one of the applications of the incremental charging of a fine metal particle, a single electron transistor was proposed by Likharev (Ref 47) in 1987. After that, many people have tried to realize such a transistor by using microlithography techniques; the key to realize such a transistor is to make very small capacitors. Recently, a few groups (Ref 48-50) have succeeded in realizing such a transistor, but it works only at temperatures as low as 4 K. As mentioned above, the STS tip-molecule-substrate double tunnel junction causes the incremental charging of the molecule. We added the third electrode to this double tunneling junction to realize a single electron transistor of a capacitive type that works even at room temperature. In this transistor, islands of Pt-Pd deposited on a SiO_2 substrate act as the source and the drain and the STS tip acts as the gate in the usual FET. This single electron transistor was currently biased and the output voltage was measured. The output voltage versus input voltage characteristic agrees with theoretical simulations by Likharev (Ref 47), although the output voltage has an offset. We attribute this offset to a current through the surrounding media of the single electron transistor.

Atomic-Scale Control of Material Structures

Ataru Kobayashi, Surface Measurement Group

The scanning tunneling microscope (STM), which was invented by Binnig and Rohrer (Ref 51), is useful not only to "observe" atoms but to "manipulate" atoms. The first demonstration of the latter was done by Becker et al. (Ref 52); they manipulated a single atom on a Ge surface by using an STM tip, although the reproducibility of the manipulation was not necessarily good. After that, many reports have appeared on the manipulation of a single atom or a cluster of atoms on a sample surface using an STM tip. The most recent striking report was done by Eigler et al. (Ref 53); they demonstrated that it was possible to exchange a single Xe atom between an STM tip and a Ni surface at will, if the tip and the surface were cooled to 4 K. However, in almost all the cases mentioned above, the mechanism of the manipulation has not been clarified.

We have found that if we place an STM tip close to a Si(111) surface and apply an appropriate positive or negative voltage to the tip, Si atoms are removed from the surface (Ref 54). That is, a hole is created on the surface. If we scan the tip parallel to the surface, a ditch is created on the surface. The diameter of the hole and the width of the ditch can be controlled by changing the magnitude and duration of the voltage (Ref 54). In this way, we can create a desired nanometer-scale etching pattern on the Si surface (Ref 54). As we can suppose easily, this technique will be of great importance in the near future in relation to the realization of novel nanometer-scale devices, huge memories, etc.

In order to clarify the mechanism of the removal of Si atoms from the Si surface, we have observed how the amount of removed Si atoms depends on various experimental parameters (the polarity, magnitude, duration of the voltage applied to the tip, the electron tunneling current between the tip and the surface, and the material of the tip) (Ref 54 and 55). From detailed experiments we have found the following mechanism. If we apply an appropriate positive (negative) voltage to the STM tip, a strong positive (negative) field is created at the Si surface, and the strong field ionizes Si atoms at the surface into a negative (positive) ion and pulls them apart from the surface. That is, Si atoms at the surface evaporate as a negative or positive ion, depending on the polarity of the tip voltage. The field evaporation of negative ions observed in the experiments is a new phenomenon in that there has been little study about it, although recent theoretical studies (Ref 56-58) indicate the possibility of the phenomenon.

In the course of the present study, we have clearly observed that even if the tip voltage is zero, a strong field is created at the sample surface because of the contact potential (the difference in work function) between the tip and the surface (Ref 55). This is of general importance because it is indicated that a strong field is automatically applied to the sample surface during STM imaging of the surface even if the tip voltage is small. The strong field possibly affects the electronic structure of the surface.

TONOMURA ELECTRON-WAVEFRONT PROJECT: EXPLORATION OF MICROSCOPIC WORLD WITH ELECTRON WAVE

Project Director: Akira Tonomura

Although the wave nature of electrons once was evident only in the microscopic region, such as in atoms and molecules, interference phenomena have been observable on the macroscopic scale since the advent of a "coherent" field emission electron beam. Its use in combination with electron holography has opened up various new possibilities, since versatile optical techniques can be employed in the optical reconstruction stage of electron holography. An actual example is the optical and numerical compensation for the inevitable aberrations of an electron lens for higher resolution. In addition, the phase of an electron wave can now be employed to observe and measure microscopic fields and matter that have been inaccessible by conventional electron microscopy, in which only the intensity of the wave is observed. This study investigates the basic nature of a coherent electron beam, developments in high-precision real-time computer image analysis, and applications of electron holography to various fields ranging from physics to biology.

A New Method for Real-Time Electron Holography

Junji Endo, Fundamental Property Group

A new method for real-time electron holography is proposed and experimentally confirmed to be effective (Ref 59). This method is based on fringe scanning interferometry developed in laser optics.

As the phase difference between an object wave and a reference wave is changed from 0 to 2 pi, a brightness at each pixel varies in a sinusoidal manner. When more than three brightness values between 0 to 2 pi are measured for each pixel, we can calculate a phase value of the sine curve, i.e., a phase value of the object wave passed through the pixel (Ref 60). To realize this method, we controlled an incident angle of the electron beam step by step by changing the excitation current of a beam-tilt coil. The increment of the current was selected so that a movement of biprism fringes was equal to 1 Nth (N = integer greater than 3) of the fringe spacing. In each step, an interference pattern viewed through a TV camera was digitized. From N interference patterns, a phase value of each pixel was calculated.

The time required to obtain phase distribution of the object wave is about 1 minute. This value is two orders of magnitude shorter than that of the conventional method in which a photographic process is employed. The time will be further shortened by a factor of one order of magnitude by improvement of the image processing method (Ref 61). The accuracy and image quality obtained in this method have not yet been superior to those obtained in the conventional method. These problems may be caused by inaccuracy in controlling the phase difference and by the definition of the image processed.

Phase Measurements at Atomic Dimensions

Kazoo Ishizuka, Image Analysis Group

Electron holograms have been mainly processed optically. In this case, the process is troublesome and requires a long processing time. Moreover, it is difficult to obtain quantitative results. To overcome these constraints, we developed a digital system to process electron holograms based on a personal computer. To increase processing power, we installed an array processor on our system. By using this system, we can measure a phase distribution at atomic dimension. We also proposed a new technique to process an electron hologram from a crystal specimen. With this technique, we can obtain phase information from the reconstructed wave, even when the interference fringe spacing is one-third of the usual requirement.

Direct Observation of Atomic Surface Potentials by Electron Holography

Takayoshi Tanji, Measurement and Observation Group

Electron holography allows the direct and clear observation of how each potential of Mg and O atoms located at an MgO crystal surface extends far into a vacuum when an electron beam is incident parallel to the surface in a certain direction, i.e., a profile mode (Ref 62-65).

In high resolution electron microscopy, images near the crystal edge are affected by strong Fresnel diffraction, especially in this profile mode. Clear surface images are for the first time obtained by the electron phase distribution, which greatly reduces the difficulty in this mode (Ref 66).

KIMURA METAMELT PROJECT: QUEST FOR SOLUTION OF MELT MYSTERIES

Project Director: Shigeyuki Kimura

Most products around us are solids made from melts--glass, steel, aluminum, copper wire, plastics, semiconductors. All are made by cooling melts. Melts and the ways melts are cooled are critically important. Silicon semiconductors must be grown from melted silicon, but impurities enter while the silicon is molten. Molten glass must be cooled at just the right rate in order that the resulting glass has good properties. Melts, their microstructures, and their internal movements are critically important, yet little is known about them. Everyone knows that molasses is slow in January, but knowledge about why is superficial. Since the attractions between molecules in a melt are stronger than in air, we know that the melt must have structure. Yet, because the melt is fluid, it is hard to study. It does not stand still for pictures. Despite years of research, our knowledge of melts is only partial and mainly founded on mathematical models.

Recently, we have learned that melts change with time, even as they are kept at a constant temperature and in a constant environment. It is known that the crystalline state of an aged melt differs from that of a fresh melt. The viscosity of a melt depends not only on its temperature but also on how that temperature was reached. The slowness of molasses depends not only on how cold it is but also on how fast it was cooled and on how long it has been cold. It is assumed that this is due to differing structures, but our knowledge does not go beyond this assumption.

The scientific tools for studying melt structure are just now being established. There are new technologies using x rays and neutron beams. For melts that can be studied with light, a new method of melt structure analysis has been developed using a technique called Rayleigh scattering. Recent research has attempted to combine computer modeling with radiographic observation of melts.

This project will focus on the changes that occur in melts over time, will analyze the changes in melt structure and behavior, and will explore new ways to grow crystals. We will use the melts of semiconductors and oxide materials and follow their changes with sophisticated methods including x rays. Other quick and precise methods will be developed to determine the causes of changes. These will include measurements of viscosity, surface tension, density, and heat conduction, as well as research on the measurements themselves. Direct observations of flow pattern in melts will be combined with simultaneous computer modeling.

Our increased understanding of the microstructure and ordering of melts is expected to lead to new materials and new processing technology.

NAGAYAMA PROTEIN ARRAY PROJECT: A TECHNOLOGY EMERGENT FROM BIOSYSTEMS

Project Director: Kuniaki Nagayama

The Protein Array Project is attempting to establish a universal technology of fabricating 2D protein crystals with desired molecular alignment and crystal form of excellent quality (protein array). The basic strategy is to explore techniques that can implement the biological principle for making the macromolecule and proteins and then assembling them into intercellular devices, called organelles ("biological technology"). Component parts should then be automatically assembled to give final forms through mutual recognition (specific interaction manifested through structural information). The direction of such structuring into a 2D manner can be achieved by mutating amino acids on the protein surface and reshuffling domains as well as introducing a 2D substratum, which is extremely well defined, using "human technology." This is a technology emergent from biosystems, arising from a combination between "biological technology" and "human technology."

The project is composed of three research groups: Array Design Group, Array Engineering Group, and Array Characterization Group. In addition to these domestic groups, a research group from the Laboratory of Thermodynamics and Physico-Chemical Hydrodynamics, the University of Sofia in Bulgaria, participates in the project. Each group is individually unique in its academic major. The point of this kind of organization in terms of promoting the new technology is extensive and there is active fusion of a variety of expertise. The Array Design Group aims to design a protein array based on analysis of interprotein interactions. The major techniques used are computational physics, computer graphics, and nuclear magnetic resonance (NMR) spectroscopy. The Array Engineering Group, which is composed of molecular biologists, protein biochemists, and organic chemists, seeks mass production of pure protein specimens underlying the protein array. The Array Characterization Group is required to fabricate an excellent protein array and to define its structure using modern and accurate morphological techniques like transmission electron microscopy (TEM), scanning tunneling microscopy, and scanning atomic force microscopy. It is also expected to develop an ideal substratum not only for array fabrication but also for transferring the array on it, which may possess potential as a prototype device utilizing a protein array. The Bulgarian team specializes in the process of lattice formation since the array formation is directed firstly by lattice formation as well as the following crystallization.

The Array Design Group has been engaged mostly in analysis of electrostatic interactions that likely contribute predominantly toward the crystallization process: computational simulation of the 2D crystallization process of the poker chip model and analysis of atomic interactions found in the protein-protein interface of real 3D crystals of proteins. The simulation experiment of the poker chip model, in which edge both positive and negative charges are hexagonally distributed, succeeds in designing a uniformly aligned array, trimmer-unit array, etc. The analysis of the 3D crystals illustrates that electrostatic pairing, such as salt-bridge and hydrogen bonding, principally governs crystallization of proteins. The Array Engineering and Characterization Groups have shown that the quality of array depends significantly on the purity of the protein specimen using horse spleen ferritin. They also obtained a preliminary clue as to possibly controlling the crystal form by examining ferritin from different species, in which not many numbers of amino acids are different from each other. Using polystyrene lattices the Bulgarian team has developed a basic and very universal method that enables governing the process of lattice formation of submicron particles by adjusting water level of the particle suspension laid on a 2D substratum. These research products are to be combined and reorganized as set advanced research subjects in order to approach the process toward the final goal of the project.

SHINKAI CHEMIRECOGNICS PROJECT

Project Director: Seiji Shinkai

Introduction

Chemical reactions have conventionally been explained in terms of the "collision probability" among molecules governed by thermodynamics. In contrast, reactions taking place in living organisms can be grasped as "inevitable or necessitated outcome" rather than "probability." These two positions are totally different: the former sees chemical reactions as phenomena explainable by molecular dynamics, while the latter reactions are characterized as proceeding by way of "recognition process."

A primary objective of our research in this project is to analyze the "recognition process" from a chemist's viewpoint and to construct this process at the molecular level. This can be accomplished only if we establish a powerful methodology and the tools to implement it. Fortunately, now we have "calixarenes," which have increasingly been attracting the attention of many chemists as "the third inclusion compound" following cyclodextrin and crownethers. Evidence is mounting that as single compounds calixarenes can be designed as elements capable of recognizing atoms and molecules and also that as molecular assemblies they are capable of exhibiting very unique and interesting functions.

Thus, the project consists of three groups: (1) the Atomic Recognition Group, (2) the Molecular Recognition Group, and (3) the Intelligent Assembly Group. These groups will be working in cooperation, by using calixarenes and related compounds as the "tools," to answer the question, "What is recognition?"

Research Activities and Results So Far

One year has passed since the Shinkai Project was launched. As of September 1991, the project consists of 12 researchers. While the project's research activities are still generally at the beginning stage, we have obtained some interesting and novel results, as summarized below.

(1) Atomic Recognition Group: Various systems have been designed as elements for recognizing metal ions, in which a site for chemically binding a metal ion and a reporter site are introduced in a calixarene. The reporter site is for outputting the binding as a physical signal, such as fluorescence or luminescence, or an electrochemical signal. Some systems have excellent potential as elements capable of recognizing metal ions.

(2) Molecular Recognition Group: Studies are currently being conducted mainly with saccharides as guest molecules. Various phenyl borates are synthesized and used as the hosts for studying selective recognition of the guest saccharides.

Methods for the preparation of novel calixarenes are being established, in which the OH groups are selectively substituted with amino groups or deoxylated. The resulting calixarenes are promising elements for molecular recognition.

(3) Intelligent Assembly Group: Studies in progress are aimed at constructing higher structures by assembling the modified calixarenes to develop new functions that cannot be obtained by a single calixarene. The assembly methods being tried include gellation, polymerization, liquid crystallization, and micelle formation. It has been found that certain calixarenes and crownether-bearing compounds act as gellators of organic fluids, and studies are being done to elucidate the gellator mechanism in connection with the recognition of metal ions.

YOSHIMURA PI-ELECTRON MATERIALS PROJECT: NEW HORIZON OF PI-ELECTRON MATERIALS

Project Director: Susumu Yoshimura

The plants, animals, and minerals of nature contain two kinds of electrons, sigma electrons and pi electrons. The sigma electrons hold nature together. They provide the strength that holds trees up and keeps mountains high. The pi electrons make nature work. They give us the bright greens and reds. They catch the light needed for photosynthesis.

Organic chemistry has a long history of making new compounds that hold pi electrons. But the pi electrons in these compounds can only move in small areas; they cannot wander freely very far without running into walls. One compound of nature is different. In graphite, the pi electrons can wander far and wide. Recently, scientists have learned to make graphites that are large single crystals. They have also found pi electrons in inorganic materials, for example, on the surface of silicon that is used in transistors and in compounds of boron or nitrogen.

The pi electrons in large single crystals of graphite are light and fast. They can be faster than the electrons in the gallium arsenide high electron mobility transistors (HEMTs) that are being developed for the newest generation of supercomputers. Under the right conditions, they may become superconducting. When placed in electric fields, pi electrons move to and fro over long distances, a phenomenon called "superpolarizability."

Up until now, our knowledge of pi electrons has come indirectly from research not aimed at pi electrons themselves. For example, pi electrons are important for photosynthesis so research on photosynthesis has taught us something about pi electrons. Little research has focused directly on pi electrons and the pi-electron materials that carry them. The Yoshimura Pi-Electron Materials Project will do this.

The Yoshimura Pi-Electron Materials Project will assemble international teams of chemists, physicists, materials scientists, and biochemists to attack the secrets of pi electrons and pi-electron materials. These researchers will discover ways to make new pi-electron materials. What they learn about why pi electrons are so light and fast may lead to new high-speed electronic devices. What they learn about superpolarizability may lead to new nonlinear (red light in, blue light out) optical devices, which are essential for computers based on light. Their study of the biocompatibility of pi-electron materials may lead to new materials for use in medicine.

By focusing the attention of researchers from a wide range of backgrounds on pi-electron materials, the Yoshimura Pi-Electron Materials Project hopes to generate a wide range of new knowledge, new materials, and new devices.

"Pi electrons" are mobile electrons whose cloud extends normal to the bond axis between atoms. Since the delocalized pi electrons can move about throughout a crystal or molecule without distorting it, pi-electron materials have many peculiar characteristics, such as extremely high electron mobility and superpolarization. The pi-electron cloud is also a fundamental reaction field for organic and biological materials. Examples are photo-charge-transfer reaction and photosynthesis. Little is known, however, about the roles of pi electrons in solid surface state or quantum effects in two-dimensional conductors.

Low-dimensional graphites, which are typical organic pi-electron materials, have been made in the forms of fibers and sheets that have physical properties almost identical to those of single crystals. Superaromatic carbon clusters such as C_{60} and C_{70} can now be obtained in quantity. As a result, the materials science of carbon is active again. Single crystals of inorganic materials that have a pi-electron system based on boron, nitrogen, or oxygen molecules have recently been synthesized. Scanning tunneling microscope observations have recently revealed that the reconstructed surface of a silicon single crystal contains pi-electron-like defect states. These new pi-electron materials prompt research on the solid state physics and on the control of their electronic behaviors.

The Yoshimura Pi-Electron Materials Project will view the large space occupied by the freely moving pi electrons as domains of electron motion and materials transformation. The project will exploit and elucidate unique physical, chemical, and biochemical phenomena that result from these domains. For this, the project will develop synthetic methods and processes for new organic and inorganic materials with extended pi-electron systems and with high crystallinity. It will elucidate the mechanisms of superpolarization, high electron mobility, and nonlinear phenomena (Ref 67). The project may propose new electronic devices based on unique features of pi electrons. Other work will focus on biological or biochemical activities of pi electrons and reactions in two dimensions that take place in graphite intercalation compounds (Ref 68). The project will study selective and/or anomalous reactions in which the pi-electron domains participate. This work may shed light on mechanisms of biocompatibility and proliferation on carbonaceous materials in relation to electronic structures of the pi-electron systems.

This project hopes to establish a materials science based on pi electrons by reexamining and enriching our knowledge on optical, electronic, magnetic, chemical, and biochemical properties of pi-electron materials.

NOYORI MOLECULAR CATALYSIS PROJECT: FROM READY-MADE TO TAILOR-MADE CATALYSTS

Project Director: Ryoji Noyori

The perfect chemical reaction produces only the desired product and no wastes. It starts with economical raw materials and wastes little energy. It allows the chemist to construct exactly the molecule desired in the shape desired.

Until recently, perfect chemical reactions were found almost only in nature. The chemical reactions developed by man are still far from perfect. Many consume large amounts of energy and produce hazardous wastes that endanger the environment. Removing reaction wastes from pharmaceuticals is very expensive.

The reactions of nature are brought about by catalysts called enzymes. These catalysts speed reactions by reducing the barriers to the reactions. They also direct the reactions along exactly the right pathways. They have long been the envy of chemists. Indeed, many chemists are trying to adapt the reactions of nature to make the chemicals needed for our modern everyday lives.

The Noyori Molecular Catalysis Project, however, is taking a different approach. Rather than try to improve on nature, which is already close to perfect, researchers in this project will design and study molecules that approach perfection in catalyzing reactions that nature cannot perform.

The researchers will start with metal atoms or ions. Metals can catalyze many reactions. However, a metal ion by itself is somewhat like a naked bit on a woodworker's tool. It cuts quickly but is very hard to control. It often cuts wrong and wastes the wood. The researchers of the Noyori Molecular Catalysis Project will mount these metal ions in special organic "jigs" called ligands. These ligands will make certain that the metal ion cuts only the desired bonds and joins only the desired molecules in the desired way, much as a woodworker's jig hold the wood pieces so that precisely the desired joint can be made quickly, efficiently, and with little waste. These metal-ligand catalysts are called "molecular catalysts."

The Noyori Molecular Catalysis Project will focus mainly on reactions that can make either left-handed or right-handed molecules. Many reactions used for making drugs do this. Getting rid of the undesired molecule can be very expensive. Researchers in the project will design metal-ligand catalysts that cause the reaction to make only one of the two molecules.

Researchers will also design and study molecular catalysts for making polymers. Many polymers come in left-handed and right-handed helices. By themselves, the left-handed helices may have special electrical or optical properties. However, if the right-handed helices are also present, they cancel out the special effects. Polymers that are purely left-handed or purely right-handed may provide new electronic or optical devices.

The Noyori Molecular Catalysis Project will also research molecular catalysts for making polymers in which all the chains are the same length. Currently, most reactions for making polymers make the chains in many different lengths. If the chains are all the same length, the polymer may have special properties, much as a paintbrush with bristles of the same length spreads paint better than a brush having bristles of varying lengths.

Intrinsic properties and functionalities in materials are strongly influenced not only by their molecular and/or atomic composition but also by their purity. Particularly, chirality plays an important role in science and technologies related to molecular electronics and optics. The perfect chemical reaction producing only the desired substances and no wastes is crucially significant. In contrast to enzymatic reaction, which efficiently gives chiral substances, synthetic reaction remains far from perfect.

Recently, synthetic chemists are meeting this challenge by developing highly selective reactions catalyzed by organometallic complexes, and the chemist's dream of achieving perfect reaction is now being converted into reality. Particularly, homogeneous asymmetric catalysis using chiral metal complexes provides a promising way and powerful tool to produce chiral substances, complementary to biological transformations, structural modification of naturally occurring chiral substances, classical resolution methods, etc.

Asymmetric catalysis is capable of multiplying chirality, and the efficiency of the chiral multiplication, defined as [major enantiomer-minor enantiomer (in mole)]/chiral source (catalyst) in mole, can be increased to infinite depending on catalyst designing. The selection of central metals and molecular designing of chiral ligands are particularly significant to attain perfect reaction. Such a molecular catalyst consisting of reactive metal center and auxiliaries (chiral source) not only promotes reactions of associated substrates but also controls the stereochemical outcome in an absolute sense.

To our knowledge, the first catalytic asymmetric reaction of prochiral compounds promoted by homogeneous transition metal complexes was reported in 1966. Ever since this discovery spectacular progress has been made in this field, and with synthetic chiral metal complex catalysts optical yields over 80%, or even close to 100%, are frequently obtained. In certain cases, the efficiency of artificial complexes rivals that of natural enzymes and we can produce large amounts of chiral compounds having natural and unnatural configurations with the use of only a very small amount of a chiral source.

Some of them are applied to commercial production of chiral products of extremely high enantiomeric purity.

The Noyori Molecular Catalysis Project will focus mainly on perfectly controlled reactions leading to only desired small or large molecules. For this purpose we will design new, well-defined organometallic complexes as molecular catalysts. The concept for "molecular catalysis" will generate a new type of chiral materials having potent biological functions and unique physical properties.

Our basic principle, "molecular catalysis," relies on "four-dimensional chemistry," in which high efficiency is only attainable through a combination of both an ideal three-dimensional structure (x,y,z) and appropriate kinetics (t). This chemical methodology will certainly contribute to industrial production and molecular science and industry in the emerging generation.

FUSETANI BIOFOULING PROJECT

Project Director: Nobuhiro Fusetani

A barnacle larva hatches from its egg and embarks on its search for a place to settle and grow into an adult. Carried by ocean currents, it floats and swims, bumping into plants, fish, and rocks until, maybe days later, it touches the right place. In minutes, the larva bonds tightly to its new home and begins making its shell and growing. This settling process is repeated by countless sea animals: sponges, corals, mussels, barnacles, and tunicates.

How does a larva know what surface is right and what surfaces are not? There must be some kind of chemical signal. Scientists have learned, for example, that if ocean sand contains certain odors (chemicals) that result from other adults of the same species, these odors will cause the larvae to attach to the sand and begin growing. Other species are unaffected by the same odors.

Once a larva touches the right place and receives the signal to stop and grow, what happens inside the larva? Are there internal chemical messengers? Or is there some kind of electrical signal such as occurs in nerves? Little is known and research has tended to be scattered among disciplines and target species.

The Fusetani Biofouling Project will gather international teams of marine biologists, organic chemists, biochemists, and electrophysiologists to research how these marine larvae know when to stop, attach, and grow. They will pay special attention to barnacles, mussels, and bryozoans.

The biggest challenge for the Fusetani Biofouling Project will be to learn how to test chemical signals and settling in the laboratory. Once this is achieved the researchers will be able to proceed rapidly to learn what kinds of chemical signals trigger settling and transformation of the larvae. They will be able to decipher the changes that occur inside the larvae after they receive the chemical signal and how the signal is transmitted inside the larvae.

Even before the Fusetani Biofouling Project develops the tests for the chemical signals, the researchers will be isolating and characterizing possible signal chemicals. They will also be researching the basic physiology of the larvae to learn what pathways are there for the signals to follow.

From this research we may learn better ways for controlling these marine organisms and thus help solve problems that have plagued man for millennia, such as barnacle growth on ships, and more recent problems such as beach erosion, the fouling of underwater pipes by clams, and the disruption of coral reefs. We may also learn better ways to cultivate clams, mussels, and other marine organisms for food.

OKAYAMA CELL-SWITCHING PROJECT: UNDERSTANDING THE "MASTER SWITCH" CONTROLLING CELL GROWTH AND DIFFERENTIATION

Project Director: Hiroto Okayama

Cells in higher life forms such as yeasts, plants, and animals grow and divide in a four-step cycle. They divide, then grow some, then make a copy of their genes, grow some more, then divide again. This simple cycle is crucially important. Evolution has left it almost untouched. Genes controlling growth in human cells also work when they are put into yeasts.

Among the four steps, the growth right after division (called G1) is a most critical time. Will the cell divide? Will it produce sperm and egg cells? Will it change form such as into a muscle cell or into a blood vessel cell? Or will it lose control and become cancer? The cell's fate is determined by events that occur during G1.

The Okayama Cell-Switching Project will use an amazing array of recently developed tools to unravel the secrets of G1 and how genes control it.

One tool is a specially designed gene library. This is not a library of books but a library containing DNA cloned from cells, for example, human muscle cells. There are millions of volumes in a gene library. There may be many duplicates and some may be missing pages or chapters. This library, however, is not a mere collection of cloned genes. It consists of genes engineered so as to work in a wide variety of cells from human to yeast. The Okayama Cell-Switching Project will search these libraries for genes that control G1.

One search will be done with fission yeast mutants that have defects in G1. Using such a mutant, the researchers can find the human gene that fixes the defect. They can then decode the gene, that is, find out the structure of the protein that is made from it. From the protein's structure they can get clues to its role in G1.

A different search will be done with a special kind of rat-kidney cell. These cells become cancerous if they are exposed to growth factors. If the growth factors are taken away, the cancer stops and the cells return to normal. In other words, the cancer can be turned on and off. Scientists have made several mutants of this rat-kidney cell and know that there are switches in G1. The Okayama Cell-Switching Project will search the human gene library for genes that correct the defects in the mutants. From these genes, the researchers hope to learn about switches that turn on cancer in humans and, perhaps, clues as to how to turn it off.

Proliferation is a unique attribute of living organisms. Multicellular organisms proliferate through the process called development, which involves concerted replication and/or differentiation of each cell composing the organisms. However, cell differentiation is not unique to multicellular organisms, as yeast undergoes sexual differentiation and forms spores when it encounters poor nutrition, thereby surviving hostile environments.

Eukaryotic cells replicate in a four-step cycle called the cell cycle. Most cells in organisms are in a G1 phase, and they can stay there for quite a long period of time. When a cell receives growth stimuli, its enter the S phase, in which DNA synthesis occurs and its genetic information is duplicated. After DNA is synthesized, the cell proceeds to the G2 phase, in which the timing of mitosis is determined, based on nutrition, cell organelle synthesis, and the completion of DNA synthesis. Finally, in mitosis, the cell divides into two identical cells. After division, the cell may enter another cell cycle or stay in G1 until it receives the next growth stimulus or a stimulus for differentiation. When differentiation stimuli are received, the cell stays in G1 but changes form into such specialized cells as muscle, nerve, or kidney. Thus, the cell's fate is determined by events that occur during G1. The switch mechanism controlling cell growth and differentiation is ubiquitous among all eukaryotes and seems to be evolutionally well conserved.

This project will use one of the most sophisticated gene cloning techniques presently available, which we developed, to unravel the secret of the "master switch." The technique is expression cloning using heterologous hosts, which allows us to use fission yeast mutants as hosts for isolation of mammalian genes. Using yeast mutants with defects in G1, we can clone mammalian genes that complement the defect. In parallel, we will isolate extragenic suppressors of known G1 mutants of fission yeast and use them to generate mutants that would in turn serve as hosts for isolation of their mammalian counterparts. Repeating these steps, we hope to isolate most of the genes comprising the "master switch" of mammalian and yeast cells.

Unraveling the mechanism controlling cell growth and differentiation will provide a clue to understanding the molecular mechanism of malignant transformation and cell aging. We also hope to find a basis for the next generation of biotechnology, which would allow us to manipulate the development of organisms.

CONCLUSIONS

The ERATO program is certainly unique in several aspects. Although clearly aimed at increasing Japan's technology base in wide areas of science, project managers are given encouragement to follow their scientific and technological intuition, even if it leads away from the stated objectives of the project. Basic scientific objectives are served as well as societal needs and objectives, with a focus on the distant future.

Within the Japanese scientific and technical community, ERATO is given wide publicity and has earned great respect over its first decade of operation. The nation's best young scientists are attracted to work on ERATO projects, even though they have a limited 5-year lifetime (see Tables 1 and 2). Younger scientists are employed for the bulk of the research, and their experience prepares them well for greater responsibilities in the future. Even with the 5-year cutoff, mid-career scientists are not reluctant to accept such a limited 5-year appointment because they are confident that the experience and the contacts developed during the ERATO adventure will ensure them a satisfactory follow-on appointment.

Assessing the overall success of ERATO is hardly necessary. A brief glance at the project reports above is enough to convince all but the most skeptical of the value of ERATO's technical achievements to date. In addition, the opportunity for younger and mid-career scientists to devote 5 years of their career to innovative, team-type, project research is of great value in their professional development. Many of the projects involve cross-disciplinary research teams and some involve international teams, thereby presenting a broadening of scope for most younger scientists.

As Japanese scientists struggle to find the meaning and value of their role in global scientific leadership, ERATO's international component, while not large, contributes significantly to the international interaction, in both science and technology, that seems destined to grow in the next few years. Some data on this latter point are given in Table 3.

Table 1. Sources of ERATO Personnel by Organization

[Average age: 32.8 yr.]

Source	No. of Organizations	No. of Persons
Industry	127	264
Universities	8	9
National labs	4	8
Other	6	18
Individual		198
Foreign	24	79
Total	169	576

Table 2. Sources of ERATO Personnel by Country

Country	No.
U.S.	14
England	5
Italy	2
India	2
Australia	1
Austria	1
Holland	1
Canada	6
Korea	6
Singapore	2
Sweden	1
Spain	1
Czechoslovakia	1
China	8
Taiwan	4
Nigeria	1
Germany	7
New Zealand	1
Hungary	4
France	4
Poland	4
Bulgaria	1
Finland	1
Philippines	1

Table 3. Distribution of Research Results

Source	No. of Patent Applications	No. of External Publications
Domestic	583	1693
Overseas	108	813
Total	691	2506

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Victor Rehn is currently a liaison scientist with the Office of Naval Research Asian Office in Tokyo. He assumed this position in May 1991. Since 1965 Dr. Rehn has been a research physicist with the Naval Weapons Center, China Lake, California. He started there as a research physicist in the Semiconductor Physics Branch, then as a supervisory research physicist he headed the Electron Structure of Solids Branch and the Semiconductor and Surface Science Branch, both in the Physics Division, Research Department. Dr. Rehn received his B.A. in physics at the University of California, Berkeley in 1953 and his Ph.D. in physics from the University of Pittsburgh in 1962. After completing his thesis research in nuclear quadrupole resonance studies of para dichlorobenzene and related materials, Dr. Rehn studied magneto-acoustic attenuation in metals at the University of Chicago. Upon moving to China Lake, he undertook research in electroreflectance of wide-gap semiconductors and insulators. Beginning in 1973, he participated in the establishment of the Stanford Synchrotron Radiation Laboratory and continued with the application of synchrotron radiation in research in semiconductors and semiconductor surfaces. In 1976 he initiated a research program in liquid-phase epitaxy, followed in 1984 by research in molecular-beam epitaxial growth and characterization of semiconductor materials and heterostructures. In 1987 he initiated research in the production of yttrium barium copper oxide superconductive thin films using excimer-laser ablation.

Appendix A

COMPLETED ERATO PROJECTS

1986-1991

A. Goto Quantum Magnetoflux Logic Project: Supercomputers Through Superconductors

PD: Prof. Eiichi Goto (Kanagawa University)
Bassin Shinobazu 202
2-1-42 Ikenohata
Tai'o-ku, Tokyo 110, Japan
Tel: 03-3828-3794
Fax: 03-3828-4094

1. Quantum Flux Parametron as a High-Speed Logic Device (Ryotaro Kamikawai)

2. Evaluation of a Cyclic Pipeline Computer, FLATS 2 (Mitsuhisa Sato)

3. Detection of Trapped Flux Quantum in Superconductors (Junpei Yuyama)

B. Hotani Molecular Dynamic Assembly Project

PD: Prof. Hirokazu Hotani (Teikyo University)
c/o Research Institute for Production Development
15 Morimoto-cho, Shimogamo
Sakyo-ku, Kyoto 606, Japan
Tel: 075-711-5924
Fax: 075-791-7056

C. Inaba Biophoton Project

PD: Prof. Humio Inaba (Research Institute of Electrical Communication, Tohoku University)
c/o Kozinkai Center Hospital
2-1-6 Tsutsujigaoka, Miyagino-ku
Sendai, Miyagi 980, Japan

1985-1990

D. Yoshida Nanomechanism Project: The Way to Nanometer Technology (continuing as a post-project project until 1995)

PD: Mr. Shoichiro Yoshida (Managing Director, Nikon Corporation)

E. Kuroda Solid Surface Project

PD: Prof. Haruo Kuroda (Dept. of Chemistry, University of Tokyo)

1984-1989

F. Horikoshi Superbugs Project

PD: Prof. Koki Horikoshi (Tokyo Institute of Technology, Chief Scientist, RIKEN)

1983-1988

G. Hayaishi Bioinformation Transfer Project

PD: Dr. Osamu Hayaishi (Osaka Bioscience Institute)

1982-1987

H. Mizuno Bioholonics Project

PD: Prof. Den'ichi Mizuno (Teikyo University)

1981-1986

I. Hayashi Ultrafine Particle Project

PD: Dr. Chikara Hayashi (Chairman, ULVAC Corp.)

J. Masumoto Amorphous and Intercalation Compounds Project

PD: Dr. Tsuyoshi Masumoto (Director, Research Institute for Iron, Steel and Other Metals, Tohoku University)

K. Ogata Fine Polymer Project

PD: Prof. Naoya Ogata (Sophia University)

L. Nishizawa Perfect Crystal Project

PD: Dr. Jun'ichi Nishizawa (President, Tohoku University)

Appendix B

CURRENT ERATO PROJECTS

Both the permanent institutional affiliation of the Project Director and the mailing address and phone numbers of the project office are given. Anyone interested in further information concerning specific projects is encouraged to contact the Project Director directly. General information concerning ERATO projects or about other activities of the Japan Research and Development Corporation (JRDC) should be addressed to:

ERATO
Research and Development Corp. of Japan
2-5-2 Hagata-cho
Chiyoda-ku, Tokyo 100, Japan
Tel: 03-3507-3070
Fax: 03-3581-1486
Cable: J33135 JAREDECO

Projects running from 1987 to 1992:

I. Kunitake Molecular Architecture Project: Novel Functions Through Self-Organization of Molecular Materials

PD: Prof. Toyoki Kunitake (Kyushu University)
Kurume Research Center Building
2432 Aikawa-cho
Kurume, Fukuoka 830, Japan
Tel: 0942-37-6030
Fax: 0942-37-6035

A. Direct Nanometer-Scale Measurements of Surface Morphology and Surface Interactions (Kazue Kurihara, Fundamental Design Group, Kurume Research Park)

B. Molecular Silicates and Related Materials (Kanji Sakata, Functional Architecture Group, Kurume Research Park)

C. Preparation of Highly Stabilized LB Films by Molecular Design and 2-D Crosslinking (Tetsuo Ueno, Composite Architecture Group, Kurume Research Park)

II. Furusawa MorphoGene Project: Searching for Genes Controlling Development

PD: Dr. Mitsuru Furusawa (Director, Molecular Biology Research Laboratory, Daiichi Pharmaceutical Co.)
2F, The Thirteenth Noyone Building
5-6-17 Nishikashi
Edogawa-ku, Tokyo 134, Japan
Tel: 03-3688-8944
Fax: 03-3675-0634

III. Nishizawa Terahertz Project: Exploration for Terahertz Semiconductor Devices

PD: Prof. Jun'ichi Nishizawa (President, Tohoku University)
c/o Semiconductor Research Institute
Semiconductor Research Foundation
Aoba, Aramaki, Aoba-ku
Sendai, Miyagi 980, Japan
Tel: 022-229-1511
Fax: 022-229-8576

A. Semiconductor Raman Laser for Optical Communications (Ken Suto, Semiconductor Research Institute, Tohoku University)

B. Terahertz-Band Circuits and Measurements (Koji Mizuno, Semiconductor Research Institute, Tohoku University)

C. Research in High Frequency Optical Waveguide Modulators (Makoto Minakata and Takatoshi Ikegami, Semiconductor Research Institute, Tohoku University)

Projects running from 1988 to 1993:

IV. Mitzutani Plant Ecochemicals Project

PD: Junya Mitzutani (Hokkaido University)

V. Masuhara Microphotoconversion Project: New Chemistry by Laser and Microfabrication

PD: Prof. Hiroshi Masuhara (Osaka University)
c/o Research Institute for Production Development
15 Moritomo-cho, Shimogamo
Sakyo-ku, Kyoto 606, Japan
Tel: 075-702-4600
Fax: 075-702-4646

A. Dynamic Microspectroscopy Group, KRI, Kyoto Research Park

B. Microchemical Function Group, Idemitsu Kosan Co., Central Laboratory, Chiba

C. Microconversion System Group, Research Institute for Production Development, Kyoto

VI. Sakaki Quantum Wave Project: Creation of 3-D Quantum Functional Structures and Electron Wave Control

PD: Prof. Hiroyuki Sakaki (University of Tokyo)
Keyaki House 302
4-3-24 Komaba
Meguro-ku, Tokyo 153, Japan
Tel: 03-3485-9434
Fax: 03-3460-9026

A. ALE for Creating Quantum Functional Structures (A. Usui, NEC Corp., Tsukuba Research Laboratory)

B. Formation of Advanced Quantum Structures by the Overgrowth on the Edge of Quantum Well Structures (Y. Kadoya, Matsushita Research Institute Tokyo, Inc., Kawasaki)

C. Quantum Materials Having Pi-Conjugated Electronic Systems (Alkyl-Substituted Oligothiophenes): Properties and FET Operations (S. Hotta, Komaba, Meguro-ku, Tokyo)

Projects running from 1989 to 1994:

VII. Ikeda Genosphere Project

PD: Dr. Joh-E Ikeda (Laboratory Chief of Molecular Genetics, National Institute of Agrobiological Resources)
D-6 Tsukuba Center, Inc.
2-1-6 Sengen
Tsukuba, Ibaraki 305, Japan
Tel: 0298-58-6246
Fax: 0298-58-6248

VIII. Aono Atomcraft Project

PD: Dr. Masakazu Aono (Chief Scientist)
RIKEN, Itabashi Branch
1-7 13 Kaga
Itabashi-ku, Tokyo 173, Japan
Tel: 03-3961-4608
Fax: 03-3961-1408

A. Basic Analysis Group, RIKEN Itabashi Branch, Tokyo

B. Structure Control Group, Tsukuba Research Consortium

C. Surface Measurement Group, Tsukuba Research Consortium

IX. Tonomura Electron Wavefront Project: Microworld Viewed with Electron Waves

PD: Dr. Akira Tonomura (Senior Chief Scientist, Advanced Research Laboratory, Hitachi, Ltd.)
Akanuma, Hatoyama-machi
Haki-gun, Saitama 350-03, Japan
Tel: 0492-96-6310
Fax: 0492-96-6319

A. Fundamental Property Group, Hitachi Advanced Research Laboratory

B. Image Analysis Group, Toyo University Faculty of Engineering, Saitama

C. Measurement and Observation Group, Hitachi Advanced Research Laboratory

Projects running from 1990 to 1995:

X. Kimura Metamelt Project

PD: Dr. Shigeyuki Kimura (National Institute for Research in Inorganic Materials)

A. Structure Quest Group, Research Institute of Electric and Magnetic Alloys, Sendai

B. Property Fixing Group, Tsukuba Research Consortium

C. Dynamics Analysis Group, Tsukuba Research Consortium

XI. Nagayama Protein Array Project

PD: Dr. Kuniaki Nagayama (Biometrology Laboratory, JEOL, Ltd.)
18-1 Higashiarai
Tsukuba, Ibaraki 305, Japan
Tel: 0298-58-1510
Fax: 0298-58-1558

XII. Torii Nutrient Stasis Project: Eat Well, Be Well

PD: Dr. Kunio Torii (Chief Researcher, Central Research Laboratories, Ajinomoto Co., Inc.)
Technowave 100
1-1-25 Shin-urashima-cho, Kanagawa-ku
Yokohama, Kanagawa 221, Japan
Tel: 045-451-2550
Fax: 045-451-2553

XIII. Shinkai Chemirecognics Project

PD: Prof. Seiji Shinkai (Kyushu University)
c/o Fukuoka Industrial Technology Center
332-1 Kamikoga
Chikushino, Fukuoka 818, Japan
Tel: 092-928-4666
Fax: 092-928-0729

Projects running from 1991 to 1996:

XIV. Yoshimura Pi-Electron Materials Project

PD: Dr. Susumu Yoshimura (Director, Matsushita Research Institute Tokyo, Inc.)
3-10-1 Higashimita, Tama-ku
Kawasaki, Kanagawa 214, Japan
Tel: 044-922-2351
Fax: 044-922-6893

XV. Noyori Molecular Catalysis Project

PD: Prof. Ryoji Noyori (Dept. of Chemistry, Nagoya University)
c/o Aichi Institute of Technology
1247 Yachigusa, Yakusa-cho
Toyota, Aichi 470-03, Japan
Tel: 0565-48-4900
Fax: 0565-48-4909

XVI. Fusetani Biofouling Project

PD: Prof. Nobuhiro Fusetani (Laboratory of Marine Biochemistry, Faculty of Agriculture, University of Tokyo)
c/o Yokohama R&D Center
Niigata Engineering Co., Ltd.
27 Shin-Isogo-cho, Isogo-ku
Yokohama, Kanagawa 235, Japan
Tel: 045-753-9088
Fax: 045-753-9089

XVII. Okayama Cell Switching Project

PD: Prof. Hiroto Okayama (Research Institute for Microbial Diseases, Osaka University)
c/o Institu Pasteur de Kyoto
Pasteur Bldg 4F, Tanaka Monzen-cho
Sakyo-ku, Kyoto 606, Japan
Tel: 075-712-5406
Fax: 075-712-5492

STATE OF THE ART IN JAPANESE COMPUTER-AIDED DESIGN METHODOLOGIES FOR MECHANICAL PRODUCTS: REPORTS ON INDIVIDUAL VISITS TO COMPANIES AND UNIVERSITIES

The author spent 3 months in Japan as a temporary liaison scientist with the Office of Naval Research Asian Office to survey Japanese use of computers in design of mechanical products, to report on the state of practice in Japanese companies, and to determine research needs and trends in both industry and academia. A summary report was published in the first issue of 1992; this is an appendix that contains detailed information on the author's visits to companies and universities.

by Daniel E. Whitney

UNIVERSITY OF TOKYO: NEW DEPARTMENTAL ALIGNMENT IN MECHANICAL ENGINEERING

5 June 1991

Background

Prof. H. Inoue is in the Mechanical Engineering Department and is currently head of the new Mechano-Informatics Department. How this new department came into being is the subject of this report.

The University of Tokyo (Todai) is Japan's most prestigious. Its graduates go into the best government and university positions, including most of the new hires into Todai's own faculty. The buildings are quite old, solid reinforced concrete, and hard to modernize. Budgets are tight. Almost all the students are self-supporting, including graduate students. Tuition is high but apparently not nearly as high as at private U.S. universities.

The typical course of study is 4 years for a bachelor's degree, 2 more for a master's, and 3 more for a Ph.D. The undergraduate curriculum is almost all classroom courses while graduate study is mostly laboratory work and thesis with only a few classes. This is important to understand in view of the subject of this report, which depends heavily on curriculum reform.

New Departments

Mechanical engineering used to be split into three subdepartments called Mechanical Engineering (ME), Mechanical Engineering for Production, and Marine Engineering. The latter came into being about 20 to 30 years ago as Japan became a prime shipbuilding country. Since Japan no longer leads in shipbuilding, this department has been totally eliminated in the new structure. When it existed, it dealt primarily with engines and other ship machinery, not with ship structure or other traditional naval architecture. Elsewhere in Todai there is now a Department of Shipbuilding and Naval Architecture.

Three years ago the ME Department decided that it was losing students or would soon, with the defectors going into more modern technologies based on computers and information sciences. (Inoue said this twice during our talk.) The response was to "restructure" and modernize the curriculum.

The pressure to restructure came not only from trends visible in student registrations but also in general from the rush of technological change in society and industry. Japan identified information-intensive products as strategically important as early as 1970 with the launching of the PIPS (Pattern Information Processing Systems) 5-year national project and has pursued this area intensely since. Obviously mechatronic products will proliferate and engineers will be needed to design them. Industry is quite interested in this new restructuring

Inoue noted that the restructuring began 3 years ago and the Ministry of Education took until this January to give final approval. Todai is a national university subject to the Ministry's governance I do not know if there is an equivalent of ABET other than the Ministry, but I doubt it. He also notes that all the debate, curriculum creation, and course design occurred during this time, so the big fights are over and the new structure is fully in effect.

Department and Curricular Structure

The new department structure recognizes "traditional deep" ME, broad ME, and mechano-informatics (new ME).

Dept of Mechanical Engineering (Deep ME)

1. Strength of Materials and Structure
2. Fluid Dynamics
3. Thermodynamics
4. Mechanical Vibration and Mechanics
5. Material Physics and Tribology
6. Energy Conversion, Combustion Physics
7. Heat and Mass Transfer
8. Mechanical Science, Measurement Instrumentation

Dept of Mechanical and Industrial Engineering (Broad ME)

1. Production Systems, Manufacturing Systems
2. Machine Creation and Manufacturing
3. Systems Engineering, Security Engineering
4. Design Engineering
5. Human Systems Engineering
6. Industrial Systems, Transportation Systems
7. Humanware Systems Engineering (donated chair by JR East Japan)

Dept of Mechano-Informatics (New ME)

1. Electronics and Computer in Machinery (digital systems, microcomputer, interface, micro-machine)
2. Mechanism and Control (mechatronics, control theory, mechanics and mechanisms)
3. Pattern Information Processing (sensors, signal processing, image processing, visualization)
4. Software Engineering (algorithm design, programming languages, operating system)
5. Computation Mechanical Engineering (computational mechanics, simulation, FEM analysis, CAE)
6. Bio-Mechanical Engineering (biomechanics, neuro engineering, cognitive engineering)
7. Information Systems Engineering (robotics, artificial intelligence, information systems)

Broad ME includes industrial engineering and production engineering. Both design and computing appear in all three subdivisions. Students majoring in any one of these three take courses from the various chairs, with 50% recommended from the home department and 25% each from the other two. There are no required subjects. The requirements for what we call "humanities" subjects, basic science, and math are satisfied in the first 1.5 years when the students attend a different campus. This way of setting up the curriculum may have been adopted in order to reduce conflict between the advocates of the new curriculum and those of the old who usually ask in such debates what mechanical engineering really is. The new structure actually moots this question in a very realistic way, acknowledging the fact that the old curricular and discipline boundaries have long since been destroyed by external events and it is necessary to build new ones.

According to Inoue, the purpose of the Department of Mechano-Informatics is to enhance the research and education of computer-intensive mechanical engineering. Primary research fields include:

- creation of intelligent machinery such as robotics and mechatronics
- computer-intensive design and analysis of mechanical systems
- introducing new functions or approaches into machinery such as bionic functions, neuro science, and micro-machines
- advanced human-machine interface, virtual reality, cognitive engineering, etc.

On subsequent visits I hope to delve deeper into such questions as the relation between university training and company training and whether the university thinks any one student can really learn all the things that are offered. What should a competent design engineer know in a world of mechatronics? Since there are no required subjects, only "strongly recommended" ones, the department has not taken a rigid stand on these points. [This topic is addressed in the report on Hitachi Construction Machinery.]

I raised the question of the place of algorithms in this curriculum. It may seem odd to relate algorithms to mechanical design but Inoue agreed immediately that this is an essential ingredient. Many complex products are algorithm-driven by their embedded microprocessors. Many have complex user interfaces and multiple internal states, both mechanical and electronic. Thus a sense of algorithms is essential for a comprehensive design approach.

A related question is why algorithm-aware students don't go into computer science (CS). The simple answer is that there is no CS department in Todai's engineering school! There is a CS department in the School of Science, however. I did not learn much about what it teaches. The electrical engineering (EE) department in the School of Engineering deals mostly with power and information systems, including signal processing and vision. Most U.S. universities have CS departments or CS divisions of EE departments. At Todai such competition does not exist, leaving a clear path to ME for such students who also have a mechanical bent.

Discussion

Many universities in the United States have trouble changing their curricula radically, in spite of obvious reasons to do so. At the Massachusetts Institute of Technology (MIT) I saw leading professors introduce new material at the graduate level and prove it out before trickling it down to the undergraduate curriculum. This can take many years and lacks a department-wide strategic approach. It also lacks a methodology for removing outdated material, leading to crowding in the undergraduate syllabus. At Todai the graduate curriculum has so few classes that this method may not be available.

The methodology at Todai is not totally clear to me, except that the pressure came from within the department, apparently, and not from the dean. The methodology for selecting elements of the new curriculum is also not clear, except that the chairs focus on areas that are related to their research. This creates expertise but does not guarantee that generic material will be taught or that the students will obtain a balanced education.

What is clear is that the change was quite radical and has defined "mechanical engineering" in a way that would be almost unrecognizable at many schools in the United States.

Postscript

This report was distributed in draft form to many U.S. educators and drew an interesting response from Prof. Masayoshi Tomizuka, Vice Department Chairman of Mechanical Engineering at UC Berkeley. Tomizuka did his Ph.D. research with me at MIT in the early 1970s after getting his SB and SM from Keio University in Tokyo.

Tomizuka said (and Dr. Kozo Ono of Hitachi Construction Machinery Company and a Todai graduate confirmed) that Japanese undergraduate engineering education is broad and shallow. One is exposed to many fields but learns almost no deep knowledge. Tomizuka said he was surprised by the depth of the MIT doctoral qualifying exams and had to study very hard to learn the material to pass them.

Tomizuka also said that curricular reforms like those described above actually happen fairly frequently in Japan and do not represent the revolution that is implied by my report.

The comments of Tomizuka and Ono raise a difficult question: if Japanese university education in engineering is so shallow, how come Japanese product engineering is so good? The answer apparently lies in the additional education the young engineers get on the job, plus such factors as lifetime employment, extensive use of past design data on new designs, and the length of time an engineer keeps the same job responsibilities.

An advantage of this kind of education is that it sets the pattern for "universal experience," meaning that an engineer more easily learns and practices many fields during his/her career. "Mechanical" engineering graduates do not feel a professional commitment to mechanical engineering but rather to their employer, who may alter their professional concentration as a result of assignments and training. These alterations apparently do not cause much discomfort. Cross-trained engineers perhaps can understand each other's design problems, making concurrent engineering easier to implement.

U.S. engineering students, on the other hand, devote a lot of their education to becoming "mechanical engineers," for example, and might feel their school time was wasted if their employer tried retraining them as EEs. Similarly, U.S. companies expect new hires to function productively soon after being hired, just because of the focussed character of their education, and would not think of retraining them to a different field. Engineers thus rapidly become specialized and less able to communicate with engineers in other fields.

Therefore, education, career paths, and company training (or lack of it) are symbiotic in both countries.

PROF. FUJIMOTO, DEPT. OF ECONOMICS, UNIVERSITY OF TOKYO

7 June 1991

Background

Prof. Takahiro Fujimoto is a recent graduate of Harvard Business School, where he collaborated with Prof. Kim Clark. They have already written a book and are continuing their joint studies. The subject is management methods in the automobile business world-wide, with a prime focus on the product development cycle; specifically, the issues studied are lead time, development productivity, and total product quality. The questions they addressed are:

1. How do auto companies in Europe, Japan, and the United States organize the product development process?

2. What are the main bottlenecks that cause the process to take a long time?

3. What regional differences are there in the length of the process?

4. What managerial techniques and organizational practices account for the relative differences found between companies and regions?

Their past studies have focussed on body and chassis design of cars and the design of the manufacturing systems that make those parts. Although engines generally take longer to design than bodies, bodies change more frequently, so their development time, which is long as well, tends to dominate the design cycle for individual car models. Future studies will focus on engines, which have relatively more engineering analysis and less (though NOT no) esthetics behind them, and semiconductors, which have even more analysis and no esthetics at all. (For more about engine esthetics, see below on designing the sound of a car.)

Research Methodology

Clark and Fujimoto pursue a style of research that is often called "determining best practice." It differs markedly from accepted academic research in most fields and at most business schools, where scholarly research is typically about economic models, financial analysis methods, or investment strategies. This method is practiced by conducting field studies, sending out questionnaires (typically 80 to 100 questions), and doing some statistical analyses on the results. Thus it is more like anthropology than management science. The results often make fascinating reading and are taken seriously by forward-thinking people in the subject industries. However, the studies often require a leap from "form" to "content" in the sense that the characteristics of a company that can be gleaned from questionnaires and interviews may not be the root causes of the differences between company achievements.

For example, a recent MIT study (Ref 1) revealed that car factories with more democratic management styles, more flexibility in job classifications, and more automation were able to make more cars in more model varieties with fewer defects than factories that lacked any one or two of the above characteristics. Yet it is not obvious that if one started up a new factory and included all these characteristics one would automatically obtain high quality, high model-mix production capability. The authors of the study show statistical significance in their survey results but this study method does not really lend itself to the typical methods of statistical analysis. For example, there is no way to create a control set; you cannot create a double blind environment; you cannot establish a controlled set of features whose effects are to be tested in isolation since numerous other features are operating out of your control which may not be captured in the questionnaire.

Fujimoto says that companies are willing to participate in such studies because their own data are disguised and they are able to benchmark themselves against regional averages. Sometimes they can decode the data a little and discern information about single companies, but such opportunities are limited.

Importance of This Kind of Research

It is essential that different methods of managing the design and production process be identified and compared. It is well known that different companies in the same industry can differ in productivity by as much as a factor of two. Increasing attention is being given to the length of the product development cycle in particular because it gives so much competitive advantage to companies. They can follow the market as it changes, absorb new technology into their products sooner, and build experience in their technologies and in the design process itself at a higher rate. The ability to "climb the learning curve" of design and technology faster has been cited by Gomory and Schmitt (Ref 2) as a major factor in national and international competition based on national productivity and economic strength.

Two distinct approaches to speeding and improving the product development process have been identified. These may be called roughly the management-intensive approach and the technology-intensive approach. The former emphasizes management and organizational methods while the latter emphasizes use of computer-aided design and similar techniques. Companies using managerial methods employ design teams from different technical disciplines. Those pursuing the technical track make use of computers for design or for internal communication. Others use modern computer-controlled manufacturing equipment to obtain better uniformity of output, hence higher quality. No company uses one technique alone. The differences are matters of degree only.

In some industries it is taken for granted that design technology is essential. Modern complex products require so much data to describe their design, so many calculations to determine performance, and so much attention to detail during fabrication and assembly that human capabilities are severely challenged. In the semiconductor industry, human capabilities in design and design checking were far surpassed over 15 years ago; only use of large scale computing permits modern microprocessors to be designed at all.

American companies in particular are known for using computers heavily in many aspects of design and production whereas Japanese companies are not so well known for this. In fact, some of the most productive Japanese companies, such as Toyota (the Just in Time (JIT) method for making cars) and Ishikawajima-Harima Heavy Industries (IHI) (the moduler method for making ships), achieved their famous production efficiencies without large scale use of computers for factory management. Since Japanese performance in these industries sets the standard for the world, it is somewhat ironic to find, at least based on current outside knowledge, that computers do not play a leading role.

The purpose of my own study in Japan has been to pursue the question of how computers are used in the design process, not the factory management process. It appears, however, that Japanese companies have spent the last 10 to 20 years refining both design and manufacturing processes independently of computers and are now applying computers to the methods already developed. Fujimoto believes that this is the right sequence for obtaining the best processes, at least in the auto industry. Others feel that the technical challenges of complex products are so great that without help from computers, no company can surmount them merely with management techniques.

Therefore the book is still open on what is the best approach or mix of approaches to improving product development methods. Clark and Fujimoto have learned a great deal about the auto industry, and a summary of their findings follows.

Fujimoto/Clark Major Findings

Fujimoto and Clark approached their study as a management problem and asked management questions. They did not, in fact, investigate use of computers, either in extent or kind of use. The implications of this are discussed below. At the same time, Fujimoto knows that CAD/CAM has had a major effect on car development time, referring to Toyota's finding that wide introduction of CAD terminals reduced lead time half a year.

Their basic finding is that Japanese car companies on average take a year less to design a car than U.S. or European companies and that this shorter development time results from two factors. The largest one is overlapping of phases of the process that normally are accomplished sequentially. The second factor is that some of the phases are accomplished faster, although some of the time saved is used to perfect the design rather than to shorten the overall process further. The main method by which overlapping is achieved, according to Fujimoto/Clark, is via intense communication between product designers and production tooling designers. This communication allows the tooling designers to critique the design and to begin key phases of their own work. This process can be risky because second phase activities start before first phase activities are finalized. Intense communication is used to minimize the effect of such risks, as discussed below (Ref 3).

Importance of Overlapping Design Functions and Interfunction Communication

The overlapping design process is often called "Concurrent Design" (CD) (Ref 4). Other synonyms are Concurrent Engineering and Simultaneous Engineering. All refer to a process during which product designers and production system designers exchange information in order to maximize the producibility of the product. In more sophisticated CD environments, factors such as marketability and field repairability are also taken carefully into account. The contrasting situation, which occurs in the defense industry as well as in high performance companies such as Mercedes, is that product performance dominates design, with all other factors being secondary or not considered during design proper. They are considered later, during production system design, or not at all. This is called "throwing the design over the wall."

The trouble with allowing performance to dominate design is that the other factors cannot be served except by including them in the original design or by changing the design later. But changing the design is prohibitively expensive once it is complete. A design often represents a long chain of interdependent decisions and roads not taken. Changes that are more than cosmetic may threaten to unravel the entire chain. Producibility or repairability problems that are discovered after design are said to cost 10 times as much to fix as if they were discovered when the design was only drawings; if discovered during production the cost is 100 times as much. In addition, poor producibility and repairability lead to low quality and a bad image for the product in the marketplace.

Therefore, it is now accepted that decisions made during design dominate the cost and performance of the product, and most downstream decisions are subordinate, with little ability to affect cost or performance. Thus intense attention is being given to how to accomplish CD. Even Toyota and Honda, according to Fujimoto, feel the need to do this better.

Honda used to have a separate design "company" called Honda R&D, which essentially sold finished car designs to Honda Motors. The manufacturing system engineers at Honda Motors prided themselves on their flexibility, their ability to accept a lot of "wild changes at the last minute," though not after the product was launched. My own opinion is that in the United States the wish of manufacturing engineers to appear flexible has been a barrier to increased CD. Until the early 1980s in the United States, the quickest way to be swept aside was to complain that the design needed to be changed. It is possible that Honda R&D's designers knew enough about producibility that they could avoid a lot of obvious problems. U.S. designers are less likely to have such knowledge.

Particular Fujimoto/Clark Findings

In automobile companies, the time to design and field a car model is dominated by the time to design the body and the stamping dies needed to make the body parts. This time is, in turn, dominated by the time to design, make, and test the dies themselves. In Japanese companies, the lead time for dies is about 1 year versus 2 years in the United States and Europe. Furthermore, the impact of a die design change on both cost and schedule is much lower (10% to 20% excess cost over budget versus 30% to 50% in the United States and Europe). On the other hand, the absolute number of engineering changes is not too different, he says (500/month versus 1,000/month). Thus the difference must lie in the extent of the changes: apparently they can be rather large and disruptive in the United States whereas in Japan communication has ironed out the big problems early and only small ones crop up.

The difference between regional performance here lies in the organization of the design process, the timing of information transfer between phases, and the type of information transferred. Japanese production tooling designers can use sketches, line drawings, or preliminary drawings to begin their own designs. In the United States, tooling designers are reluctant to use such information and body designers are reluctant to provide it because changes give rise to blame-fixing and finger-pointing. Furthermore, some information is not directly obtained in Japan but rather is intuited in the sense that designers know each other and their styles, as well as the most change-prone regions of a design. Thus they can anticipate some changes by providing safety factors, such as excess metal on the die face that will be removed later when final designs are in hand.

Strangely, much of the information of most forward use to die designers exists when the final clay models are finished, which is before any body panel design begins. According to Fujimoto, the die designers "lack access" to the clays, which can be many miles away, or locked behind elaborate security barriers. Another source of such information that is not used is the model shops where preliminary dies are designed. Habit plays a big role in such lack of information transfer.

Die designers are not used to being asked what information they would need and thus have not taken the time to decide what would be of the most use. They take it all in at once without partitioning it in their minds or in their design process. Formal methods to partition a design process are only recently drawing attention as a research topic and may indeed represent a new way of thinking (Ref 5). On the other hand, Japanese designers, when forced to do things faster, may have thought the problem through and made priority lists of what information they really need early in the die design process. They may have also found out that such information may be easier to obtain than they thought, especially if they promise not to complain if the design changes later. In fact, Fujimoto claims that overlapping of the process steps came first, as a means to shorten the cycle, and communication lines developed in response. (See the Toyota reports, where the claim is made that information release is tightly controlled and does not occur freely between long-time acquaintances.)

As another example, in the aircraft engine business, it has been found that the most useful advance information for tooling engineers about an engine shaft is its length and outer diameter. This information permits them to order raw material and begin machine design. However, the shaft's inner diameter does not strongly influence preliminary machine design and can be learned later. Also, preliminary finite element method (FEM) analysis can be done knowing only a rough inner diameter, and this analysis helps determine what the final inner diameter must be.

Another important factor is a company's reward structure and management culture. Companies that penalize design changes may stifle early communication and overlapping of processes and force designers to furnish only "final" designs.

Human Communication Versus Computer Implementations

Fujimoto/Clark represent a research paradigm that is not surprising in a business school, namely, that management techniques and human activities dominate, and computer tools and other advanced design and manufacturing technology are subordinate. Toyota seems to be living proof of this. Fujimoto extends this claim by pointing out that many aspects of car design simply cannot be handled long distance by any existing technology, such as electronic mail or real time links between computer workstations. "Only face to face communication will suffice." Examples concern how to capture certain human expressions in the design, such as the feel of the suspension or the handling, or even the sound the engine and exhaust system will make (so-called esthetics of engines mentioned above). Fujimoto/ Clark posit the existence of "heavyweight product design managers" as the main carriers of this type of information (Ref 6). Such managers are deeply experienced in both market and engineering aspects of car design and have been raised from a background in engineering. Their use has been adopted in the car industry world-wide as car designs have become more sophisticated and complex. Heavyweights do not simply push schedule and budget but meet with designers every day, personally drive the cars on the test track, talk intensely with the test engineers, and so on.

However, an alternate paradigm exists in the engineering schools and in engineering research on the design process. This paradigm states that advanced computer tools are essential to the design of complex products, the prime examples being microprocessors, aircraft, and cars. The unification of design data, production orders, market information, and control commands to production machines is a major goal of modern integrated manufacturing and is the subject of the emerging IMS project (Intelligent Manufacturing System) among others. Another similar effort is the international standards project called PDES (Product Data Exchange Standard using STEP). (STEP is the European acronym for PDES.) PDES will establish a data exchange standard that will permit all the data describing a product to be converted and communicated within and between factories, design studios, suppliers, vendors, and so on.

Fujimoto argues that communication capability is an organizational skill that takes years to build up. It is based on personal contacts developed over years of working on similar design projects and is fortified by the stability of employment and length of job assignments typical of Japanese companies. By contrast, he views computers as commodities that anyone can buy and install quickly. Thus no competitive advantage is gained by going this route, although anyone who does not will be left behind. But adopting the right communication methods is not a commodity and others cannot quickly jump in and achieve the same results.

The engineer paradigm people view the situation exactly oppositely. There is increasing evidence in U.S. companies that communication and overlapping of product design and production equipment design can be introduced quickly and effectively. Methods used so far require intense personal pressure and long working hours (same as in Japan!) and considerable fatigue results. This means that such methods have not been institutionalized yet, but they will be, at least in the survivor companies.

However, computers may not be commodities after all. It is true that workstations are becoming commodities, and so is basic commercial design software, such as CAD tools. However, the true differences between companies will soon shift: right now the difference is in how much CAD has been adopted. In the future, the difference will be how much beyond CAD is achieved. This includes capturing design knowledge from past designs in computer-readable form, making product design data available to tooling designers, creating computer "design critics" that can automatically comment on a product design and alert designers to producibility problems, integrating engineering and business data, and so on. Much of this kind of information is currently embodied in the experience of each company's engineers, meaning that new kinds of software tools and knowledge capture methods will be needed. Companies that put effort into this kind of computing will definitely gain a competitive advantage that others will not be easily able to copy.

The willingness of companies to invest internally in computerized design infrastructures, including supporting research on advanced design tools and methodologies, may be an essential factor in future productivity and commercial health. This will be especially important as cadres of experienced engineers retire and take their experience with them.

Final Comment

Clark and Fujimoto have focussed on one industry, automobiles, one aspect of car design, some moderately complex parts with aesthetic elements, and one period of industrial history, the 1980s. Other industries are characterized differently, as are other items they make. Electronic component design is heavily computerized and data driven, whereas almost no mechanical design is similarly structured. In another report, I describe a Japanese company's methods and equipment for designing small VCR mechanisms as well as their outlook for future competitive advantage. While cars are designed by teams numbering in the thousands, these VCRs are designed by a team of 10 engineers total. Communication problems clearly vary with the scale of the project. Yet, with 300 parts, VCR mechanisms are not simple.

Fujimoto added in later a communication with me that the characteristics of the auto industry in the 1980s may not apply to the 1990s. Indeed, computers and their constituent software and databases may become the dominant feature of leading companies, especially those that have already improved their design productivity, learned how to overlap design tasks, and identified the knowledge and algorithms that must be captured in software.

Finally, I might add that this is the first report written while I was in Japan. My subsequent findings amply support the main points raised in this report: the advanced companies indeed are building on their accumulated experience, capturing their efficient management methods and experience in computer tools. See especially the reports on Toyota, Nissan, Mazda, and Nippondenso.

CAD AND PRODUCT DESIGN METHODOLOGY AT HITACHI

11 June 1991

Background

I visited Hitachi Yokohama works on 11 June. My host was Mr. Michio Takahashi of the Production Engineering Research Laboratory (PERL). The visit focussed on design of VCR mechanisms and camcorders and our hosts were designers in the Image and Media System Laboratory (I&MSL), which is next door to PERL.

The I&MSL is a product development laboratory within the Consumer Products Division. Its role is to create new technology for products as well as to design new kinds of products embodying such technology. Products are manufactured at factories (called works) and such works also have design departments. The latter make small updates to existing designs and lead in the conversion of preliminary designs into manufacturable ones. PERL is one of nine research laboratories, others dealing with energy, basic research, mechanical engineering, systems development, microelectronics, design, and "advanced research."

Hitachi's organization is a hybrid of product-line orientation and function orientation. Each business group (such as Consumer Products, Industrial Products, Power Plants, etc.) reports directly to the president. But there is a separate Production Engineering Department that also reports directly. Finally, the nine research laboratories also report directly. This means that the president directly can control research, marketing, and production engineering and can in principle mediate disputes among them. These are among the deepest disputes that can occur in a diverse technically sophisticated manufacturing company.

In many Japanese companies, there is an executive vice president of production engineering, attesting to the importance these companies give to manufacturing excellence. In most U.S. companies the organization is strictly by product line, with each factory having its own manufacturing engineers. These people usually have little say in the design of the product and often merely take care of equipment that the company has purchased outside. Differences like these contribute to relative strengths and weaknesses of manufacturing companies, in my opinion.

At I&MSL there are 350 researchers, of whom 70% have an electronics background while the rest are mechanical, physical, and chemical. Products include VCRs, camcorders, optical disk storage systems, high definition TVs (HDTV), digital audio tape systems, and their associated electronics. The laboratory has extensive large scale integration (LSI) design and test fabrication facilities and obviously puts most of its efforts into the electronic aspects of design.

Most of the above information and what is reported below are illustrated (though sketchily) in a brochure they gave me about I&MSL.

Focus of the Visit

The focus of this visit was Hitachi's approach to the design of complex mechanical items. Takahashi chose the VCR, and it is a good choice. The tape changer-player mechanism typically has 300 metal and plastic parts, stamped or injection molded. Most parts are riveted together, although there are a few very small screws. This is a delicate, precise mechanism which must be rugged and reliable while at the same time handling delicate tape, being lightweight, easy to assemble, and low cost. Similar products are made by Sony, Matsushita, and other companies.

Products with similar characteristics include compact disk players, cameras, and miniature hard disk drives for laptop computers. Such products are often called "mechatronic" to call attention to their hybrid mechanical-electrical-optical-computational character. Major issues in their design include deciding whether to embody a function optically, electronically, computationally, or mechanically. Their fabrication and assembly involve cleanliness, high tolerances, as few adjustments as possible, and extreme efforts at uniformity and quality of output. An additional complication is that all such products are extremely small and getting smaller.

My goal in visiting was to see how Hitachi meets these challenges, what computer aids if any are being used, and what future computer aids Hitachi thinks it needs. Additional goals were to see where Hitachi obtained the computer tools it has and to see whether it plans to develop its own in the future, deal with universities, or buy from commercial companies.

Summary of Discussions and Tours

I met in the morning with Dr. Yoshihiko Noro, Chief Researcher, and several of his main assistants. We discussed the product design cycle for miniature VCRs, including how long it takes, what the chief obstacles are, and who does what. I was also shown the CAD center.

After lunch, I got a brief tour of PERL's robotics laboratory where I saw several things I had seen in earlier stages of development on previous visits (six in all since 1974).

Finally, there was a presentation by PERL of a recent paper on their approach to Concurrent Design (see the report on my visit to Prof. Fujimoto) and an open discussion on this topic. We planned several additional visits, including to factories where washing machines and automotive components are made. These visits are covered in other reports.

VCR Design Cycle

I&MSL is responsible for consumer stand-alone VCRs, VCRs inside camcorders, and professional studio VCRs. The latter are their newest products and are made at the glacial rate of 10 per month. By contrast, the others are made in the hundreds of thousands per month. Naturally, the design of something made at 10 per month is quite different from 100,000 per month, since automation of the latter is almost a necessity. Thus each part must be very simple, must be able to be picked up by a simple gripper, and installed in a simple straight-line motion.

These VCRs are an incredible jumble of stacked, nested, and intertwined levers, rollers, springs, sliders, cams, and bars, run by a motor and several little rubber belts. Most of the parts occupy the bottom 3-mm-thick layer of a unit that is about 2 cm thick, 10 by 14 cm. Design is therefore an exacting process requiring fitting parts into small spaces as well as determining how the moving parts will travel while carrying the tape from the cassette to the read head.

A totally new product may absorb 2 years of advanced development of its basic technologies before any specific product design begins. Then it takes about 2 more years to create a product. For a relatively mature product, one of these years will be devoted to design development at the laboratory while the other year will be spent converting it into a manufacturable item utilizing the works designers. For less mature products, correspondingly more of the 2-year cycle is spent at the laboratory.

Design is accomplished using CAD (see below), but most of the early effort is put into a series of prototypes. These are uniformly named at Hitachi as follows:

- First prototype--preliminary design.
- Second prototype--the main focus is to achieve a design that fits the size required by the market goals; the I&MSL engineers use Hitachi's assembly evaluation method during this phase.
- Third prototype--responsibility of works designers. The main focus is cost reduction; in this prototype, Hitachi's assembleability evaluation method (AEM) is used in cooperation with the production technology group.
- Pre-mass production prototype--30 units made on production tooling and tested for performance, then 100 more tested for quality assurance and final checkout of the tooling.

I was shown several such prototypes.

Computers are used to lay out the mechanical parts, check for interference during functional motions, see if straight line assembly motions are possible, perform stress analyses, and avoid "simple" and "obvious" errors that would seriously delay the design. See below for details of computer facilities. It appears that computer models are mainly used to fix ideas that have been previously worked out in the designers' heads, on scratch paper, and physically using prototypes. How the original concepts are generated and what role if any a computer plays are not easy to determine.

In answer to my question, they said that the main design challenges are weight, cost, part count reduction, meeting the specification, reducing the cost, and getting the production tooling and factory up to speed. These are, of course, just the concerns one would expect, but the order in which they were given might be indicative of descending order of difficulty.

The early prototypes are naturally very clunky and heavy, with many handmade parts. Function can be tested but final size and weight are difficult to discern. When the works designers begin converting the design to a manufacturable form, they apparently deal directly with the physical prototype itself rather than a computer rendition. A major tool available for this purpose is Hitachi's Producibility Evaluation Method (PEM) of which they are very proud. More on this below.

The Tokai works where these units are made is 2 hours away by train. This distance might be a barrier in a U.S. company but it is nothing to them. Meetings occur every week or two, with the majority at the laboratory during the first year, at the works during the second. This communication is "difficult" but apparently effective. Electronic communication is used mostly for sending text. Hitachi is aware of the advantages of being able to send engineering drawings between designers by computers, but right now such capability appears too costly in comparison to the benefits.

It is important to understand the scale of typical design projects when comparing use of computers and strategies for communicating between designers and works. In the car industry it is common for projects to involve

3,000 or more engineers. Here we are talking about a few dedicated people working feverishly 10 to 14 hours per day, with almost no assistance from draftsmen or technicians. These people will really own this design and will know every screw and hole.

Can the design cycle be reduced substantially below its current duration? In response to this they noted that use of the computer cut a short time out but in my opinion the amount quoted is not a lot. Could it be reduced by half? Their response is that the current duration is about the minimum, but this must be evaluated in the context of the kind of computer aids they are using and their outlook on what the future holds in CAD. As discussed below, this view is somewhat narrow. The computer saves them from time-consuming mistakes such as interfering parts that must be made over. They claim that they will try to reduce the number of prototypes but they did not discuss or show me any concrete techniques for accomplishing this goal.

CAD Facilities

The mechanical design activities of I&MSL are supported by a CAD system comprising Hewlett-Packard workstations running HP's ME 30 solid modeling CAD software plus Structural Dynamics Research Corporation's (SDRC) I-DEAS solid modeler. Hitachi's contributions to this setup are a data translator for exchanging ME 30 and I-DEAS files plus a finite element package called CADAS. In addition, they have a nonlinear finite element package called ADINA, purchased from a small company founded by Professor Bathe at MIT. ME 30 is used mainly for its ability to represent many separate solid models of parts and assemblies of them, whereas I-DEAS is used because its solid models can be linked to analysis software such as FEM and plastic mold filling simulations. Apparently no single design package can do all the things Hitachi wanted, a common situation.

The typical data flow of a design begins with a simple two-dimensional layout in Hitachi software called GMM which is sent via local area network to the HP machine for conversion to a rough solid model in ME 30. Some animation of the motions is done by using a separate computer to generate intermediate position data for moving parts and loading the data into ME 30 to create a series of views. No kinematic analysis software is used, although such has been available for almost 20 years. Hitachi will soon buy a package for this called ADAMS, which has recently been interfaced to I-DEAS.

After simulation, the rough solid model is refined into a complete model. Since there are 300 parts, this step can take a month or two. The model is broken into separate parts, on some of which FEM or mold fill analyses are done. A line drawing in 3D is then done and sent by LAN to another computer which makes conventional-looking drawings for the machine shop to use.

The above description is not intended to imply that 2D and 3D work are done sequentially; much work is done in parallel, with 2D being used for simple almost plane parts and 3D for complex parts or those with many surfaces.

In their opinion they could not design these VCRs without the 3D modeling. However, they admit that such tools permit only functional modeling and basic part fit studies. They cannot do tolerancing, kinematics, cost analyses, or their AEM. Reluctantly they admitted that they want to integrate AEM into CAD but they acknowledged in later discussions that they really do not have a technical approach for doing this.

Hitachi's View of the Product Development Process

My hosts from PERL made a presentation of the contents of a paper describing their approach to product development (Ref 7). No one from I&MSL was present at this time so I do not know the extent of their agreement with its contents or whether they follow this process. It is likely that the paper represents an idealization of a procedure that has emerged over a long period of time.

Simultaneous Cooperative Development

The process has both an organizational component and a technological one. The organizational component is called SCD (Simultaneous Cooperative Development) and is similar in spirit and methodology to Concurrent Design (CD), Simultaneous Engineering, and so on. However, SCD has developed "cumulatively," whereas they see CD as a U.S. innovation implying a drastic new development that puts SCD on computers and makes heavy use of computer technology, design aids, and communications. Hitachi is presently surveying CD methods and research world-wide, especially in the United States. "Everyone in Japan sees the need to do SCD better and faster and it seems that the United States has more researchers working on this. Only a few Japanese companies see how to do it."

Hitachi admits that the idea of SCD is easier to define than to implement. It requires cooperation between marketing, design, and manufacturing to create a design that balances the goals of each group: utility, assurance of performance, and producibility. "Conflict breaks out as soon as the project starts." The spirit of cooperation is instilled by defining the ultimate user of the product as the one they are all working for. This is a good slogan but there is nothing to back it up in their methodology except to hold lots of meetings. The only clear guideline is that the project leader is someone assigned by the factory that will make the product, and this person, similar to the heavyweight defined by Clark and Fujimoto, draws on the skills of several laboratories and works to form his team.

Producibility Evaluation Method

The Producibility Evaluation Method (PEM) is an outgrowth of the Assembleability Evaluation Method (AEM) dating from 1976 combined with the Machining Productivity Evaluation Method (MEM) developed in 1985. Since AEM and MEM can have conflicting recommendations about the design of parts, the goal of PEM is to blend the two and give a composite evaluation.

These evaluations are done on a part-by-part basis and are intended to give a designer a way to evaluate his own design. The method is designed to be simple and easy to use with minimal training. Thus it demands very little of the engineer. The evaluation proceeds by means of a checklist in which the designer deducts points from each part's score based on various undesirable features. For example, one might deduct 5 points if the part must be twisted while being inserted; another 10 points might be deducted if there is almost no space for fingers or a tool around the part during insertion. A perfect part gets 100 points and a part with a score of less than about 70 is a definite candidate for improvement.

The procedure for a group of parts in an assembly is to attack the lowest scoring parts first, then the higher ones, until no further improvement can be made or the average reaches about 80.

Hitachi's main claim for the AEM and MEM is that they have validated some cost reduction ratio predictions that accompany the checklists. These predictions are said to be valid within ±15% on individual part assembly cost reduction and ±10% on product assembly cost reduction. Details of the method are hard to come by because Hitachi sells it and reveals little to those who do not buy.

Hitachi is quick to claim that this method is superior to the Boothroyd and Dewhurst method for Design for Assembly (DFA) that is widely used in the United States. The difference seems to be that Hitachi's cost reduction predictions have been validated in an industrial setting whereas Boothroyd and Dewhurst's (according to Hitachi) have not. Otherwise the methods are quite similar.

How Will Hitachi Drastically Improve Its Product Design Cycle?

Presently, Hitachi's I&MSL depends on commercial CAD and PERL's PEM for its main design aids, plus a lot of very hard work by skilled designers. From these two groups I did not get a feeling that long term design tool development is underway. They are quite concerned that just buying CAD software and hardware from outside will not give them a competitive advantage.

The one step they are planning to take, or hope to take, is to combine CAD and the PEM, but as stated above they do not have a clear methodology for doing this. Furthermore, they do not see Japanese research institutions as having anything to contribute to such problems. For security reasons, they were reluctant to discuss their progress in this area.

It was interesting to compare this attitude to that of a researcher familiar with Hitachi's VLSI computer support. This software does what most such systems do, namely, supports all aspects of VLSI design from circuit simulation to manufacturing. Naturally, I asked what competitive advantage it gives Hitachi and the answer was "Hitachi's extensive database." Such data include materials behavior, design rules for line width, methods for calculating capacitance, and so on. Thus a lot of engineering expertise and company experience and standards have been captured and is available to other designers. While no definitive competitive comparisons can be made, it is clear that Hitachi has been able to put a great deal of its own work into this system, differentiating it from anything commercially available.

What is the analog of such a system in design of mechatronic items? Apparently Hitachi has no vision of such a system. However, several research groups in the United States, Europe, and Japan are investigating such problems under the covering name of integrated product models. A common theme is "Feature-Based Design." This approach seeks to extend the idea of using a computer to capture the shape of parts so that nonshape information is captured and stored along with the shape. Such information includes materials properties, tolerances, assembly approach directions, manufacturing process plans, process costs, and so on. Typical features might be threaded holes, slots, ribs, round passageways, and so on. Since many of these have obvious functional attributes as well as manufacturing and assembly aspects, one can imagine building up enough information to support a physical simulation of the design.

At this time, there is no agreed-upon approach to constructing such design systems. A number of barriers exist. One is a lack of understanding about how designers like to work and express their ideas. Another is a lack of mathematical models of physical behavior of sufficient accuracy to capture the behavior of a whole product. A third is how to achieve unity in a model of a part or product by building up from many individual features. It is not clear how a concept of the whole item can be achieved based on many little pieces or if this is necessary in every case.

Other important engineering and computational barriers exist. Foremost among these is the need to represent the stochastic nature of manufactured items. While the design describes the perfect item, each real part differs in many ways from the ideal. This fact is impossible to overcome. Instead it is acknowledged that reality can be approached more nearly with increasing cost, and that a point is reached where cost overwhelms the effort or adequate performance can be had without additional improvement.

Knowing where this point is constitutes a major challenge in every design activity, and virtually no computer support exists for it. It is called the tolerancing problem and is "solved" in every company by using experience, company guidelines, and prototypes. In many cases, tolerances are set based on the best the factory can be expected to do.

The only systematic approach to this problem that I know of is called the Taguchi method in the United States, or statistical quality control and statistical process control in Japan. Usually this involves making a series of controlled experiments to determine the most important variables, typically utilizing ANOVA, and then focussing design efforts on these variables. The approach is to choose values for the most sensitive parameters in order to minimize the effect that these variables will have on performance. The Taguchi method is most easily applied to tuning a manufacturing process, since the experimental series can be accomplished by varying process parameters. To apply it to design requires making many prototypes or manipulating a mathematical model of the design. Both are difficult to do: prototypes are expensive and take a long time to create; accurate comprehensive math models usually do not exist.

Among the people I talked to at Hitachi I could find no one who had formulated these long term problems in terms similar to those used above. I did not even hear such blockages listed and identified as ones whose solution was fundamental to drastically improving the product design cycle. Finally, I did not hear an alternative description of the problem or an alternative list of target subproblems. Or, if they recognize the problems, they have not identified sources of solutions inside or outside the company. Yet the people I talked to have definitely taken on the task of improving design methods. I will try to find out if others at Hitachi have similar goals as well as what their approaches and progress are.

It is important to note (see the report on my visit to Prof. Kimura at Todai) that in spite of any shortcomings in either Hitachi's CAD or view of future design tools, they are able to design remarkable products just the same. Would "better" design tools make them supermen or just get in their way?

Also, Hitachi is not alone in having goals but few methods for achieving them. Many other companies seem to be in the same fix. Only a few have detailed plans and a clear statement of the blockages.

DISCUSSION ABOUT DESIGN WITH PROF. KIMURA

13 June 1991

Background

I visited Prof. Fumihiko Kimura to plan my visits to companies and to discuss research problems in design. Kimura is an expert on the mathematical models of complex 3D surfaces. He did his Ph.D. with Prof. Hosaka who, along with Coons in the United States and Bezier in France, is responsible for all math models of surfaces used in CAD (computer-aided design) of automobiles and airplanes world-wide. Kimura led two national big projects through the Ministry of International Trade and Industry (MITI) on development of surface modeling software for CAD. Toyota, among others, is a major user of this software.

Kimura is a respected thinker about design research, product modeling, CAD, and CIM (computer integrated manufacturing). His view is entirely that of the design engineer focussing on performance of the product. He is less aware of design for producibility issues and does not know Prof. Fujimoto. We had a wide-ranging discussion of many issues: what the elements of next-generation CAD should be, how to effect technology transfer from R&D to practicing engineers, and what characterizes design problems in general.

Kimura's Current Research

He has just launched an industry-funded project on product modeling to support next generation CAD. He admits that he has no experience as a designer himself and it is interesting to hear him bemoan the complexity of design as it is described by engineers. As an academic he is looking for clean categories and well-defined steps in the design process. What he finds instead are intuitive leaps, a mixture of primary and secondary issues being considered at once, and unlikely linkages between causes and effects that "good designers" seem to know but are not visible to the uninitiated.

The problem of technology transfer is especially perplexing. He wants to define next generation CAD but can't describe it to engineers who know only existing CAD. They, in turn, cannot imagine what does not exist and cannot formulate or describe design tools they do not have and for which they substitute experience, intuition, and naive or sophisticated mental models.

He notes that the IMS (intelligent manufacturing system) proposal is blocked by doubts about the efficacy of technology transfer. Apparently he feels that this is an illusion created by typical communication barriers between researchers and engineers, as described above. Foreigners are especially prone to think that Japanese engineers are holding back whereas the Japanese feel they are making rather full disclosure.

Problems like this lead to bad feelings and slow progress.

A Design Technology Transfer Example

To encourage this discussion, I brought up the case of IHI's shipbuilding methods. These were developed over about 15 years beginning in 1955 by Mr. Shinto, who became famous for them. They are a sophisticated extension of U.S. modular shipbuilding methods developed by H.J. Kaiser during the war. The extensions include

- adding statistical process control so that very large modules can be built accurately
- choosing module shapes skillfully so that most of a ship is made of simple modules
- training groups of workers to deal with the same type of module day after day

The method is an application of Group Technology, a technique that combines similar but not identical things into groups where they are treated as though they were identical. Except for this application to shipbuilding, Group Technology usually is applied to machining.

The entire approach used at IHI apparently grew almost organically in the minds of its originators. In the early 1970s the U.S. Navy hired a consultant, Mr. Louis Chirillo, to visit IHI, write down their method, and transfer it to U.S. shipyards to reduce the cost and construction time of Navy ships. This effort took him over 5 years and resulted in about 2 feet of shelf space of reports. These reports describe the method in full pedagogical form, complete with terminology, hierarchies of entities (Grand Block Modules, Modules, Submodules, Panels, Subpanels, etc.), kinds of production entities (simple flat panel in large quantity, panel curved in one direction in small quantity, etc.), and procedures for negotiating contracts, painting compartments, bending pipes, and so on.

Chirillo told me that he had to evoke all of this from the IHI people. In fact, they did not have or use any of this terminology. He just held a tape recorder up while they talked, then got a running translation, then interpreted it and wrote it up. After several iterations with IHI comments, the final reports emerged.

Ultimately, technology transfer to U.S. shipyards resulted from a combination of these reports plus on-site tutoring at the yards by IHI personnel for up to a year. If the reports had not been written, it is doubtful that technology transfer could have succeeded.

This story is interesting because it indicates the efforts which may be necessary in order to determine what designers and design managers do. They are not used to formalizing their activities and rarely have time to do so. An outsider can hardly find out by making superficial visits or talking in generalities. An alternative is to be or have been a designer oneself, but this is rare in academia.

Kinds of Design

It is customary to distinguish three kinds of design: original, variant, and routine. These roughly distinguish design of totally new things, redesign of existing things, and routine modifications of catalog items. Kimura also distinguishes products whose design method is understood and those whose method is not. He feels that basic automobiles and copiers, for example, are understood, whereas space stations are not. There is little to be learned from studying cars and copiers, he feels. One can observe a set process in operation but cannot witness the struggles that occur when something really new is being created.

If we acknowledge that designing a car or copier can be quite challenging, what is it that makes it so? Again roughly speaking, he is distinguishing innovation from complexity. Cars are merely complex, made so because they comprise a combination of very many but probably simple things. These things are well modeled in an engineering sense, he feels, so the real challenge is past. This is probably the reason why he does not feel that Fujimoto's work bears directly on the main challenges of design research. "It's just a social problem," says Kimura.

Yet if cars were a done deal, so to speak, then why are so many mistakes made designing them, why do they take a long time, what is it that some companies do that permits them to design cars faster and better, and is this question worth pursuing?

And, is Kimura seeking an unachievable goal in trying to capture innovation? Can one imitate the experience of a designer who "knows" that a particular structural material, when used in a certain way, plays, say, a vital electromagnetic role in the function of the product, desirable or undesirable, and that this effect or a chain of such effects must be considered when designing with that material? Can such knowledge ever be captured? Put another way, could Chirillo have written his reports in 1955, 1960, or 1965, while Shinto's work was still evolving?

Another way to pose the question is to ask if computers can ever be more than mere tools that help designers in routine ways. To go beyond the routine requires "knowing" a great deal about nature or capturing it in engineering and mathematical models. Engineers must be able to construct such models with the expectation that behavior they did not anticipate will be represented, and represented accurately. This might be called Data in, Genius out. (See the report on Prof. Tomiyama, who is attempting something like this.)

Finally, can such tools be generic, or will we have copier design systems, car design systems, and so on? Kimura worries that the latter will be the only result.

IBM TOKYO RESEARCH LABORATORY (TRL)

18 June 1991

Background

My hosts for this visit were Mr. Chihiro Sawada (Robotics Group) and Mr. Akira Okano (CIM Technology Group). Also attending were Mr. Masayuki Numao and Mr. Keisuke Inoue of the CIM group. These are young researchers who work for Mr. Hazeki and Dr. Koda, whom I did not see on this visit. This group has close ties to Todai, both because the campus is nearby and because all are graduates. Okano was a student of Prof. Inoue, Inoue was a student of Prof. Kimura, and Sawada was a student of Prof. Miura. IBM TRL is a member of Prof. Kimura's new Product Realization Project and one or more of these people attend monthly meetings of the industrial participants.

CIM to these people means more than computer integrated manufacturing, since the latter implies communication, networking, databases, and so on. This research group focusses on advanced CAD, robotics, automated assembly, feature-based design, and concurrent design. Their views are very advanced and their knowledge of the research literature and the status of commercial CAD is very good. Their opinions on fruitful research directions and approaches are very similar to my own, as discussed below.

The topics we discussed were

- the status of their recent research
- their plans for the next phase of research
- recent work in micromachines

Informally we discussed the status of young engineers, salaries, cost of homes, commuting distances, style of communication in Japan and at IBM Japan in particular (slightly Americanized, they said). [See IBM Fujisawa plant visit for more on this last point.]

Recent Research

For the past 2 or 3 years the CIM group has been developing a solid modeler for mechanical parts based on features and constraints, plus some assembly modeling and assembleability evaluation (Ref 8). I was shown this work when I visited a year ago. In the intervening year, there has been no additional progress because Okano, the leader, has been busy converting it for use by designers in the factory. He is aware that SDRC's recent I-DEAS solid modeler Release VI has both feature-definition capabilities and constraint modeling.

TRL's feature modeler is very similar to our own (Ref 9), capturing shapes of parts and form features and expressing disassembly directions of assembly features in a database that accompanies each feature. (No commercial modeler can do this.) Assembly sequences are determined by a method again very similar to our own, in which the computer determines all the easy assembly constraints (such as parts completely trapped by neighboring parts), and the designer supplies the rest of the constraints. In the TRL system, assemblies are defined by means of mathematical solution of constraints: the designer designs each part and tells the computer which surfaces mate to which; the computer solves for the relative positions of the parts. This is more complicated than our method, which permits the user to name or click on the mating features directly. Okano notes that he has incorporated into his software our method for visualizing networks of assembly sequences and the accompanying techniques for editing sets of possible sequences and eliminating undesirable ones (Ref 10). He has also added some assembleability evaluation capability.

The assembleability evaluation is fairly simple at this point. It seeks to determine when parts need extra fixtures during their assembly as well as how many screw or other nonsimple moves are required. An algorithm selects the "best" assembly sequence. There is no assembly cost analysis. The scoring system for evaluation bears some similarity to the Hitachi method, which they purchased. However, their papers and discussions omit any detail about the Hitachi method due to proprietary restrictions, so I cannot tell if their software actually implements any of it. I believe, however, that they are dissatisfied with the Hitachi method and this is why they have tried developing their own.

Example scoring in the TRL system is relative to full credit for downward simple insertion, with some points off for upward insertion, more off for horizontal, rotating, or diagonal, and still more if a separate fixture is needed to establish or maintain special relationships between parts during assembly.

Their software also has, or will soon have, an expert system shell and some rules for simple ease of assembly judgments, such as determining if holes and pegs have chamfers on them. Such facts about individual features are fairly easy to determine and can be deduced from simple table lookups if the form features have been described in the database properly. However, I do not know how they store their features.

CAD in general at IBM seems to be based on CADAM, a two-dimensional drafting system. About 70% of the designers use it; perhaps 30% use CATIA, a 3D solid modeler. Both of these are commercial products. CATIA is too hard to use, say the designers, who were trained in conventional drafting. The problem of difficult user interface to 3D modelers is widely discussed in Japan, not only at IBM, but no one has a really good solution.

According to Okano, shortcomings in CAD and in design evaluation methods have a common factor, namely that CAD, especially solid modeling, enforces the wrong kind of design methodology. One wants to begin with a complete rough layout that shows all the parts in approximate relative locations; then one wants to design each part in detail. CAD supports the second step but not the first. He feels this is one reason why products turn out to have too many parts: the designer begins designing single parts right away and does not see the whole product until too late.

Reducing the number of parts is a key assembleability evaluation technique. Several methods exist for judging if a design might have too many parts but no method exists for advising the designer on which parts should be eliminated. The same is true of any other evaluation, such as tolerances (see below). One can tell if a given assignment of tolerances permits assembly but no method exists for advising the designer on how to do the original assignment.

Research Priorities and Technology Transfer

Okano and his colleagues apparently have come to these conclusions more or less independently. I could not detect strong interactions with the factory or any attempt by upper management to encourage such contact. Management does not provide a research agenda and neither does the factory. The researchers do not actively generate research ideas by regular consultation with the factory, but instead use their own judgment and pursue their own goals. Transfer of the assembly modeling technology, like most of this laboratory's work, seems rather haphazard. Okano said that he merely gave a presentation on it to people at the factory one day and they expressed interest in having it developed for their use. Whatever pressure there is for increased producibility in designs apparently comes from the plant engineers, not from the product designers themselves. Moreover, any pressure for technology transfer at all seems to come from haphazard interactions or the whim of the researchers, who are judged each year by management on the basis of "good work," patents, publications, and technology transfer, apparently with about equal weight.

Yet no one else in IBM world-wide is studying advanced CAD, according to Okano. He was surprised to learn that CADAM, which is now owned by IBM, is planning a solid modeler. He told me that CADAM representatives were scheduled to visit him on 20 June, probably to review their work with the possible goal of including it in their next product release.

Sawada knew of Toyota's work in CAD, perhaps due to the group's contact with Prof. Kimura. He asked me if I knew about any plans Toyota was rumored to have regarding releasing their CAD as a product. [Toyota announced their intention to do so later that summer.] I tried to pursue this point by relating advanced CAD to the product realization process. I described Toyota's drive to reduce the time needed to design a car and the importance of their CAD to this effort. I also related Toyota's feeling that faster product development was important to the company's long term survival. This story drew no comment from them at all.

So, while the group understands that the goal of concurrent design is to improve and shorten the design cycle, they do not feel any pressure from the company to contribute to the goal, except if they feel like it. The current design cycle consists of performance-oriented designers doing their thing, followed by a "pre-analysis for manufacture" performed by the plant engineers. This analysis results in requests for design changes, which add a few months to the cycle. No one told me that this is a bad system or in dire need of improvement. Maybe if solid modelers were easier to use and CAD didn't take up so much of the designers' time, then they would have time to consider producibility. As it is, according to Okano, all their time is spent trying to meet performance goals, a typical situation.

New Research Directions

The group is currently in the process of developing its plans for future research. I had some difficulty determining any details. The emphasis will be on assembly. (They have no interest in machining, molding, or other fabrication processes.) A major theme is providing active advice to designers. This extends any existing work on evaluation or scoring of a design and hopes to provide particular suggestions for how redesign should proceed so as to improve assembleability, reduce part count, or improve tolerances. Another theme is improving CAD interfaces, most likely by extending feature-based design to include "analogical design." This term refers to reusable designs. Also, they want to explore the idea of "top-down design," meaning designing all of the parts of an assembly first in a rough way and then doing detailed design on each part. A fourth topic is sculptured surfaces. Finally, they are interested in helping designers evaluate tradeoffs that occur when product performance must be balanced against other factors, such as producibility. Peals of laughter greeted my question: "What do the designers do now?"

Reusable designs seem to have been given the most thought so far. Okano was quite clear in several of his points. First, current commercial CAD focuses on design of completely new parts. There is no library of previously designed parts, although he and others realize that feature libraries are a start in this direction. CAD also permits editing of existing parts, but his goal is to produce a design that is "similar" to one or more existing designs. Since designs involve many parts with interrelated constraints, a similar design might be one with slightly different constraints, or with some parts replaced by new ones while others remain the same. He referred to "experienced product data." By this he probably means data on parts that have stable process plans, assemblies whose tolerances have proven to be satisfactory, and so on.

I asked Okano if he saw analogies between feature-based design and object-oriented databases, or between analogic design and reusable software. To each he answered "yes" immediately. "I am currently reading papers on reusable code," he said. So his thinking is again very similar to our own. (He also said he was keenly aware of Prof. Inoue's new curriculum at Todai.)

It would seem that "top-down design" would be related to "analogic design" if one could come up with a high level description of a product that the designer then filled in with specific geometries and constraints.

Another problem on their agenda is tolerance analysis and synthesis. This is Inoue's project. He has been reading the literature but also has no concrete approach, or else he did not want to reveal it. The group has already rejected tolerance analysis via the worst case method and has opted for a statistical approach. This is the most common choice because the latter is tractable and the results are more economical in manufacturing.

One of the group's first steps was to buy and evaluate a commercial product called VSA, developed by a small U.S. company. This program can do statistical analyses of tolerances by using a Monte Carlo technique. IBM's evaluation is not complete but Okano said in his opinion it was a useful program for designers. However, it has two drawbacks. First, it deals with dimensional tolerances, such as ± specifications for distances, but does not deal with modern methods called geometric dimensioning and tolerancing (GD&T). The latter is supported by an international standard and attempts to provide ways to describe entire shapes or relations between surfaces, such as flatness, parallelism, concentricity, roundness, and so on, not merely individual distances.

A problem with GD&T, shared by all other methods, is that there does not exist at present a rigorous mathematical description of the various tolerance specifications. Several international standards committees are addressing this problem now but little progress has been made. The TRL people were unaware of this effort.

A shortcoming of VSA, according to Okano, is that it cannot really evaluate tolerances in assemblies. His reason is that VSA assumes surfaces are perfect and that the mating surfaces on two parts are in fact the same surface. He cites tolerance specifications on surface roughness as proof that mating surfaces will not be the same. For precision assemblies such as disk drives, such distinctions can be quite important. He briefly described a situation in which a plant engineer complained that one of his problems was due to insufficient specification of roughness tolerances leading to assemblies that were out of specification.

Regarding the larger issue of design tradeoffs, Mr. Numao suggested that sensitivity analyses might be useful. "Similar to simulations in operations research," he said. I brought up the Taguchi method and asked what they thought about it as a design aid. They did not have strong opinions, indicating that they did not think it was widely used or in demand at IBM.

We had some informal discussion of concurrent engineering (CE). Okano asked about CAD vendors' claims that their product supported CE because one could design a part and automatically have the computer generate numerical control machining instructions. This is what used to be called CAD/CAM (computer-aided design/computer-aided machining). He agreed with this assessment. They feel that CE is like groupware in software engineering, that is, many programmers working on the same program. However, they agreed with me that mechanical product design is much more complex. Okano suggested that levels of abstraction and modularity were common themes. This remark, like others, indicates that he is the thinker in the group, seeking to find analogies in far-flung fields.

Micromachines

Repeating last year's visit, they showed me videos of micromachines that the robotics group has been making. These are linear actuators driven by comb devices, which are electrostatic actuators with the stator and motor interleaved like two combs with their teeth pressed together. The comb teeth are typically 4 microns thick. Last October's version is like the original UC Berkeley devices, exploiting mechanical resonance to create motion in the form of vibration at the structural natural frequency (typically 5-7 kHz). No other motion frequency is possible with this design since the force generated by the actuator is too small and needs the amplification provided by resonance. The January 1991 version is able to move deliberately rather than under vibration. The reason is that the gap in the actuator is extremely small, perhaps less than 0.1 micron, permitting larger forces to be generated.

The new design has two interesting features. First, it assembles itself under the action of another actuator built in series with the operating one. The details were hard to see in the video. The assembly motion consists of delicately sliding the moving part of the comb into the stationary part. Once this is done, the moving part can proceed to move under external control. The other feature is an elastic suspension that greatly improves rotational stiffness over earlier designs. This improvement was necessary since the small operating gap in this design would easily jam if a very slight rotation occurred during actuation.

Last year Hazeki expressed the hope that these actuators would find application in disk drives, perhaps for adjusting heads. However, I was told this year that no applications have been identified.

Final Observations

This group clearly is technically very competent and has a coherent vision about improved CAD, but it does not have much evident drive from within or spur from without to really apply their work to improving IBM's productivity. This is in sharp contrast to both Hitachi and Toyota, where the drive is right on the surface.

SONY

1 July 1991

Background

This visit was arranged by Lynda Strupp, a U.S.-born member of Sony FA (flexible automation) marketing staff. She is bilingual and helps with U.S. marketing. Sony people present were Mr. Yoshihiro Tsukamura, Deputy General Manager, FA Group; Mr. Yunosuke Hayakawa, General Manager, Planning Division FA; Mr. Tohru Fujimori, General Manager, Robotics Products FA; Mr. Hiroyuki Segawa, Engineer; and Mr. Junichi Kuzusako, Assistant Manager, CAD/CAM, Product Technology Group. Tsukamura is the most senior person among these, quite experienced in design methods, although he joined FA only a year ago.

Ms. Strupp has communicated with me before and stressed that Sony is very protective of its CAD and design methods, as well as of its manufacturing methods for the most advanced and competitive products, such as Handicams. The purpose of this visit was for Sony to determine if there was enough for them to learn from me that they should open up. Apparently this was a successful visit because they decided to host me for further meetings with Mr. Fujimori and Mr. Kuzusako (see the followup report).

Business of the FA Group

The FA Group makes and sells robots and assembly automation equipment, including circuit board assembly machines, both inside and outside Sony. In both markets it competes with other vendors. There are now several hundred Sony robots inside Sony (the number is not clear, or they did not want to quote a precise number, so perhaps it is as few as 150 or as many as 450), mostly at the Koda plant where VCRs and Handicams are made. In the United States they have had a hard time selling robots or complete systems. This has been true for as long as the FA division has existed, which is about 6 years. Their best U.S. customer bought 24 robots in a complete "turn-key" system about 2 years ago and recently bought about 40 more. This customer will make all the tooling and do all the programming and system integration for the new 40 itself, a major achievement.

The FA Group's promotional video attempts to leverage FA products off of Sony's own high tech products. The challenge is to make smaller and lighter products with better performance. This requires production technology that only Sony can deliver, etc. Examples given are assembly robots, surface mount circuit board assembly machines, wire bonders, semiconductor manufacturing equipment, and so on.

Ms. Strupp says that Sony's biggest competitors are Seiko and ADEPT. Both have better programming systems, which attracts customers. This annoys Sony since the best controller is often not needed. ("Only Motorola wants the best of everything.") Sony often has better accuracy or payload and has much more experience with product redesign for robot assembly and system integration. They want more of this kind of business but can't get it, often because they are short of people. This is in contrast to most robot makers who are also system integrators, since it is usually more profitable to sell naked robots than to do the engineering necessary to tailor a system to a customer's product.

Sony will even sell robots and systems to direct competitors such as Hitachi. I asked if this might result in the transfer of Sony's product design for assembly know-how and was told that Sony sells only naked robots to such customers since they already know how to design the tools and do the programming and system integration. In this sense, Hitachi or other Japanese customers are typical, and European companies also commonly have such capabilities. U.S. companies normally do not, and this fact makes the above-mentioned customer's capability especially unusual.

The Sony people were surprised to learn that Nippondenso has 2,600 robots (as of 1990) of which they made 90% in-house. Nippondenso does not bother to try selling robots outside and does not buy many either, since they get better service from their own engineers and in any case domestic robot manufacturers are saturated with orders and cannot deliver fast enough.

Sony Product Design Practices

Sony regards itself as especially skilled in mechanical design, less so in electronics and software. This is important because mechanical design practices and the usefulness of new CAD tools were the focus of the visit. It is Sony's impression that they do not need help in mechanical CAD but do in electronics. Yet when I showed them our feature-based design software video they asked immediately whether it would be available commercially and when.

According to Fujimori, Sony's mechanical designers consider assembly right during design, including assigning tolerances and considering assembly sequence. In fact, sequence is determined first and then tolerances are decided, which is the correct method. "Good designers consider both the sequence and the type of equipment that will be used. They start doing this right from the beginning of design, when there are no parts and you must imagine the final assembly." (See the followup report where this statement was made clearer.)

When I asked if redesign was needed for robot assembly, I was told yes. This seemed paradoxical in view of the earlier statement. When pressed for examples, they cited the need to add chamfers around holes if the tolerances could not be tightened. This is an especially trivial change to make and indeed to include in the original design. Thus the discussion did not seem productive and I could not get a better definition of the situation, except for the remark that not every designer has the skills of the best one. I also could not get them to agree that software to help calculate tolerance stackups would be useful.

The latter comment recurs in many of my visits: the hosts are proud of the CAD and CAE software they have and know how useful it is. But they often see no need to have anything better even when they agree that doing some design task manually is either tedious or is even skipped due to its difficulty.

Hayakawa noted that in 1986 top management launched a campaign called "innovate 86" whose aim was (and still is) to improve product design, industrial engineering, and automation. When we note that a company the size of Sony has only a few hundred robots, it is evident that a lot of assembly is still being done manually. Since several of the items being assembled by robots (VCR mechanisms, Handicams, etc.) are very complex and demanding, it is not a lack of robot technology that accounts for this fact. It may well be a sheer lack of robot system design engineers, a fact cited in other areas and other companies repeatedly. Or it could be that many products are assembled in low labor cost countries.

Products are designed by teams of engineers, typically 20 to a team. The product design cycle comprises four prototypes called Research, Function, Manufacturing, and Preproduction. These appear on about 4- to 6-month centers. Cost and manufacturability are considered after the functional prototype achieves the required performance. Manufacturing engineers and FA engineers join the design project at that point. A new product will take 2 years to pass through this cycle, whereas a modification of an existing product can be accomplished in 1 year by a team of five engineers. Projects are run by an engineer with 10 years of experience. He may run more than one project at a time but not usually. Previous designs are scrutinized carefully to determine applicable tolerances and assembly methods.

An example given was the optical pickup for a compact disc (CD) player, where tolerances are in the microns. Several people from different disciplines join a discussion about how to best achieve the specifications. Sometimes an adjustment method is used rather than aim for a perfect result in the first place. At various points in the design process there are design reviews, a typical practice in many industries. At Sony it is common for engineers from other projects to attend and make suggestions for improvement or warn of possible problems with the current design.

Uses for Computers in Design

Sony buys most of its CAD software. The commonly used packages are CATIA and CADAM, both supported by IBM. Sony also has an in-house freeform surface program called FRESDAM that creates very realistic views of the exterior of a camera, say, using a Silicon Graphics terminal. Recently they acquired a robot motion simulation program from a U.S. company, Silma. However, the database of part designs and tolerances, plus information about robot tolerances, does not exist so full advantage of this software cannot be had. "Japan is weak in robot simulation software."

They do not have any solid modeling software. Instead they model exterior surfaces in FRESDAM with Bezier's formulation. No analysis can be performed in this software. In a few cases, the surfaces are transferred to SDRC's solid modeler, from which a plastic mold flow analysis is often done. FRESDAM has recently been linked with a stereolithography system.

What do they want in the future? Kuzusako says that feature-based design (FBD) sounds like a good idea but solid modelers are too hard for designers to interface with right now. (Many hosts said this.) Kuzusako also said that FBD would be the most help if it were connected to information databases such as for materials properties and costs. Designers should be able to create their own features. This would be useful for robot programming as well as for design.

Currently they have no organized system for keeping track of previous designs in software or of reusing them. Kuzusako felt (unless he misunderstood the question) that it is more important for all the designers of the current product to be able to access a common database about information technology (IT). This is logical if one realizes that many Sony products are quite different from their previous versions, due to extreme size reductions or performance changes.

What about the need for or usefulness of software to calculate tolerances or make fabrication and assembly cost analyses? Kuzusako allows that this might be useful but he has no plans to start in this direction, only a hope. He has no experience in this area.

Tsukamura, the senior man and most experienced, said that his top priority, based on inputs from the designers, would be for software that accomplishes or aids end-to-end design of circuit boards and their manufacturing processes. Such software exists commercially, I said. Sony has a mix of homegrown and bought, and they are not satisfied with it. His judgment was based in part on the valid observation that the opportunity for using computers is greatest where design is the most routine or uses (or reuses) the most standardized shapes. This characterizes electronics design, not mechanical design.

HITACHI SAWA WORKS AND TAGA WORKS

3 July 1991

Mr. Takahashi accompanied me to Hitachi's Sawa and Taga Works. Sawa makes automotive components, and Taga makes a variety of consumer products.

Background of Sawa Works

At Sawa, our host was Mr. Sato, responsible for improving Sawa's CAD and CAE capability. He came there 5 years ago from Hitachi's Mechanical Engineering Laboratory, a more research-oriented facility. At that time, CAD at Sawa was little more than computerized drafting of ordinary machine drawings. He has had something of a hard sell and has written at least one of the new engineering applications himself, a program that does vibration analyses on rigid assemblies. It works by linking models of individual shapes such as bars and plates, for which individual vibration models have been worked out. The assemblies are joined observing the boundary conditions, so a valid model results. Uses include studying the effect of vibration on solder joints between circuit elements and circuit boards. This is a fairly sophisticated approach and indicates that Sato is a good analyst who has the horsepower, if not the manpower, to change how Sawa operates.

Sawa's business comprises electrical and fuel components such as alternators, generators, engine controllers, pressure and flow sensors, microcomputer controlled carburetors, turbochargers, distributors, brake system controls, fuel delivery systems (injectors and manifolds), air conditioning systems, and so on. The plant has annual sales of ¥200B as of 1986 ($1.5B), 2,700 employees, and 100,000 m^2 of space. Major customers are Nissan, Fuji, Mazda, Suzuki, Honda, Ford, Chrysler, and Audi. Competitors include DELCO and the powerful Nippondenso.

Their introductory video heavily emphasized reliability, testing, reliability, design, reliability, and so on. Apparently this video is shown to prospective customers. It showed many robots and automated machines, including a line in a clean room for making injectors, a robot assembly line for alternators, and typical automatic production of circuit boards.

Another video of CAE showed use of supercomputers to evaluate flow out of injectors into fuel manifolds, including studies of the effect of fuel particle size (100 microns is too big) as well as supercomputer simulation of air flow from air conditioner vents into the car. Also shown was a simulation of use of active suppression of air conditioner noise using extra loudspeakers. A last supercomputer application was a dynamic analysis of stresses on a Nissan engine ring gear caused by meshing of Hitachi's starter pinion. Sato stressed the importance of being able to access Nissan's CAD data in order to do this analysis.

So this factory makes heavily engineered products to exacting specifications under strong price and quality competition from other vendors in a world-wide market. They are still in the process of building a strong CAD/CAM/CAE capability under Sato's direction. An important subissue is computer data communication between Hitachi and its suppliers. (See a later report on Nissan's attitude and methods for communicating with its suppliers.)

Product Development Methodology

Sawa has some luxury in being able to work to the development pace of car companies. This gives Sawa much more than that available to the Image and Media Systems Laboratory people developing video cameras. Also, it is typical that 20 engineers might work on one item such as an alternator. Since alternators are far less complex than video cameras and change much less from model to model, this means that Sawa has effectively lots more engineers per project.

When I remarked to Takahashi later that Sawa should send some engineers to I&MSL, he said that although no exchanges have occurred between Sawa and Yokohama, people from the slow life often cannot adjust to the pell-mell environment of designing fast-paced consumer products. Slow cycle automotive people are used to extreme reliability requirements, to which they respond with lots of analysis, many experiments, many prototypes, and heavy reuse of prior designs.

More importantly, the 4-year pace has given Sato the chance to think ahead about his future needs for CAD/CAM/CAE.

The product development process consists of a series of prototypes and accompanying analyses developed in response to a specification from a customer. The process was illustrated with their current effort on a new small alternator for Nissan. The original request for proposal (RFQ) came in 1989 for an anticipated car launch in the 1995 model year (fall 1994). The specification included target power, size, weight, and cost. The specification was negotiated and probably adjusted in monthly meetings for a year while Hitachi did lots of computer studies based on varying existing factors and technologies. Later this year Sawa must deliver primary samples which Nissan will road and lab test for performance, reliability, and noise. Responses from other vendors will be tested during this period, and a decision will be made a year from now. If it wins a contract, Hitachi will then have over 2 years to develop final designs and process plans, design and facilitize the factory, and start up production. During this time, Nissan will finalize its engine design, perhaps altering the mounting conditions for the alternator and requiring additional noise and vibration studies.

Use of Computers in the Design Process

The engineering analyses supported by Hitachi software presently include:

- FEM to study vibration of cast housings and circuit boards
- magnetic field analyses of rotor, stator, gap, materials, windings, etc.
- a spreadsheet for quickly doing the basic electrical calculations such as power-speed-voltage tradeoff curves (an example of what Sato calls a "handy program") - a nice color graphics interface and graphic output, including documentation of all the engineer's calculations, like an engineer's notebook
- sensitivity analysis software to determine the effect of varying certain parameters in the hope of obtaining a less sensitive design or of finding a way to improve performance by changing parameters
- rotor dynamics to predict bending and vibration
- various commercial FEM programs, two mold flow programs, Hitachi's in-house CADAS CAD software, and occasional use of the assemble-ability evaluation software from Hitachi PERL

On a tour of the CAD laboratory I saw several displays of simulation outputs plus demos of several of the above capabilities. Others were

- fuel particle flow in several vendors' designs of manifolds
- analysis of impact of injector valve on valve seat
- starter motor magnetic flux
- airflow over a hot wire anemometer
- sensitivity and modal analysis of alternator end casting vibration (display on workstation of mainframe calculations done earlier)
- parametric creation of new "designs" for alternators by combining menu choices of 18 parameter values (3 shaft diameters, 5 lengths, 3 outer shell diameters, and so on)

In the last program, the designer chooses the parameter values, and the computer creates a consistent set of drawings, except where the combination chosen could not be resolved by the computer. Such areas are left blank and the designer draws them in using typical 2D CAD methods. In this way, routine products can be put out very quickly, as long as they do not challenge the state of the art and require real design engineering. Such programs have been written for alternators, starters, and distributors. They are not linked to any of the CAE software so they are good only for deploying existing proven designs. Thus it is really a documentation management program rather than a design program, but it hints at what might be done in the future. In particular, it contains no artificial intelligence (AI), no feature-based representations, and no constraint-based descriptions. Application of these methods would permit substantial design variations to be accommodated without leaving blanks.

With the exception of a few Silicon Graphics and HP9000 workstations, these demos ran on Hitachi workstations or PCs and often utilized output from three Hitachi mainframes elsewhere in the building. UNIX appears to be the operating system (OS) of choice.

Much of the effort to computerize design is driven by the need to make all components smaller and lighter, with the ultimate aim being the car-maker's need to meet the 1995 CAFE standards. To make things lighter, one chooses lighter (often relatively weaker) materials and thinner sections. These, in turn, are subject to vibration which, in turn, causes noise or, worse, structural failure. Low noise is a major Japanese automotive design goal and competitive feature, so the goals of low weight and low noise naturally conflict. Identifying and resolving design conflicts is a major challenge for both designers and researchers. Here the response is to build up over the years an extensive analytical capability and drive it night and day to gradually improve and refine the designs. Trial and error on the computer seems to be the main modus operandi.

An interesting point is that a bench test is different from a test in a car, since benches are rigid compared to cars, which have resonant vibration frequencies of their own. Thus the software has been written to simulate either environment so that test data can be compared with computer predictions. One of their test setups is a GENRAD vibration stand, analyzer, and display linked to the computer.

Sato categorized his emerging software tool set as follows:

Design Stage	Tool or Type of Tool
Conceptual	Commercial CAE tools (visualization)
Product	Routine design work, small changes to existing designs, commercial CAD tools
Production	FEM tools for designing press processes
Testing	GENRAD vibration system and other lab analysis and experimental support software

Concerning what he would like to see in the future, he will provide what the designers ask for. On his own wish list are

Design Stage	Tools Desired
Conceptual	Easier communication of files and data between Hitachi and both its customers & suppliers: includes geometry models & CAD data, plus test data, analysis results, etc.
Product	Sensitivity analyses, parameter manipulation, expert system for effect of tolerances on performance & reliability. Structural optimization for both shape and dimensions.
Production	Better assembly analysis tools? No clear wish here.
Testing	No clear wish here.

Visit to Taga Works

In the afternoon we travelled to the Taga Works. There the host was Dr. Murakami, who came to Taga from PERL several years ago with the same mission as Sato has at Sawa.

Background of Taga Works

The Taga Works makes a wide variety of consumer products (50% by yen sales) such as washers, vacuums, and fans; office equipment (30%) like word processors, laptops, and laser printers; and industrial labor saving devices (20%) such as electric motors, hoists, and factory ink-jet printers. Their introductory video tied this assemblage together by the fact that all (laptops, too?) contain electric motors. The plant covers 400,000 m^2, has [only!] 2,500 employees, and turns over $960M per year.

Product Development Illustrated with Fuzzy Control Washer

A recent washing machine was used as the example product for illustrating use of CAD/CAM in design. This is a "fuzzy controlled" machine with one button: START. Using sensors, it determines the amount of clothes, the average weight of material in the clothes, and the degree of completion of washing. It adjusts the wash, rinse, or spin time to suit. It has been on the market for about a year and costs ¥119,000, or $881 at ¥136/$. (A Big Mac is ¥380, or $2.80, and a good electric iron--without any fuzzy control aspirations--can cost anywhere from ¥9,000 to ¥28,000, or $66 to $207.)

This washer took 3 years to develop, involving 10 to 15 engineers at a time, including all the test and inspection teams. Three prototypes were made during this period. The most difficult design challenges were the motor controller and the shape of the agitator. At least 15 agitator shapes were thought up and tried, being machined out of solid blocks of acrylonitrile butadiene styrene (ABS).

The marketing objective was to produce a user-friendly smart appliance having the ability to run and diagnose itself. It has a timer like microwave ovens and coffee makers so it can be set to run at night when everyone is asleep and be ready in the morning for drying to be done. Since Japanese apartments and houses are very small, it is likely that someone sleeps near the washer, so it must be very quiet. It also must be small and light, so all the parts must be light.

All the noisy solenoid valves have been replaced by quiet motor-driven ones, a quiet balancing system was designed, and gear noise was removed by reversing the motor to create the agitation. They do not know if this will cause motor failures in future years. This must be the reason why motor controller design was difficult. No special materials or sound deadening paints were used. No software for predicting noise was used either. However, like Japanese cars, this washer aims at the trend toward quieter and friendlier products, and much of the CAE used was directed at achieving these goals.

Clothes quantity and weight are measured by filling the tub with a known amount of water and spinning up, then letting the motor coast and measuring the decay time. This is done twice with different water levels to determine quantity and weight separately. A conductivity sensor measures soap concentration and dirt quantity in the water. Wash and rinse times and their water amounts are adjusted accordingly.

While they call this fuzzy control, I think it is in fact a set of lookup tables. Most fuzzy logic applications I am aware of use linear interpolation between preset responses for full set membership to generate a graded response for partial set membership. [For example, "if clothes are heavy weight, use full water level" and "if clothes are medium weight, use half water level" would generate three-quarter water level for clothes that measure halfway between heavy and medium.] So while fuzzy control is a great marketing idea and the machine is truly useful, the technology development is in the sensing and in converting sensory readings into good estimates of clothes weight, not in design of the controller itself.

Final assembly of this washer is entirely manual, but motors and other drive train parts like clutches are built up by robots. The cabinet and tub are made from sheet metal cut and bent automatically. Controls, lid, and agitator are injection molded plastic. Since both outer cabinets and drive trains are redesigned infrequently, automation can be applied to their fabrication and assembly. But control surfaces and lids change as fast as twice per year. This causes a strain on Taga's design talent. Marketing creates the pressure. Takahashi agrees that these redesigns are superficial but he adds that a shortage of engineers keeps Taga from undertaking the deeper redesigns that they would like to pursue.

Use of CAD/CAM/CAE

Only recently has CAD/CAM/CAE come to Taga. In this sense, the Image and Media Systems Laboratory is well ahead of Sawa which is, in turn, well ahead of Taga. They have had Hitachi's CADAS for several years but only recently got Moldflow for plastic molding analysis and ADAMS for kinematic analysis, both linked to SDRC's I-DEAS solid modeler. Their first attempt recently to transfer CAD data to the machine shop did not work very well. The factory's software development center set all this up for them.

[Prof. Kimura told me later that Hitachi has a System or Software Development Laboratory that is responsible for finding and trying CAD products and getting the factories to use them.]

So the fast response to the market has been accomplished "by our sweat and tears." Right now it is faster to redesign by hand than to create a solid model and run Moldflow. Usually only small changes occur so their experienced designers know what to do to design a new mold. Presumably a feature-based approach would speed things up, since many of the plastic parts consist of regular flat surfaces with rims around the edges and bosses underneath to take screws. Expressing this in terms of features would not be difficult.

They do not have any software to analyze water flow patterns created by different agitator designs. Energy transfer to the clothes is more important than water flow in this kind of machine anyway, but still there is no software.

The CAE Laboratory contains numerous Hitachi workstations operating under UNIX. There are also several Silicon Graphics terminals. In the laboratory they showed me use of Moldflow plus a verification part that agreed fairly well with the simulation. Another demo concerned using ADAMS to predict how the tub would sway for particular unbalance loads. This information can be used to size the clearance between the tub and the outer housing. The FEM program ADINA is used to test the strength of a crimped joint in the tank, based on loads caused by unbalance. Another use for ADAMS is to predict how a vacuum cleaner will track when pulled by the hose, based on various caster designs and locations.

The CAD office also contains Hitachi workstations and UNIX. Drafting is the main activity. Some computers are linked directly to the factory floor or to the purchasing department, to which drawings are sent defining the specifications for in-house and purchased parts. "Engineers have a lot of power over purchasing decisions." Altogether they have many workstations and have invested a lot in computers and LANs.

Another interesting program is a parametric design system for hoists. When an order is received, the engineer types in the specifications, such as capacity, lifting speed, and so on. The computer searches the database of past designs and finds the one(s) whose individual specifications match exactly or come the closest. Some items in the specification may be missing completely so they are left blank. The designer then retrieves the useful drawings and makes the missing ones. Mr. Sagawa, representative of the software service department, said it took them a year to write this program. It has been in operation for 6 months.

This is a version of what GE calls "purchase order engineering." It is called variant design in the academic world. GE told me that 85% of their engineers do this kind of work and it has been largely automated on workstations. I saw a more sophisticated version at Cooper Industries where high capacity industrial air compressors are made. The compressor vanes are the most complex to design, so existing designs are used to the extent possible. A similar database exists with 10,000 prior designs in it, and the three nearest are found by least squares optimization of the parameter matches.

Discussion

At this and several other plants I have visited, there are a few female engineers and "draftsmen." In view of the rising shortage of engineers that every company is feeling, this trend toward women engineers is expected to increase.

It appears that the shortage is causing many problems. A major one is that companies can no longer make the design changes they want to, or cannot put them into effect as fast as they would like. Yet rapidity of model changes is the main competitive weapon between Japanese companies and is the biggest advantage they feel they have over international competitors. This must mean that every Japanese company has the same problems, but Hitachi feels that some of its competitors, certainly Sony, can do things faster. They feel that Sony may have some "secret weapons" such as better management methods or better computer tools. They are frankly puzzled and worried.

It is interesting to compare this reaction to Sony's, which is that the engineers just work hard and marshall their experience effectively. At Nissan I was told the same thing. Nissan especially disavows the importance of computer aids in relation to management and work methods, ascribing the "Japanese advantage" to precisely the points made by Prof. Fujimoto.

While it is true that engineers at most companies I visited work hard and stay late, I think it is disingenuous to say that computer aids have had little effect. As far as I can tell, every company I have visited has bought the best and latest U.S. hardware and software and applied it intensively. Rates of penetration differ, and some companies use their own hardware (Hitachi) or software (Nissan), but the trend is the same. Still, CAD/CAM/CAE cannot do enough of the job to relieve the pressure on the engineers. They are now so tired out that some companies are openly discussing slowing down the pace of new designs (see Hitachi Construction Machine Co. report).

DISCUSSIONS WITH PROF. KIMURA AT HIS CAD RESEARCH LABORATORY ABOUT PRODUCT REALIZATION, IMS, AND PRODUCT DEVELOPMENT CYCLES

5 and 19 July 1991

Background

The general topic of research in the laboratory is product realization via computer. The work is currently sponsored by the Japan Society of Precision Engineers, of which Prof. Kimura is a prominent member. Similar research has been going on for at least 5 years under the original leadership of Prof. Sata (now retired) and Prof. Yoshikawa, now Vice President of Todai. Kimura said that he expects a new large government grant starting this fall.

Sata and Yoshikawa apparently are responsible for the highest level view of this topic. It has matured from long-standing research by them and Kimura on numerical control (NC) machining of complex surfaces into the notion of CAD systems that contain engineering knowledge, capture the designer's intent, and connect design and manufacturing. Its most recent manifestation is in Yoshikawa's proposal for internationally supported research on intelligent manufacturing systems (IMS).

Note: On the second visit I was accompanied by two researchers from Hitachi Production Engineering Research Laboratory.

New Approach to Manufacturing

"Manufacturing" often connotes fabrication of single parts, typically by metal cutting. Interpreting IMS in this way seriously misses the point. Taking the more general view that "manufacturing" means fabrication, assembly, test, and logistics activities in factories also seriously misses the point. It is important to realize that the idea of IMS extends well beyond "manufacturing" all the way back to conceptual design.

Therefore, IMS is the same as "product realization," which encompasses all of the processes, intellectual and physical, that are undertaken as an idea for a product is hatched, refined, turned into design data, analyzed and simulated, cost-analyzed, turned into process plans and instructions, the parts made, assembled, tested, and shipped, the factory designed and operated, customer responses factored into the next design, and so on.

Kimura's career illustrates the process by which these ideas have grown and matured. His background is in 3D modeling of complex shapes such as car bodies and creation of computer software for representing these shapes. He was involved in several MITI projects that created GEOMAP I in the late 1970s and GEOMAP II in the early 1980s. This software was taken up by Toyota and used in their car design

CAD software. Kimura consults regularly for Toyota.

Such software ultimately must represent two distinct but mutually indispensable components: (1) the mathematics of the surfaces themselves, so that they can be displayed realistically and manipulated into the desired shape; and (2) the physical processes by which metal will be pressed and stamped into those shapes, so that the designer can find out if the shape is possible to make and how much it will cost. A complete design system must therefore contain a great deal of manufacturing process knowledge. Developing this knowledge has been a 20-year effort for most automobile companies but is only being integrated into design software in the last 5 years or so at the most advanced companies. On the other hand, software to represent the shapes mathematically has existed in various forms and levels of sophistication since the 1950s.

The above pattern (namely, that computer-aided design software is incomplete without manufacturing/assembly/test process knowledge) is at the heart of a new wave of research and commercial progress in CAD. It is redefining the meaning of CAD, once embodying only making mechanical drawings of single parts, into someday representing all the knowledge needed to design, analyze, make, and even sell entire products.

State of the Art in Different Design Domains

The use of computers in design has grown rapidly in the last 30 years, but the most complete representation of product and process design methodologies is in the domain of microelectronics. Here, the products are so complex that they are impossible to design without pervasive use of computers. A typical microprocessor design looks like the map of a city's streets. Recent designs contain as much information as the entire New York metropolitan area including much of western Connecticut and northern New Jersey. Because microelectronic designs consist of layers of 2D information, mostly in the form of circles and straight lines, they are easy to represent mathematically. Similarly, all the manufacturing tooling consists of photographic replicas of exactly this information. Thus the conversion of the design into manufacturing equipment is relatively straightforward in the sense that no further complex mathematical processing is required to convert the design data.

By contrast, the shapes of car bodies cannot be made by making the press die the same shape as the mathematical model because of the mechanical properties of the sheet metal (springback) and the behavior of the metal-die interface during stamping. Accurate models for these factors are difficult to create. Bridging this design-process gap is the essential obstacle in car body design-manufacturing. The trial and error involved here is responsible for much of the time needed to design cars, and thus better prediction and less error are of extreme competitive value as well as being an extreme intellectual challenge.

The conversion of microelectronic designs into working manufacturing processes is not straightforward either, but the obstacles are in keeping the processes free of contamination and in learning how to make the patterns of lines and circles smaller and smaller. The limits of the manufacturing processes create "design rules" that must be followed, but these are relatively simple to state and to check for during design. This is not to say that making microelectronic products is easy but rather that representing the designs in the computer in ways that translate directly into manufacturing instructions is relatively straightforward.

In addition, the geometric layout of a microcircuit determines its electrical behavior, so it is relatively straightforward to obtain a computer simulation of the behavior during design.

On the other hand, drawings and mathematical shape representations of mechanical items contain no clue at all as to how they will operate and little about how they should be made, except when their shapes are simple circles, cylinders, and so on. On the contrary, most mechanical drawings and CAD versions of them are merely symbolic notation that refers to both physical things (circles that refer to circular holes) and nonphysical things (arrows pointing to extensions of surfaces that represent measurements between those surfaces). Drawings thus represent a well-developed language that people know how to interpret. Many statements in this language are inferred and do not appear directly on the drawing.

Another difference is that in electronics most of the parts are standardized. In larger parts, the externals are designed almost exclusively for handling. In smaller items like microcircuit elements, the shape completely determines the performance, but these shapes are simple and are also standardized. The behavior of each item has been well modeled and the behavior of both single elements and large systems of them can be predicted with excellent accuracy.

By contrast, the shape of mechanical items must be tailored specifically for each item to the tasks it must perform. Rarely does a part do one thing. Most items do several, such as provide strength, electrical or heat conduction, and geometric arrangement. All of these functions can be difficult to model and predict accurately even when performed in isolation. Little modeling capability exists for sets of mechanical items operating together as a system except if many simplifying assumptions are made.

Thus the essential elements of a complete design-manufacturing system are in many ways much easier to establish for microelectronic items than for mechanical items.

Research Activities at Todai

Kimura has two bright assistants, Prof. Suzuki and Prof. Inue. In other laboratories there are additional faculty with similar aims. Kimura and his assistants have 12 graduate students, 8 undergraduates, and 13 visiting researchers from industry. Their research breaks down into three main categories: geometric modeling, product modeling, and design/manufacturing. Their participation in the IMS is in such areas as concurrent engineering, virtual manufacturing (meaning wide use of simulation of product and processes), design by customers, information transparency (meaning good user interfaces) and self-organizing and distributed systems.

Kimura also divides up the topics into objects, processes, and environments. All three are essential, he says. In this sense, he reflects his machining and NC background. "There is nothing without understanding of the basic processes," he says, and I agree. Yet right now their research tools consist entirely of workstations, due to lack of space, funds, and a process-oriented colleague to replace Sata.

Geometric Modeling. The laboratory has a long history of studying geometric modeling. Recently they have been overtaken by developments in commercial software and by the fact that students do not like software thesis topics. So he is using commercial solid modelers as the basis for additional work. This work is heavily related to constraint-based modeling and design. A typical project is on use of constraints to determine the size or shape of an item based on a statement of its performance requirements. Feature-based design is another related topic.

A typical project involves allowing the designer to call forth standardized elements such as shaft ends and their mating bearings, which together form a functional feature made of several geometric features. These functional features can be given specific dimensions, or some larger requirement such as a torque or side load can be given by the designer and the computer will resize the parts. The example shown was hardwired (i.e., preprogrammed in LISP) by the student. There is no graphic design interface.

Another project is design of sheet metal parts based on partial input of geometric constraints. These include locations of holes, portions of the part's outline, and areas the part should avoid. The computer draws the rest of the outline. This project is similar to others where the spirit is to permit partial information to be used effectively.

Another series of projects deals with tolerances. These include use of solid modeling methods to predict all the possible mating arrangements of parts with deformed mating features, such as machine tool ways or peg-hole mates. These methods are enumerative rather than statistical so they are threatened with combinatoric explosion.

Another series of projects involves specification of geometric constraints. The portion that accepts 2D constraints has probably been overtaken by commercial modelers such as SDRC's I-DEAS Level 6. Three-dimensional constraints are much harder to deal with and include lining up features on different parts in order to describe constraints in an assembly.

Product Modeling. Several of the above projects could fall into product modeling, since the line is rightfully indistinct. The goal in product modeling, however, is to work top-down from specifications toward assemblies and finally to parts, with the computer progressively doing more and more of the routine work. Kimura wants to capture what he calls "product structure," something he distinguishes from assembly structure or machining structure, which have their own geometric features.

Product structure is about function and its relation to technological knowledge: kinematics, dynamics, dimensions, and tolerances. In one form of this idea, a product model is realized as a set of objects (in the database sense) together with object models of the tools that make them. To these models must be linked models of the processes (machining, assembly, test) that will make the parts and the product. He agrees that "this is a quite difficult topic."

Clearly, AI has deeply penetrated this laboratory. One can see it in the magazines the group subscribes to. They cover robotics, graphics, CAD, AI, graph theory, UNIX, and a wide variety of nonmechanical engineering topics.

He is also interested in modeling the design process. He does not approach this directly by observing the behavior of designers but rather by observing the work they do. He was inspired by how Toyota did this. It is very pragmatic and seeks to identify what takes the designer's time that could be computed readily, or what tools the designer uses (colors, multiple views of solid examples) that the computer could reproduce. Right now he has identified "routine design" as an approachable topic. An example is the feature-constraint-driven model of shafts and bearings mentioned above.

He notes that such models are easy to construct so as to obey physical laws. The same is not true of more innovative design. This is not a linear process dominated by well-trod paths and procedures. Here he suggests that the computer models not be bothered by physical reality, as indeed perhaps the designer's thoughts are not either. When something useful emerges, the designer can impose reality. The likelihood of the computer's suggestions being real is enhanced if they are built up from verified elements.

Thus his model is that the designer can manipulate such elements in what he calls a "virtual factory" that contains models of machining, molding, and assembly processes. These models may be approximate but that would be good enough for preliminary design.

Aside on Model Accuracy

The idea that a rough model with imprecise or incomplete data should be sought for early design is consistent with Toyota and Nissan being willing to launch downstream design tasks when only partial information is available. Body styling data accurate within 1 mm are available months before the last mm is pinned down. Yet nearly all of the design of dies can be done within 1 mm and finalized at the end. None of the stamping simulations is likely to be affected by a 1-mm change.

Thus a major component of research in support of early design should focus on determining just what information is of real value in launching any given step in the design and the level of accuracy at which this information must be provided. Such a study will likely reveal that much of the demanded perfection of data is not needed right away and that a preoccupation with perfection and finality is a time waster in many design processes. It also may be a time waster in many searches for good computer models of products and processes.

He cited Toyota's method of evolving design tools: make a simple tool that helps a specific design step; observe how the designers use it and get their suggestions for improving and broadening it to cover more of the steps. This way the tools grow organically and no useless tool is pursued or imposed on the designers. It is an example of a larger difference identified to me last year by Mr. Hazeki of IBM Tokyo Research Laboratory: Americans jump too quickly into system software (equivalently are too top-down oriented) without thinking the process through first, whereas Japanese are too slow and spend too much time figuring out their processes and perfecting them manually before daring to put in any software (too bottom-up oriented).

I am also reminded of the difference in approach between Toyota and GM regarding die design software. Toyota has a series of elementary analyses that the designer can ask the computer to perform on a die shape. These are quite approximate but can avoid every known disaster. The totality of the programs is an end-to-end system for turning designs into finished dies. GM critiques this system (privately to me and to others) as not having any real engineering analyses or accurate simulations of the metal deformation process. GM has delayed implementing a similar system pending completion of accurate models, a step Toyota gave up on immediately as requiring too much computer power. Thus Toyota can be said to value integration over accuracy, while GM favors accuracy over integration. Toyota appears to be ahead, although Kimura jokes that CAD-designed cars seem to look alike.

Design and Manufacturing Problems. In this area, there is little work so far. It covers concurrent engineering, parametric design of routine objects, machining simulation, design for machining, assembly process planning, and standardization of CIM data. The group is active in STEP and other standards activities.

The Relative Importance of CAD/CAM/CAE and Management in Product Development Strategies

As a researcher in CAD/CAM/CAE, Kimura feels that these topics are central to any successful product development strategy. Thus it was interesting to hear this topic discussed by him and two researchers from Hitachi, Mr. Ohashi and Dr. Taniguchi. Both have advanced degrees from U.S. universities and are active in PERL developing software to aid manufacturing engineering, assembly evaluation, and concurrent engineering.

The Hitachi people reflect the opinion of the Nissan people, namely, that "90% of problems in product design methods can be solved by management, and only 10% can be solved by computer tools and computerized knowledge bases." They base this opinion on observing their company designing really new products for which there are no established procedures or tools. Especially important is the lack of corresponding manufacturing processes. Experiments, communication, redesign, and feedback are the essential elements, and the success of these is mostly influenced by management.

The main problem in complex design is that different groups or tasks have conflicting goals and there is no standard way to work these out. The team design method brings the issues out sooner but that only causes embarrassment. Hitachi's big point of pride is the "user first" slogan, which supposedly focusses the team on the customer and makes them forget their internal conflicts. What solution to conflict X will benefit the user the most? The fact that design tools could explore many possible answers faster is not appreciated. The reason may be that it does not seem to be a real option. It is just a promise by researchers.

In this context, what is concurrent engineering? Is it any different from simultaneous engineering? Are they just the team design method with computer support? Isn't concurrent engineering just something that Japanese companies have done for a long time?

Discussion on these points reveals little consensus except that all is not rosy inside Japanese companies. Some people refer to "big business syndrome" in which top managers want to interfere and decisions take too long to make. Ohashi cites a recent *Business Week* article on concurrent engineering as a clever way to convince managers that communication is really important.

Kimura feels that computers cannot by themselves shorten the design cycle although they can improve quality and help improve the technological level of products. But shortening the cycle is almost exclusively a management factor. Thus concurrent engineering can help shorten the cycle.

The Hitachi people feel that concurrent engineering could help improve quality because they see the current push to shorten the cycle as threatening quality. There is too little time to do the necessary analyses and tests. Thus providing knowledge bases, integrating design and test data, and improving information flow are all ways that concurrent engineering could help the design process move faster.

Now that the United States seems to be catching on to the big secret of communication and team design, will Japan have to invent something better? They secretly worry about this but have no answer. It is the big debate inside Hitachi right now.

Closing Comments

Kimura's view of design research is both impressively broad and very pragmatic. His topics seem to be aimed directly at the main needs of mechanical design: higher levels of modeling that include symbolic components such as constraints, maintaining the link between design and manufacturing processes, and striving to support design in fuzzy situations like early design where answers are needed but data are limited.

The IMS idea was born in this environment and thus it has a very sophisticated intellectual base. Kimura surprised me by asking me a "very general question:" How can the IMS project achieve its main goal, which is for Japan to relieve many international trade problems by giving its advanced manufacturing technology to the United States and Europe? Why are there so many political problems over IMS? Surrounding this question are his wonderment that the United States can develop advanced ideas like CAD and concurrent engineering with computers and still not spread them around adequately.

In one sense Kimura answered the question himself but I also offered an answer. The United States is behind Japan in its sophistication regarding manufacturing. It is not clear if we could adequately absorb Japanese technology if it were "given" to us. Thus I said that successful international projects must have well-defined technology transfer mechanisms built into them. Such mechanisms must include long-term hands-on contact with the technology and cannot be confined to delivering reports or presenting papers. Such conditions should apply to any kind of "manufacturing" technology, including management techniques, computer software, robots, sensors, and so on.

NISSAN TECHNICAL CENTER (NTC)

8 July 1991

Background

Our hosts were Mr. Jun-ichi Kobayashi (Product Development Section, planning Nissan's future CAD capabilities), Mr. Yoshida (in CAE user support), Mr. Katoh (Yoshida's boss), and Mr. Ono (Production Engineering CAE). Kobayashi was the most informative and interesting of these. He has been with Nissan since 1974 and spent 10 years in Manufacturing Engineering before coming to NTC to work on CAD/CAM/CAE.

Background of Nissan and the Nissan Technical Center (NTC)

Nissan is Japan's second largest car company, behind Toyota, and fourth in the world. In the last several years there has been considerable progress upgrading CAE and an effort is underway to link styling, design, engineering, and test data into one system world wide. Kobayashi acknowledges that this will be difficult for two main reasons: software incompatibility and people incompatibility. So far they have linked design and engineering offices in Japan, the United States, the United Kingdom, and Spain and can share data and software because (luckily, says Kobayashi) all these offices had IBM or IBM-compatible mainframes already when the integration effort began.

The Nissan Technical Center is in a beautiful location and comprises many modern buildings. "Amenities are becoming more and more important." The main design/engineering building, where we visited, is new since April and has an open, airy, atrium design. There are no offices, only wide open spaces with many large tables where meetings can be held. All the engineering disciplines for car design and prototype production are housed in this building except the engine people, who will move in next year. Thus, colocation has been adopted as a design efficiency strategy.

All of Nissan's car design in Japan is centered at NTC or at the Central Laboratory in Yokosuka, where fundamental studies are carried out in materials, power trains, electronics, and vehicle technology (body, chassis, user interface). In the styling and design area (perhaps half of all vehicle design and engineering?) the engineers are working on several vehicle design projects at any one time. I estimate that 100 to 200 stylists and designers are at work on one car project (plus probably another 200 doing more detailed engineering).

Unless I misunderstand badly, this is a remarkably small number of engineers for the number of cars they design. Uncounted in this total are manufacturing engineers at NTC and at the factories.

Product Development Process

I estimate that the typical new car development process takes about 4 years. Styling and design occur during the first 1.5 years or so. "The rest is trial, error, and design changes." In the first prototype, new components are often tested by attaching them to existing cars. Later prototypes use completely new equipment. Die design in particular takes about 1 year, but changes keep coming in during the last year before production starts. During the first 1.5 years or so, or whenever prototypes are being built at NTC, the factory people make frequent visits to NTC. As prototype work shifts to the factories, the NTC people travel there. CAD data do not travel well to the factories (see below).

Design begins while styling is still in progress. This is typical of overlapped jobs in Nissan and other Japanese car companies. At some point during styling, the exterior shape is frozen and this master data package is then passed on to downstream activities. Interior styling continues to be worked on after the exterior is frozen.

Apparently all Japanese companies feel pressure to reduce the design cycle but there is no specific program at Nissan to do so. "We already design cars in 4 years, compared to 6 in the U.S. and 8 in Europe. If we shortened any more, we would just get a lot of negative reactions from overseas. So we will use the ability to design faster in other ways." I was not told what ways, but obviously two are to reduce the time pressure on their engineers (who often stay until 9 or 10 p.m.) and to do more analyses on each design.

The main reason why Japanese car companies can design faster is the "fuzzy design method." This means being willing/able to start a design task before all the "required" information is in fact in hand. There is less structure in this method and, yes, changes must be made later. But no one gets blamed for these changes and in any case they come amid a stream of other changes anyway, so the important thing is to be able to respond quickly to changes. The CAD system contains no explicit change management system, according to Kobayashi.

Note that this explanation agrees to the letter with that of Prof. Fujimoto (see the Fujimoto visit report.) Even though Kobayashi is responsible for planning Nissan's future CAD needs, he refused to ascribe much importance to the use of CAD/CAM/CAE in speeding up the design process. In view of later examples (crash test simulations, search for assembly problems before the first prototype, etc.), this claim is disingenuous. But I did not try too hard to fight it.

[Via a separate communication, I obtained the following opinions from Prof. Hiroshi Sakurai of Colorado State University, a graduate of Tokyo University and former employee of Nissan. The main reasons why Nissan can design a car in 4 years are: (1) average 2,700 working hours per year for engineers versus 1,800 per year in the United States (Toyota people work even longer); (2) overlapping of jobs, for example, Nissan's body engineering begins when only rough exterior data are available whereas U.S. designers wait for smoothed data even though the difference is often less than 1 mm (Fujimoto cited precisely the same example!); (3) outsourcing of many components to small companies who work their engineers even harder and pay them even less. He notes that even in 1980 Nissan could take a car from exterior freeze to volume production in 2 years even though they had only a few CAD terminals. But he admits that CAD/CAM/CAE may have kept the lead time from becoming even longer and the number of engineers from growing. I note that cars are very much more complex now than in 1980.]

It is worth noting, when considering (see below) that Nissan has distributed its design software worldwide to its overseas design offices, that exporting the fuzzy design method has been a failure so far. Real problems thus remain.

Product Development Methods and Use of Computers

Nissan's CAD/CAM/CAE consists of many computers, programs, and databases. Nissan is in the midst of trying to merge all these into one seamless process but it is a hard job. What they have is like "islands of automation" in the factory world.

Nissan is in the process of converting from styling using clay models to direct styling on the computer. In the old clay model method, stylists carve quarter and full scale models and paint them to look quite real. These models are digitized and computer data created. In the new method, stylists draw shaded sketches which "technicians" (high school graduates) put into the styling computer to create boundary patch models whose shape resembles that indicated by the shading in the sketches. These models can be shaded and rendered very realistically, including showing light reflecting off the surface. The stylists sit with the technicians and adjust the shapes of the surfaces. Apparently the technicians make a very strong contribution to this process and are not mere data input drones. They must have both artistic and computer skills as well as the ability to make the stylists confident and comfortable in the presence of the computer. At some point in this process, the model is used to drive a large gantry NC machine which carves out a clay model which is then painted and judged as in the old method.

When the stylists are satisfied, the data become the master data for the car's exterior and are never changed thereafter.

Interior styling is apparently done in a similar way.

The boundary model data are passed, perhaps with some pain, to the design and engineering computer system. This system is separate and builds a new database starting from the master exterior data. Most of the work is done in 3D wireframe form using Nissan's proprietary CADII system (see history below). This system is good for the designers, who can put in as much detail as they want without swamping the data storage and manipulation capabilities of the software. No solid modeler can hold the detail and manipulate the data efficiently, they say. However, the wireframe models are useless when communicating with the factory people or the tooling designers. So there are problems.

The master data or the design version of them are also passed to supercomputers for various analyses (see laboratory tour below). Converting data for use by these programs takes a long time, another problem that adds time, effort, or number of people required.

CADII data are also used by industrial engineers for doing manufacturability and assembleability analyses. The assembly path of a part (we saw a windshield washer tank) can be visualized as the engineer moves a view of it around the screen using knobs. He can see interferences, view from several angles, try different paths, and so on. There is no analytical support for this. He can also attach images of tools to the heads of screws or nuts to evaluate access for tools. These issues are of the most importance in designing the engine compartment, which is the most crowded area. The success of this process depends entirely on the experience of the engineer.

While there is no analytical support for assembly analysis, there are criteria. For example, a torque wrench must have 60° swing room. Less requires redesign or an OK from the factory. Nissan tried using Hitachi's assembleability evaluation method (AEM) but concluded that it is intended for small parts assembly of large production rate items for consumers. Neither Nissan nor Hitachi can do real design-performance-manufacturability trade-offs, they say. Cost should be the criterion but no one has a method.

(Ten years ago, engine compartment design problems were found by making Xerox copies of drawings of parts and sliding them around on a table, or by making transparencies of parts and doing the same.)

In this way, hundreds of assembly problems are found before any metal is cut, comprising the majority of all such problems. There isn't enough detail in the CAD models to permit the rest to be found. Many of these involve flexible items like pipes and wires. It is typical that thousands of design changes to improve assembleability will be made after prototypes are built.

There is some indication that Nissan is beginning to adopt modular assembly, similar to what shipbuilders did 20 years ago. Examples given were entire dashboards built up in advance and then inserted into the car with a robot. This is, in fact, not new, since (1) you can't install efficiently things in a dashboard once it is in the car and (2) GM and VW have used robots to put in dashboards for several years. However, the module approach has a bright future, although it may require some redesign of the vehicle's structure. Sticking one part after another into the engine compartment is getting harder and harder to do. However, more success at getting around this problem with modules will mean that maintenance and repair will become harder and harder! The modules are likely to be big and heavy and require special tools and hoists to remove later.

In any event, if Nissan continues along this track, it has the CAD tools in hand to do the necessary studies in advance of building prototypes, an essential ingredient. However, the long term effort may not be directed at effecting robot assembly. Data in a handout show that Nissan ramped up from 540 robots in 1980 to 2,000 in 1985 but has only 2,462 in 1990, indicating real saturation at this level. "In 1980 we thought robots would replace people. We know now that it won't be that easy. Yet the goal is still 100% automatic final assembly."

Stamping dies and plastic injection molds for body and interior parts can be designed in about a year. All the important exterior dies are made in-house. They are just beginning to use new nonlinear deformation software recently developed at the machine tool division. Up to now many problems had to be solved during die tryout. "Dedicated technicians are a big Japanese advantage," said Kobayashi. Stamping plant people visit NTC often during early styling design because (see above) the master data are frozen early. While some of this visiting may be done by passing CAD files around the network, most of it is done face to face.

A big problem, other than die design errors, is die design changes forced by other design changes. These cause a stream of changes throughout the final year before launch. Thus the environment of change Kobayashi referred to above makes the use of overlapped jobs less of a strain than might be supposed.

The use of CAD data to find problems and do designs prior to making any prototypes obviously saves time and money. However, it appears that this process is most successful during the three prototypes that NTC builds. When the plants start getting involved in prototypes, the use of CAD data wanes because (1) the prototypes are much more compelling, (2) they are easier for people who did not do the original design to see and understand, and (3) those CAD tools and data are NTC's, not the factory's. This is a typical problem of "ownership!" The only data easily shared by all are the exterior shell descriptions.

Tour of CAE Facility

CAE facilities are used to do exterior styling and many complex analyses, plus actual design engineering. The facilities comprise two Cray supercomputers, two IBM 3090s, two Unisys 2200s plus several more large mainframes for supporting 3D CAD drawings, solid modeling for casting and forging design, and routine data management. The Yokosuka engine design facility has its own Unisys 2200 for designing castings and forgings using solid models. The IBM and Unisys computers support 1,400 graphics terminals. Many of these terminals use SDRC's I-DEAS package. The mainframes also support I-DEAS in IBM's form (CAEDS) but all agree that performance is poor and workstation implementations are better. In addition, there are over 3,000 PCs of various types, including 1,000 Macs. The penetration ratio for PCs is about 0.5 (one PC for two engineers). The computers at NTC are networked worldwide with similar computers in the United Kingdom, the United States, Spain, and Australia. The same software is supported at all sites.

Several demonstrations of CAE were given:

- Very realistic rendering of car exterior shape, including reflection of light off the body. This is a surfaced wireframe model. It becomes the master for all later design.

- Stereo display of the car's interior, showing dashboard, seats, and shift handle. This was not too detailed. Using special glasses, one could get a pretty good stereo impression.

- Complex multicolor 3D wireframe rendition of the engine compartment. This picture occupies about 20 to 30 MB. They anticipate needing 40 or more MB. Yoshida claimed that commercial CAD packages cannot manipulate this much data. I argued this point with Kobayashi later, giving examples from shipbuilding that I was familiar with. But he countered that they discuss this problem with SDRC, who is a joint venture partner with them, and SDRC agrees.

- View out the front of the car from the driver's viewpoint. This view was not constructed from the master data file but from elsewhere, maybe from scratch. In the future all these programs will be linked with common data.

- Crash test simulation. This was a replay of Cray output. The software for this is called PAMCRASH, purchased in France and modified by Nissan.

- Aerodynamics simulation. This is also Cray data being replayed. They can analyze wind drag but not noise. This was a surprise to me. I have seen a paper presented that described Nissan efforts to calculate noise generated between the engine compartment and the ground. This simulation shown to us on this visit explicitly represented airflow under the car, however.

- Plastic flow simulation in an injection mold. This is a typical commercial software capability.

I asked if noise from engines and transmissions can be analyzed by computer and was told yes.

Other CAE applications include a few attempts to use expert systems to help designers with routine but troublesome problems, or to help junior engineers design things that only senior engineers could before. One case is design of trunk, brake, and axle systems.

Another nonartificial intelligence application is use of 3D modeling to study how to package parts in pallets and shipping containers and to see how to use last year's jigs and fixtures for this year's parts.

Considerable effort has been made to export this design software system to Nissan's suppliers. Nissan and IBM have a joint venture that supports the software and sells it. A low cost workstation version is also for sale to small suppliers. At many suppliers there are now hundreds of terminals running CADII on both host type computers and engineering workstations. Kobayashi said that Toyota and Unisys have a similar joint venture for selling Toyota's CAD to its suppliers. Problems arise trying to sell to a large supplier like Hitachi, which has its own CAD software and hardware, and to overseas suppliers who have different data standards. U.S. suppliers have a data format standard, for example, that forced Yoshida to write a data translator.

History and Goals of Nissan's CAD Efforts

CAD tool development and user support, including support of business data systems, is provided by 220 people in the R&D Systems Department. In 1985 it had only 70 people.

CAD at Nissan has three main goals and several historical threads:

1. Data processing, especially test data

2. Design specification control and parts data trees

3. Efficiency of engineering

4. Higher quality

5. Simultaneous engineering

6. Better communication

Historically these have been pursued in the above order, starting in 1960 with data processing and 1965 for specifications and parts trees. CADI, Nissan's first 3D CAD system, was installed in 1965 and used for making line drawings of body panels. It was extended into CADII, a surface modeler, by 1974 and used from that time to generate NC data for die making. While CADII was originally just used as a drawing tool, it has now become a CAD/CAM tool with many applications described above.

By 1980 parts data trees, die designs, and test data were starting to be merged into one computer system. By 1985, three programs had emerged, one for test data, one for parts lists, and one for CAD data. There is still no common database for all of this, but that is their goal for the 1990s. In common with this is the push into concurrent engineering, which to them means doing more jobs simultaneously, including manufacturability analyses during early design, before any prototypes are built. Another goal is "production CAE," meaning computer engineering aids for production engineers.

The final goal is to put this common database and set of programs out on the network for all their worldwide offices to use. This was begun in the late 1980s and continues today. They say that when production CAE can proceed in parallel with car design, they will have achieved Simultaneous Engineering.

The main improvements they seek are global information sharing (design release and CAD data), global engineering system sharing (software, not just data), and global business information sharing (now done by fax). They apparently have had some trouble justifying some of this effort because they were at pains to contrast their work with typical business computer applications. First, CAD data volumes are 100 times larger. Second, there are many applications and engineers don't read manuals, so good user interfaces are needed. Third, technology and software are always evolving and constant renewal is needed. These descriptions do not apply to business applications.

Future CAD/CAE Needs

When I asked about this, there was laughter. Their answers were a strange mix of the mundane and the far out.

They want everyone to be linked on one network so they can easily send data to each other. This is merely a matter of buying it. However, they want any new program they buy to be instantly compatible in operating system and data format. This is not so easy. In general, Ono of Production Engineering would like tools that provide end-to-end analysis of production problems and design/cost estimates of production and assembly steps. This requires a long term effort at unifying software and databases, plus integrating engineering analysis and test data.

Another desire is to "standardize" design processes. This was a bit hard to interpret. Apparently they mean that they need a way to overcome the working style differences mentioned above. A suggestion is to make design tasks more orderly or procedural so everyone will know what to do and know what the other person is doing. It also means studying each design task, such as locating the washer tank in the engine compartment, and deciding in advance what the main issues and tradeoffs are so that they can be addressed systematically and in the same style each time the problem is faced, regardless of who is doing it and what country it is being done in. (At Hewlett-Packard they call this ensuring that the result is "a Hewlett-Packard product" adhering to the company's standards and capable of being made in any of its plants.)

Katoh emphasized that you can't predict much in the car industry, in spite of the many years and many models under their belts. So much depends on experience and they mine this lode by keeping teams small and lines of communication open. Yet this practice cannot be continued forever, he says. Ways must be found to leverage this experience. Expert systems are not the answer. They are too limited in the kind of input they permit and the forms of knowledge they can store. What is needed is some easy way to put knowledge in and an easy way to get it out.

For example, existing design for assembly methods require too much information and too much detail about the parts before an analysis can begin. How can it be done at the concept phase when only the performance goals are available??

How indeed?

Summary

Nissan is an important example in any study of use of computers in engineering design because, like other large Japanese companies, Nissan does not depend totally on the software vendor community to provide it with software that the community thinks is useful. Instead Nissan has great control over the "technology transfer process" that creates CAD software. Thus its priorities are worth noting in detail.

1. Continue the process of maturing the use of computers. This began as mere data processing in 1960 and has now become CAE. It is in the process of becoming CIE (computer integrated engineering), which means wide area sharing of software and design/test/manufacturing data files. In the next decade it will become CIM (computer integrated manufacturing), meaning direct links between marketing, design, manufacturing, and sales around the world.

2. Increase the ability to capture the experience of people who are currently not well supported by computers so that this expertise can be used by less experienced engineers. Much study of the design process is needed to identify efficient ways of performing many of the tasks, identifying tradeoffs early, getting quantitative models of them, and getting answers when there are still merely preliminary designs available.

3. Increase computer support for manufacturing and industrial engineering activities in order to optimize manufacturing operations and avoid discovering design mistakes after prototypes are built.

4. Find a way, if possible, to use computers to help spread the Japanese method of design to designers in other countries. The "fuzzy" method of job overlapping has resisted exportation so far.

HITACHI CONSTRUCTION MACHINERY CO.

11 July 1991

Background

Mrs. Whitney and I visited Hitachi Construction Machinery (HCM) Co. and had a short visit at the nearby Hitachi Mechanical Engineering Research Laboratory (MERL). Our host was Dr. Kozo Ono, whose main research activity for several years has been multi-axis force-torque sensors and robots that use such sensors for grinding and deburring. He collaborates with Prof. Hatamura of Todai and funds research there on similar topics. Ono recently became General Manager of the Technical Research Laboratory. This was my second visit there.

This company is part of the Hitachi group but is an independent company. A strong point of the Hitachi group, says Ono, is that the member companies have close communication with Hitachi's research and development laboratories. They conduct joint research, and member companies receive research results which they convert into products. They also follow the parent company's lead in CAD/CAM, as I learned during this visit. MERL is part of Hitachi proper rather than a group affiliate.

The construction machine business is mature but not in the trouble it was a few years ago when I last visited. Yet HCM has been diversifying for at least 5 years into such far-flung areas as nondestructive testing equipment for the electronics industry, YAG laser products, force-controlled robots, piezo-actuators for "nano-robots," and so on. Their main product lines include excavators and cranes, tunneling machines, digital-analog controllers for same, and several lines of small excavators that they make under the John Deere label.

The company has an image problem, namely, that it makes old-fashioned equipment. This hurts them in hiring new graduates and, apparently, in selling their main line of equipment. This latter impression can be gleaned from their introductory video, shown to the two of us alone on a super wide screen in an ultramodern 300-seat auditorium. It was called "Crossings," meaning technology combinations to create imaginative new products. The exclusively commercial (nonmilitary) use of these products, such as for environmental projects, was emphasized. The video showed extensive use of welding robots, lasers, ultrasonic testing of welds, computer simulation of crane performance, use of flexible manufacturing systems to make parts, and generally "adoption of new technology as soon as it becomes available." The video claimed that CAD and CAM are linked directly, but this is not so, according to Ono and based on answers to my questions.

Products and Design Methods

The company's main plant covers 430,000 m^2 and a subassembly plant nearby covers 186,000 m^2. Production capacity in excavators is 1,700/month. These are mainly tracked vehicles of medium size including front hoes, back hoes, and clamshell excavators. No large draglines are made as far as I know. A typical excavator has about 2,000 to 3,000 parts, but bought items like engines (mostly from Isuzu) count as one part.

There are about 400 designers, of whom about 150 work on excavators. Approximately 40% of the designers are university graduates. About 10 to 15 products are under design or redesign at any one time. They agree that this is a very heavy workload for a small group of designers. Of the 400 total, about 300 have access to CAD, but the penetration is about 1:2.9 with the objective being 1:2.3 by this time next year, at which point they will be "finished" facilitizing for CAD. The approximately 125 CAD terminals include 27 Apollo workstations with the DDM 3D modeler. The first four Apollo terminals were bought in 1986. More recently they have bought 109 seats comprising Sun 3s and a few SPARCs with "Advance CAD," a 2D CAD product of the CTC Company of Japan. CTC wrote a translator to convert DDM data. All of these workstations are on one or more LANs and there is a link through exactly one of these workstations to a Hitachi mainframe.

The product redesign cycle is about 4 years. However, everyone in the industry is exhausted by this pace and a "consensus" seems to be emerging that the cycle should be stretched. This "feeling" has emerged from informal discussions (at conferences and trade shows?) that designers and managers have with their counterparts at their main competitors Komatsu and Mitsubishi Heavy Industries.

Use of Computers in Design and Manufacturing

HCM is relatively new to CAD and has surprisingly little CAM. When I visited 4 years ago I was impressed by the robot gas metal arc welding of the main structures of cranes and excavators. The robots use simple sensors to find the weld gaps, which are beautifully flame cut and polished. In this way, an enormous amount of production welding is done almost unmanned. However, the parts are cut out by hand-programmed flame cutters and the robots are similarly hand-programmed. Since the parts in question are made of simple planar sections, it is surprising that there is no link between the simple 2D CAD and the CAM of cutter and robot programming. Mr. Moroshita, the director of CAD/CAM, said that until they install a data management system (a commercial item) there will be no such links. For this reason, the entire visit focussed on CAE, that is, analyses of mechanical performance of entire cranes or large subassemblies.

Visit to Hitachi MERL CAE Laboratory

This laboratory has 40 programmers who work mostly in FORTRAN and C. Their "products" are mostly analysis programs for determining various performance factors about cranes and excavators. Some products are developed for sale outside the company. We saw:

- Geometric modeling, based on converting a 2D drawing to a 3D wireframe model
- Automatic mesh generation for FEM studies (written at the request of Hitachi's Software Laboratory and intended to be sold commercially)
- A variety of kinematics, noise, flow, heat, vibration, and similar analysis programs. Since most of these could have been purchased, I asked why they were developed in-house instead. Two answers emerged: some were developed for special purposes not available commercially, while others were developed for sale.

Visit to HCM's CAE Laboratory

First we were shown a scrapbook of hard copy examples. This consisted almost entirely of output from SDRC's I-DEAS package versions 3.1 through 4, dated 1987-91. One example used ProEngineer Level 5. These consisted of pretty shaded images, analyses using IDEAS + ADAMS, several FEM studies of stresses in welded shovel buckets during digging, and so on. One interesting study was of the dynamics induced on the excavator and its tracks while swinging the arm rapidly. Another showed the excavator driving over a bump and experiencing oscillations in the arm and its hydraulics. Yet another showed what shape a bent hose would take depending on the internal pressure. I was also shown a demo of the robot simulation program Cim Station. The robot was "welding" a complex item.

Future Needs and Trends

HCM is clearly just starting down the road to CAD/CAE/CAM. I believe that this reflects the company's old-line background. On the other hand, in only a few years they have explored many meaningful areas in product performance analysis and will probably continue to do so.

In other respects, HCM is typical of the nonautomotive companies visited: they use the best U.S. workstations and software, and their engineers work until late in the evening. Much of the software is what the parent company of the group uses, but HCM's workstations are U.S. made, not Hitachi's own.

Other Comments

Ono's English is very good and he is quite open, so some other topics of interest came up.

(1) Is it true that Japanese university engineering education is very broad but not very deep? I have been told that the reorganization of Todai's Mechanical Engineering Department looks like an upheaval, but in fact it just adds new electives while eliminating old ones, there being no required core.

His answer is that engineering education is indeed broad and shallow, but it exposes students to a lot of different technologies and leaves them malleable. When they enter a company, their initial training shapes them as the company wishes. Some standard training is given every new hire but in later years the manager decides what specific training each employee should get.

[I happened to read an article in a private circulation newsletter called *Japan Design Today*, covering graphic arts and product styling, that described Sony's training program for new designers (stylists to us). This is apparently a bit like boot camp in the sense that group bonding is a major aim of the 1-year course. The teachers are practicing designers who take time off from ongoing responsibilities that they must make up later in the evening. Design in this context includes carefully choosing exterior materials, colors, textures, "handfeel," "button-feel," and so on. The young designers are taught the "correct" view angle from which to draw a video camera. A student who chose his own view angle found that his model camera had been confiscated overnight and replaced by a Polaroid shot taken from the correct angle. In this way, Sony molds its new hires.]

Ono told of his company's difficulty hiring electronics and software engineers. To remedy this, they took the best of the mechanical engineers who showed up and promptly retrained them in electronics and software. In the United States, such an act would cause the student to regret his university education and its typical commitment to a discipline. Apparently this does not happen in Japan. U.S. companies rankle at having to supplement the education of their new hires; Japanese companies take advantage of the opportunity.

(2) Since I am told that the Japanese language is not very precise or quantitative, how come Japanese people are so good at science and engineering?

His answer is that most of the time Japanese people do not notice any disadvantage stemming from their language or methods of thinking. However, communication can sometimes be slow. Most Japanese sentences have no subject, and verbs do not distinguish number or gender. Also, he recalls translating one of his papers into English and discovering in the process that one of his Japanese sentences made no logical sense. He had been unaware of this when he first wrote it. He also added that logic is not the only component of practicing engineering. There is also "informal communication, group work, and a different way of thinking than the so-called logical way."

ISHIKAWAJIMA-HARIMA HEAVY INDUSTRIES (IHI), AERO-ENGINES DIVISION, TANASHI PLANT

16 July 1991

Background

My hosts were Mr. Nakajima (now at the Mizuho plant) and Mr. Ochiai. Both are managers of production engineering departments at their respective plants.

IHI's main business is shipbuilding and heavy construction. Aircraft engines are a small part. The aircraft engine division has 3,600 employees and sales of over $1 billion. IHI built Japan's first jet engine during the war, making the first test flight in a small fighter plane in early August 1945. Since then IHI has designed only three engines on its own (plus many research and development engines), relying mostly on manufacturing licenses from General Electric, Rolls-Royce, and Pratt & Whitney for most of its production. Products include aircraft engines, stationary gas turbines for generating electricity, gas turbines for ships, and rocket engines for space. Including several wholly owned subsidiaries, IHI can produce all of the main advanced technologies required for such products, including intricate investment castings and single crystal or directed grain castings of turbine blades, numerical controlled (NC) machining, flexible manufacturing system (FMS) operation, laser welding and cutting, and some composite materials for nose cones that are transparent to infrared rays. They are especially proud of their ability to laser weld titanium. IHI is also a prominent participant in Japan's proposed Space Station module.

The shop is well equipped with modern equipment, mostly of Japanese manufacture, including several Toshiba five-axis NC machines of the type sold to Russia, some Huffman laser drilling machines, and the most modern Messer Griesheim e-beam welders. The FMS for aluminum parts comprises five Mitsui-Seki machines that run 24 h/day in a temperature-controlled room.

Software in Use

I was shown two examples of computer use, a shop floor scheduling system they wrote themselves and CATIA for CAD.

Shop Floor Scheduler. The shop grinds surfaces and dovetails of turbine blades and has about 100 workstations. There are at least 100 kinds of blades and about 300 blades in each batch. The shop handles more than 300 lots per month according to Mr. Shibata, who demonstrated the software. It takes about 4 months to process a lot. Each blade apparently requires dozens of work steps. We noted that some of the jobs currently in the shop are 50 to 75 days late and scheduled to stay that late or get even later. The usual response in such situations is to send some work outside, but IHI hopes the scheduler will permit them to improve efficiency and keep the work in-house.

The scheduling system was installed in April 1991 and they are still improving it, assessing how well it works and learning how to use it. A major feature is its excellent user interface, permitting the shop supervisor to view data about jobs pending or in progress from several viewpoints: by job, by batch, by job step, by machine, and so on. Clicking the mouse on a job reveals a window containing the details of the process. Thus the progress of the job or the scheduled job sequence planned for each machine can be viewed easily.

The objective of the software is to decide which machine should do which task step on which batch next. Different batches are waiting for machines, and different machines, capable of doing only some of the pending tasks, are waiting for work to be assigned to them, while other machines are still busy. The task of the software is "resource selection and task assignment," a familiar task in management science algorithms. Typical criteria are to minimize the lateness of the jobs and/or to minimize the idle time of the machines. Occasionally a special high priority job must be wedged in.

The software was written using a commercial expert system shell to which IHI added its own rules. A clear explanation of how it worked was not available, but apparently it runs a number of simulations to verify its predictions. It first assigns jobs without regard to capacity limitations of the machines. Then it tries to shift work from overloaded machines to underloaded ones. Finally, it identifies jobs that cannot be assigned and puts them in a group to be assigned to outside contractors. This appears to be an imitation of how the human schedulers run the shop and does not utilize any of several algorithms in the scientific literature that could potentially solve this problem better.

CAD and CAE. Design is almost 100% paperless in the engine department. CATIA is used for 3D modeling, and CADAM and microCADAM are used for drafting. The usual CAE functions, such as mass and inertia properties, are done with CATIA. CATIA is also used for making nice pictures to show top management and customers. Piping design and interference analyses between pipes and engine structures are done in CATIA. Data are transferred to SDRC's solid modeler for thermal and stress analysis. CATIA is also used for preparing NC programs. However, the data created by engineer-designers are not sufficient for NC programming and must be augmented. But modifications are difficult because CATIA NC output is not as easy to edit as APT, which has a simple line-by-line format. Also, I was told that CATIA's surface modeling capability is limited since surfaces tend to come out with low amplitude, low frequency waves.

Facilities consist of a Fujitsu supercomputer and a mainframe for supporting aerodynamics, structural and stress analyses, plus an IBM 3090 and 50 graphics terminals running CATIA and 100 PCs running microCADAM.

Today's applications for CAE are structural analysis and weight and moment analysis. Future applications are interface between engine and airframe, assembly procedures and instruction manuals, and a link to CAM.

Medium term they are rethinking the information flow in the design process, hoping to shorten the path. At the moment, parts such as blades are designed in 3D and then 2D drawings are made. In the shop, these drawings must be reconstituted into 3D data so that a workplan (NC programs) can be made.

Longer term they are hoping to create optimization methods for designing blades, disks, and shafts. (GE already does such things either routinely or in their design R&D laboratory.)

They wish 3D modeling could support dimensioning and tolerancing and have kept to 2D drawings because of their ability to represent such information. None of my hosts are aware in detail of the extensive CAD/CAE/CAM developed in the auto industry, although they have seen some things demonstrated at trade shows. They are afraid of in-house software development since they think it would be hard to maintain and improve the programs.

In addition, in spite of many years of cooperation between IHI and GE, the IHI people were unaware of the Defense Advanced Research Projects Agency Initiative in Concurrent Engineering (DARPA/DICE) project. GE is a major participant in this project and design of turbine blades is an important demonstration of DICE capabilities.

Product Design Methodologies and Long Term Developments

Even though use of computers in the design process at IHI is a bit behind the state of the art, Nakajima is a careful thinker concerning organization of design processes. He shares Nissan's view that overlapping of tasks is essential to shortening the design cycle, and cycle shortening is a prime objective for IHI. Ochiai feels that having a common database without transcription errors is just as important if not more so.

At present, they are using the development of the new HYPER 90 engine as the base project for design process improvements. This engine design is being funded by MITI and involves many Japanese and foreign companies. A hypersonic civilian transport plane is the eventual target. IHI wants to shorten the development time from a typical 30 months to 20 months. Note that this time is a very small part of the time needed for R&D of a new kind of engine which, together with manufacturing development and certification, can take up to 8 years.

IHI wants to use the methods and technologies of Concurrent Engineering to achieve this time reduction. The basic approach is, as stated above, to overlap the tasks of design, process planning, and manufacturing development. The most important action is to make sure designs are evaluated promptly for their impact on manufacturing, assembly, cost, and quality. Second, IHI must make a direct link between CAD and CAM. Third, they must improve overall data management, including learning how to manage approval of issuing partial information in an overlapping job environment and how to organize feedback and design critiques that are based on partial information.

An essential element in Nakajima's approach is to restructure the design process to optimize the flow of information. Last year at the Japan-U.S.A. Manufacturing Research Exchange, Nakajima presented the following four-step methodology for finding a good sequence of design tasks:

1. Analyze the steps in the design-development process, find out how long each step takes and what their precedences are, and determine the critical path.

2. Subdivide the steps on the critical path and carefully determine information precedences for the newly subdivided task steps.

3. (Somehow) rearrange the sequence of these steps in view of the information available upstream that is needed downstream.

4. Determine the new length of the critical path and repeat steps 1-3 until the best arrangement is found.

Nakajima had no plans to use any computer aids in this activity except for conventional critical path analyses.

As of this year, the methodology presented by Mr. Chikata for use on the HYPER 90 project consists of

1. Find critical path as above.

2. Analyze information flows as above.

3. Begin ordering long lead time items and designing tooling and fixturing before design is finalized, using smarter awareness of when critical information is available and guessing the rest.

4. Link CAD data to CAM.

This is a very pragmatic reduction of last year's approach and seems driven by the needs of the HYPER 90 program. The more intellectual approach outlined last year still seems to be under consideration but in the background.

Also under study or active development are

- A version of feature-based design that implements generic pieces of geometry that the designer modifies to suit his needs.

- A computer-aided process planning system that uses such features and a group technology segmentation of their parts plus knowledge of expert machinists. This is written in OPS 83 and features easy entry of tabular process data by the designers themselves, since IHI has no knowledge engineers. A major objective is to extend their current ability to sequence single machining cuts into the ability to plan the sequence of major operating steps such as cut, measure, heat treat, and so on. Choice of the last operation to guarantee part quality is an important element of such plans.

- Automation of optimized blade design, including direct data transfer between aerodynamics, stress/thermal analyses, vibration, and preparation of process instructions and NC programs, with the goal of reducing blade design time from 6 months to 2. Right now 80% of the time goes to obtaining, translating, and verifying blade shape data from aero design to structural analysis!

Stated only obliquely but clearly on their minds is the shortage of engineers and the need to leverage the experience of their senior people. Much as labor shortages have forced automation of manufacturing, engineer shortages are forcing automation of design processes.

YAMAZAKI MAZAK TOKYO SALES OFFICE AND NAGOYA HEADQUARTERS

10 and 24 July 1991

Background

My host for both visits was Mr. Awane, formerly of Hitachi PERL, now director of Mazak's new Tsukuba R&D Center. Mazak is a privately held company and no sales figures are available. It has only 4,200 employees world-wide, 2,600 in Japan. Of these, about 400 are designers, split evenly between electronic and mechanical. The main products are NC lathes and milling machines, machining centers with ability to work on several parts in series, plus complete FMS (flexible manufacturing systems) including large parts stockers and transfer robots. About 7,000 to 8,000 machines are made each year.

The company is known for its advanced computer-controlled manufacturing systems. Many of the parts-making facilities operate unmanned overnight and require little tending during the day, a major reason why output per employee is so high. Unlike most machine tool builders, especially in the United States, Mazak is both a pioneer in FMS and a large scale user of them. Mazak is also responsible for a number of important machine tool design innovations, such as the integral cutter spindle and drive motor. The integral spindle runs faster and with less vibration since there are no gears or belts between the spindle and its drive motor. The machine's accuracy is thus greatly improved.

Given this background, it is surprising to learn that Mazak is relatively primitive in its use of CAD and CAE. Design of new machines "takes a long time. This is a problem for our president." Like other Japanese companies, Mazak relies heavily on the experience of its senior employees, and some senior managers do not trust computers in design roles. In this sense, Mazak is typical of conservative machine tool makers world-wide. Mazak recognizes the importance of CAE but is not satisfied with software currently available from commercial sources.

Mazak would like to sell more FMS but finds customers reluctant. Initial investments are large, and senior customer executives must approve such purchases. So the Tokyo office has been set up with plush sitting rooms and a fancy auditorium so that customers' executives can be wooed in style. A showroom of machines used to be enough, since the buyers of lower cost single machines were engineers who just drooled and bought.

Design of FMS

An FMS is a group of 5 to 15 NC machine tools connected by a parts conveyor. Each machine is equipped with many cutting tools and can change tools automatically. Parts to be machined typically visit several of the machines in a system in order to receive all the required cuts. Each part may have widely differing cutting requirements, which the machines accommodate by using their NC and tool-changing capabilities.

Mazak is such a heavy user of FMS that it is much more sophisticated about their proper use than most of its customers. Deciding what range of product types and production volumes is most suitable for FMS has been the main technical and sales challenge since the idea was born at Cincinnati Milacron and the University of Stuttgart in the middle 1960s. The goal was to meet the needs of diverse manufacturing that lies between mass production of almost identical parts and low volume piece-work production of single individuals. Economics and efficiency completely determine the choice since any of the methods is technically capable of making the parts.

However, the choice has never been easy to make and is a subject of intense ongoing research at universities and head-scratching at machine tool makers and users. The FMS easily solved the first-order problems faced by the alternatives. NC made it possible to change from one part to another, which ordinary mass production machine systems cannot do. But stand-alone machine tools, NC or not, are utilized only about 5% of the time since the machine bed is used to set up fixtures and cutting tools for the next part. The FMS solved this by permitting fixtures and tools to be set up in a separate facility equipped with good measuring tools.

With the first-order problems solved, the FMS now faces second-order problems that make the difference between economically successful and unsuccessful installations. The major issues are keeping all the machines busy when a variety of parts is moving through the system and keeping the machines provided with all the different cutting tools that such a range of parts needs. A poorly designed system will have too many machines, some of which are idle, or too many parts waiting for a machine to become available. Typical economic criteria include cost per part, including labor cost and payback of the initial investment and, in Japan, return per square foot since land is so expensive.

The traditional approach in research and most FMS makers was to look for scheduling methods that would sequence the parts into the system so that workloads on the machines were balanced. Another approach was to develop FMS design software that would survey candidate sets of parts and decide the right number and mix of different kinds of machines that should comprise the system. The criteria were that all the required cuts could be made, there was space for all the required tools, and all the parts could be processed in the required span of time. Such problems are typically solved using complex math programming methods (Ref 11).

When the required number of tools could not be made to fit in a machine's tool storage racks, "tool management systems" were proposed. Since a part could need 10 or 20 tools, the logistics of tools far exceed the logistics of the parts themselves. Tool management systems thus can cost more than they are intended to save.

As far back as 1981 Mazak took a completely different approach toward FMS for in-house use. It decided to make partially specialized FMS comprising only three or four machines. These machines were chosen to be identical and were capable of machining a small set of parts, and perhaps only a small fraction of the cuts those parts needed. Scheduling and sequencing problems essentially disappeared. A part entered the system, visited one machine where it got all its work done, and left. It then visited another small system and received more cuts.

The range of required tools was limited by the "given tool method." That is, the part designers were given a stable of tools to use and told to design the parts so that set of tools would be sufficient. For many FMS, this method eliminated the tool logistics problem. For other situations, group technology was used to find a group of parts that used 80% of the defined tool set for a particular FMS, and a tool management system was used to provide the rest. Portions of this story appear in Reference 12.

These two efficiencies have permitted Mazak to employ FMS very effectively in-house without needing solutions to the long-term scheduling and tool management problems. However, the discipline required to use the "given tool method" cannot be forced onto customers, so the easy design and highly efficient FMS operation achieved by Mazak is not always available to customers.

CAD, CAE, CAM

The company relies on CADAM and microCADAM, which runs on about 72 total terminals, of which a small number are IBM 5080 graphics terminals. Most of the CAD work is drafting, preparation of 2D drawings for part manufacture, making shop floor instructions and user manuals, and so on. There is essentially no CAE, in spite of obvious potential applications. It is up to Awane in his new post to introduce CAE.

Design Methodology for Machine Tools

The rhythm of the machine tool industry is driven by the occurrence of the major machine tool shows. These occur every 2 years in Tokyo, Chicago, and Hannover, effectively meaning a show every year or less. New machines cannot be created that fast, and the typical cycle is about 2 years. Totally new machines or technological innovations take longer. The shows are used to get customer input, look over the competition, and show your latest. In addition, at Mazak, most designers have visas up to date for most countries where the company sells and are ready to fly the moment a customer needs something. Customer input and minor changes are thus the main forces governing typical design cycles.

A major design strategy at Mazak, and probably most other companies, is "series design," meaning a series of machines based on one principal design with many variations such as number of tool storage places, size of bed, and so on. New designs are apparently not too hard to create within a series family. Information about existing machines, their drawings and their performance, is kept in computer files. Five mechanical and one electrical engineer can turn out a new lathe design in 2 years. Improvements may include faster tool changing, higher rpm, or a new spindle design.

The integral spindle-motor took five engineers 2 years to design, during which five prototypes were made. A similar one can now be turned out in a man-month (200 hours). The main problems in such units are dissipating the heat from the motor and obtaining the correct preload on the bearings. Motor heat will cause the spindle rotor to distort, causing vibration and poor machining accuracy. Incorrect preload either causes poor accuracy or low bearing life.

Predictions of heat, distortion, vibration, bearing wear, and so on are obvious candidates for CAE. However, Mazak does none of them. Motor heat and its effects are predicted by the motor manufacturer using its own CAE, and Mazak merely designs a cooling system to take away the heat. Bearing design is done at Mazak and checked by the bearing manufacturer, who has extensive CAE for this purpose. This method of farming out the hard parts is used often in Japan.

Advanced bearings such as magnetic or ceramic are used sparingly or not at all. Magnetic bearings are the subject of some Mazak-sponsored university research, while ceramic balls are used with steel races in some high speed applications.

Integral motor-spindle design is now so well understood that a routine has been established. The overall diameter of the rotor is decided by the size of chuck it will hold and the size of any hole inside the spindle. Spindle speed, motor horsepower, and required rigidity also contribute to sizing the shaft diameter. The front bearings and their preload are chosen almost straight from the handbook to support cutting loads. Required horsepower determines motor diameter, which determines the overall size and length of the spindle. The rear bearing is chosen to hold up the shaft, nothing else. This preliminary design is checked by Mazak for rigidity and by the motor and bearing manufacturers for heat and bearing stiffness and life. The rest is pretty routine.

Assembly of such a unit is driven by the need to install the rotor on the shaft and achieve the bearing preload. Balancing the rotor also is important and must be done at the right time during assembly. Mazak's engineers did not feel that there was much room for flexibility or innovation in this assembly sequence.

Cost estimating of new or series designs is important because the market and competitors often set prices. Their main cost estimating technique is to consider four factors: cost of purchased parts, amount of material (usually measured by its weight), machining costs, and assembly costs. The first two dominate the final total and are calculated very carefully using past data. The other two fluctuate too much to be of great use. CAD does not play much of a role in cost estimating except that CADAM can calculate volumes of parts easily. Cost of new entries in a series is determined by altering the data from the parent machine, which has been in production for a while.

Future Computer Design Needs

Mazak is unclear about what it needs in the future. It has a mild anticomputer frame of mind in the design department and relies on its experienced people, some of whom have been with the company decades. One identified need is to calculate machine bed and column deflections under cutting loads and (at my suggestion) under thermal distortion. Other companies sell machines with built-in temperature sensors and heaters that deliberately introduce compensating distortions to keep the machine accurate. Such companies must be ahead of Mazak in applying computers to design.

Mazak also would like an automatic design system that would take in a set of specifications for a machine tool and spit out a complete design. Such statements are heard at other companies and are not totally whimsical. However, they are totally out of step with the state of the art. Prof. Kimura notes that many companies do not have clear plans or coherent explanations of what they want. Visiting them every month for a year is often not sufficient to figure out what they are thinking, even when the company is Toyota, whose thinking would seem to be fairly systematic.

PROF. NORIO OKINO, KYOTO UNIVERSITY

26 July 1991

Background

In the 1960s and 1970s Prof. Okino developed one of the first solid modelers based on constructive solid geometry, called TIPS. He still works on CAD/CAM and solid modeling but his main interest recently has been what he calls "bionic manufacturing."

Bionic manufacturing involves two elements: self-governing behavior and object-oriented hierarchical structures. Okino has constructed a conceptual model of computer-integrated manufacturing (CIM) that begins with all of society at the top and extends downward by subdividing object classes until the lowest levels are reached somewhere in a factory.

Each level is composed of elements that have the same structure in principle. These are called "modelons." Each modelon contains a common memory and a number of processes or methods that operate using that memory. In addition, a number of lower level modelons are attached to this memory. Modelons are independent actors, like daemons or, in UNIX, processes. Each modelon looks out for the conditions under which it could run; if they are satisfied, the modelon runs and deposits its results in the common memory it is attached to. Modelons are also like methods in object-oriented programming in the sense that they can send messages to each other, activate each other, etc.

A major feature of this structure is, as said above, that each modelon acts autonomously. What the convergence problems of such a structure might be Okino does not say.

Several topics are being studied under this structure. I was shown software demonstrations of two: a robot modelon that interacts with prismatic peg and hole modelons to determine where to grasp the peg for the purposes of putting it in the hole and a hidden line removal algorithm in which modelons representing each of three prismatic parts inform each other of the locations of their vertices. We discussed a third for which there was no demonstration: a shaft modelon made of three shape features, each of which is represented by generic feature modelons. All the work is being done on Apollo Domain 10000 workstations.

1. Robot Grasp Planning: This is the recently completed work of Dr. Watabe. In this system, there are several software modelons representing the parts, the robot, and the environment. The user requests a task, such as that the peg be put in the hole. The top level modelon broadcasts this request to the lower ones, all of which attempt to respond with a solution. Finding that they cannot, they broadcast in turn to any of their subelements whose responses they need or could use, in a divide and conquer approach. This is repeated at lower levels recursively. For example, the robot needs to know several sets of faces on the peg, such as parallel faces, parallel faces free-to-grasp before inserting, the same after inserting, and so on. The peg and hole modelons respond. I could not tell how the assembled state was established for the purpose of identifying the free faces. Perhaps the user constructed it as a way of posing the problem.

There is no agenda structure in this search. Watabe had not heard the terms "forward chaining" and "backward chaining" before. (These are common techniques in expert systems for solving the kind of problem he is working on.) Such searches commonly are not very efficient since there is no gradient to follow and no metric to score how close one is to finding a solution.

2. Hidden Line Removal: In this demo, three prismatic blocks intersect each other. Before the hidden lines are removed, one cannot see what is what, even with three views, because several of the edges appear parallel and the front-back optical illusion interferes. These facts make the demo more interesting but of course have nothing to do with the intrinsic difficulty of the problem. Each block has its own hidden line removal method and seeks information from the other blocks concerning where its lines enter or leave their boundaries. Information is passed around this way for several minutes before a solution appears on the screen.

Okino points out that speeding up the algorithm or competing with existing algorithms is not the objective, but rather it is to understand modelons.

In this regard, it is interesting to review the discussion we had about the shaft made of three shapes: a plain cylinder, a conical cylinder, and a threaded cylinder, all coaxial. Each shape is supported by a generic feature that contains methods for drawing the shape, calculating its mass, and a process plan for how to make it. Presumably the process plan for the shaft is made by combining the process plans for the three supporting features.

I asked a basic question that underlies the problems in all process planning of this kind: what do you do in regions where the plans touch or intersect and presumably interact? That is, how does one compose process plans from subplans? He agreed that this was a challenging question and replied that perhaps one must declare the shaft itself to be the primitive element. A student is beginning to work on the composition problem.

Okino's reply indicates that there are many problems yet to be solved by this approach. The value of having generic elements at the leaves of the structures is clearly large and would give the approach considerable power. Requiring each specific shaft to have a representation of its own is not efficient. However, he is a software person rather than an engineer and is pursuing the structural issues first.

Prof. Kimura notes that object-oriented structures are good for some kinds of data but not others, especially those that have strong interactions as well as, or instead of, hierarchical, decomposable structures. Mechanical design and manufacturing may not be separable enough to permit object-oriented approaches to cover them completely.

NIPPONDENSO

29-30 July 1991

Background

Our hosts for this visit were Mr. Fukaya, General Manager of the Production Engineering Department; Mr. Tsuchiya, Fukaya's R&D Manager; a young engineer Mr. Harada; and at dinner Mr. Ito, the Executive Managing Director of Production Engineering.

Nippondenso Co. Ltd. is a former subsidiary of Toyota Motor Co. that makes a wide variety of automotive components, such as alternators, motors and actuators, air conditioning systems, engine components and controls, radiators, dashboard displays, brake control systems, and so on. It has manufacturing plants worldwide to satisfy many automotive manufacturers. Handling the wide diversity of product models and responding to the Just in Time (JIT) ordering system philosophy have heavily affected how Nippondenso designs and manufactures products.

Nippondenso is a high technology company. Basic and applied research cover materials, vacuum apparatus, semiconductor fabrication methods, ceramics, robotics, vision systems, factory automation software, simulation systems for testing driver reactions, and CAD/CAM. Major design thrusts over the past 10 to 15 years include "managing diversity," designing new products faster, overlapping design tasks while managing risk, and dramatically reducing the size and weight of products while increasing quality and performance.

The company has 41,000 employees. Of these, about 5,000 are design engineers and 1,500 are production engineers. At the new R&D center where the visit took place, there are currently 150 researchers. A major characteristic of Nippondenso, which I have noted in many previous reports dating back to 1977, is that it makes much of its own automation equipment and nearly all of its 3,500 robots. This commitment to manufacturing equipment excellence is one part of its commitment to manufacturing excellence in general.

The typical working year at Nippondenso and in Japan generally is 2,200 hours, compared with 1,800 in the United States. The Government is trying to get this reduced to 2,000 by 1994 and 1,800 by 1996. Each Japanese company is attempting to reach this target, facing various problems.

Nippondenso characterizes its products as follows:

- Quality first
- Wide range of product variety
- High speed mass production
- Mixed production (several varieties in one place)
- Just in Time production method
- Original equipment manufacturer (OEM) sales mainly

These conflicting characteristics (especially variety, mass production, and mixed production) have driven the company into a variety of design and automation methods. These are covered below.

Automation and Product Development Techniques

An important feature of Nippondenso is an obvious long term enterprise-wide strategy for how to grow the company into a master of manufacturing products with these characteristics. Nippondenso has evolved a systematic approach to managing design processes, designing carefully to support JIT operations, and developing larger and larger systems of automation. In the 1950s they had "spot" automation (what we would call islands); in the 1960s they had lines; in the 1970s "areas," meaning presumably several lines of the same type or several lines connected; in the 1980s and early 1990s "cube" or "totality." Such increasing automation creates serious dangers for a company whose customers switch specifications, alter model production volumes, demand instant response to orders, and increase variety of products.

Nippondenso has only gradually realized how deep the dangers can be and has instituted several procedures for combatting them. These include simultaneous product-process development, a classification of levels of necessary flexibility in production, and a classification of degree of innovation in design projects.

Classifying Flexibility

Nippondenso's classifications are as follows:

- Flexibility for Product Variation - Configuration, size, model, and type are levels of variability within the product itself that are increasingly difficult for the automation system to accommodate.

- Flexibility to Design Change - Minor changes are often easy to accommodate, model changes are harder, and the next generation of the product usually requires a new factory.

- Flexibility to Production Volume Change - Total volume fluctuation requires reassigning manufacturing systems to different products; gradually increasing volume normally requires buying more capacity; fluctuations among product types require reassigning production capability between the types.

In response to these needs, Nippondenso has utilized several strategies, beginning in the 1960s (see Figure 1):

- FMS-0 - Use specialized automation with no flexibility and make rigidly standardized products; an example is little control relays. Fukaya notes that strong efforts at standardization occur even when automation at levels 1, 2, and 3 below is adopted. Furthermore, FMS-0 is the preferred approach and is used wherever possible.

- FMS-1 - Design the product with several versions of each part, capable of being intermixed: 3 fronts, 4 middles, 3 backs, total 36 types; an example is a panel meter gage, in which many varieties of one basic model are made minute by minute based on a stream of orders from Toyota (Ref 4).

- FMS-2 - Design the product with a common outer shell and interchangeable interiors and provide robots and sensors as needed to make quick changes from one to another; several models of an air conditioner are made this way, all being essentially the same size.

- FMS-3 - Design product and process so intimately that one can even change the outside shell's length and diameter without affecting the automation system. The Type III alternator (see below) is an example.

Flexibility means not only the ability to switch some important factors of the product but to switch rapidly. Nippondenso has worked over the decades to cut the changeover time from hours to minutes to seconds, while at the same time increasing the range of flexibility.

The size of the product is one of the most important factors in the design of an automation system. Supporting a later change in product size without rebuilding the system is almost impossible. Yet as cars become smaller and lighter, so must their components. Only the largest cars can take the largest components; even here, however, the manufacturers are pressing for smaller components which perform more functions. One can no longer simply reduce the capability of the product for use in a smaller car while keeping the outer shell the same. The shell must shrink, too. As more varieties of cars are made, more sizes of the same product are needed, each made in smaller production volumes than before. Lower production volumes mean less efficient automation unless some way can be found to make all sizes on one automation system. Thus FMS-3 is a very difficult but important level to achieve.

Summarizing, the ultimate factory can make any quantity of any item without any penalty for switching. The disadvantage of current automation systems is that they are too focussed on a small range of models of one product. If demand for one version of alternator, say, rises while that for another falls, the underloaded line cannot help the overloaded one. Instead, one must build more lines, resulting in overcapacity and wasted investment. Several generic approaches exist to this longstanding problem: predict future demand perfectly, make superintelligent manufacturing systems that can switch, or design the products and their manufacturing processes to contain a measure of alterability. I call the latter "smart products" below. It is probably the best of the three approaches, the first being obviously unavailable and the second beyond the current state of the art except in restricted but very useful situations. Nippondenso has adopted the smart products approach and showed some interesting examples.

Classification of New Product Development Efforts

This classification is as follows:

1. Innovative, totally new product (10% of design efforts); examples include active suspension or cathode ray tube (CRT) dashboard displays.

2. Strategic new product (called Jikigata); these are major, market-share-grabbing improvements of existing products such as radiators, alternators, and fuel pumps.

3. Semi-new products; these are, in fact, minor improvements in performance of existing items; several such improvements come along between Jikigatas.

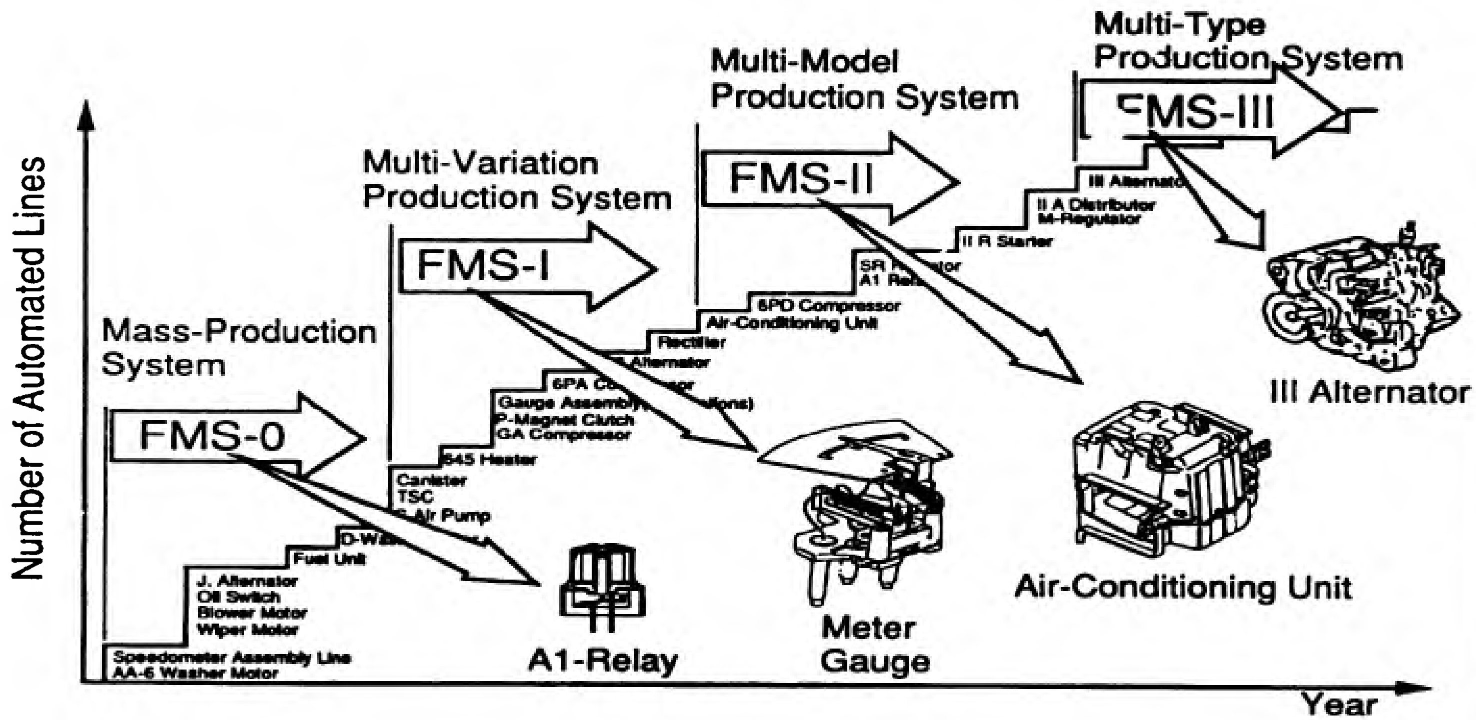


Figure 1. History of FMS in Nippondenso.

The bulk of the visit focussed on the Jikigata for a new alternator.

The Jikigata Process

Jikigata efforts are directed at products which are mainstays of the company, feed a mass production requirement for a popular car, and face important competition, thus requiring strong innovation. On top of this, such products require timely and reliable delivery. These requirements have forced the creation of new design staff organizations and close involvement of top management. While CAD and CAE have played important supporting roles, the most important element of such developments is creation of new manufacturing methods to support the "smart" flexible design. This has meant making production engineering an equal partner in the design process. Nippondenso, like many Japanese companies, maintains production engineering as a corporate level activity with a director (equivalent to executive VP) as its head. Thus the company was long prepared for the required organizational changes.

It is important to realize that this is a more sophisticated activity than mere "design for manufacture" (DFM) or "design for assembly" (DFA). A new level of automation/flexibility is being sought, and it cannot be achieved unless new manufacturing methods are created, methods which are enabled, not just eased, by the product design itself.

A Jikigata effort combines corporate production engineering and a product division's capabilities as shown in Table 1.

Product development begins after a launch decision by the New Product Development Council, which appoints a product development team (four to five engineers) and a process development team (two to three engineers). These teams work together to create the concept design specifications. Each then splits into separate activities, enlarges to about 20 members each, and comes up with an action plan to meet the specification. Once the plan is approved it is condensed to a single sheet of paper and given to everyone. These 40 to 50 engineers stay with the product until the end of the project, later being joined by about 100 manufacturing equipment designers. The most specialized one-third of the machines (by cost) are made in-house, while the more ordinary ones are built by contractors.

The plan (Figure 2) must be challenging but reasonable. It must contain the total view and plenty of detail. It involves top management, who attend monthly follow-up meetings. Each goal has a responsible person and a list of risk-management actions. Each goal is classified as to its importance to the project and its level of risk. The importance levels range from "M" (for must have) to "W1" (want very much) to "W2" (want, but not so much). Risk varies from "A" (feasible today) to "B" (currently being studied for application to mass production) to "C" (under basic examination, not out of the laboratory yet). At each point in the schedule there is a "T" (target) date after which, if a risky process or design element has not been achieved, one of the prearranged alternates will automatically be substituted.

On top of all this, Nippondenso aimed at reducing the development time from the customary 6 years to 4, by overlapping product and process development activities. For the Type III alternator the development time apparently was 5 years.

Along with this elaborate planning process, Nippondenso has some "useful tools." These comprise the usual CAD/CAM/CAE software, plus value engineering, group technology, and variation reduction, plus Nippondenso's own design for assembly evaluation method, a variety of system engineering aids like discrete event simulation and process failure modes and effects analysis (FMEA), and quality management methods (design reviews, quality control (QC) techniques, and the Taguchi method). Calling these "useful tools" reveals Nippondenso's priorities: get the methodology in place first, then support it with tools.

All of the debates and tradeoffs involved in these efforts are carried out by experienced people. When there is a major problem a top executive decides. Design is vulnerable to change, often forced by the actions of a competitor. In alternators and air conditioners, where Nippondenso dominates, competitors' actions are less disruptive of the design schedule, but in brake systems where Nippondenso does not dominate, the schedule is more vulnerable. The availability of top management and their willingness to take the responsibility and make decisions quickly are crucial. In this sense, Nippondenso is like Nissan and other companies who organize to absorb change during the design process rather than try to resist it.

Table 1. A Jikigata Effort

Corporate Production Engineering	Product Group
System Section	Planning Center
Processing Section	Product Engineer
Materials Section	Manufacturing Dept
Machinery & Tools Dept	Quality Assurance

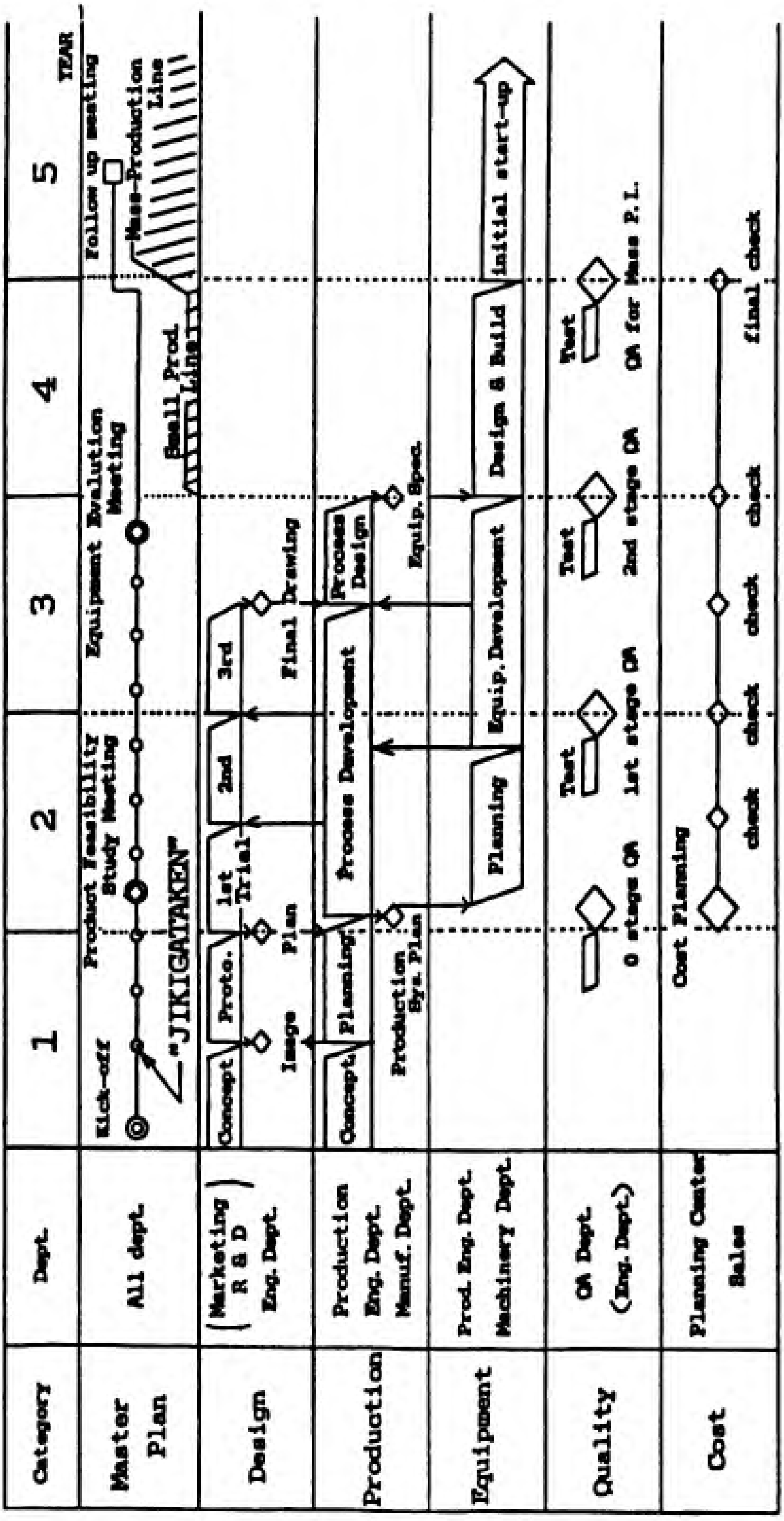


Figure 2. Whole plan of XX product development.

Note, too, that Nippondenso is willing to use the overlapping tasks method even on projects with lots of technical risk. Overlapping brings the risk of more change, but Nippondenso and Nissan both feel that changes forced by outside pressures such as competitors' actions are more severe. This fact slightly counters Prof. Kimura's feeling that only "understood" processes and products could be approached this way. Fukaya was quite clear on this point, and said that Concurrent Engineering (CE) (joint operation of product and process design teams with monthly follow-up by top management) was the way to accomplish it. They all agree that it is based on human communication and experience and wish for computerized versions of CE. I did not hear them suggest any ways to create them.

Nippondenso's production engineering people are also sympathetic to the idea that computer aids will help this process and fervently wish for such help, but they do not see it becoming available soon and do not think it will be a dominant feature of their success. Yet they are developing several effective computer tools and see where others might be introduced. See below for a summary of these.

Development of the Type III Alternator

The main components of an alternator are the stator, the rotor, the two-piece cast outer case, and the rectifier assembly. The goals of the redesign were to produce an alternator that could be made in several lengths and diameters on the same fabrication and assembly equipment. Important changes in the design of all four components were required. Some were relatively easy, such as cutting different diameter grooves on different size cases. Redesign to permit assembly from one direction was also not too difficult to achieve. Others required considerable innovation, such as making different diameter stators. This was done by coiling stator laminations stamped from long strips of steel (Figure 3) rather than stamping rings from steel sheets and stacking them up. (The amount of scrap material is also drastically cut this way.) The wire windings for the stator are formed separately from the stator itself and pushed radially outward into the grooves in the stator rather than being wound in place in the stators. Changing the diameter of the windings is easier this way. Most of the size changes can be made almost without stopping the manufacturing equipment.

Altogether 74 new manufacturing technologies were developed. This project occurred in the early 1980s.

The resulting design comes in three main sizes with capacities ranging from 35 to 80 amps. Within each size there are about 250 variations.

These alternators are assembled on automated assembly lines that use mostly specialized automation for the assembly moves themselves plus robots to feed the parts from trays to the assembly stations. A few simple fixture changes, accomplished manually, support changes in product model. Nippondenso built these lines in 1987 after seeing a film in 1980 made in 1977 by our group at Draper demonstrating complete robot assembly of Ford alternators.

The spirit of these innovations can also be seen in the way Nippondenso redesigned radiators a few years earlier (Ref 13). A major feature was machines that could switch sizes of components in a few seconds, plus a snap-together assembly method that eliminated the need for fixtures in the different sizes. The cost of the fixtures was saved but more importantly the time required to switch from one size set of fixtures to another was eliminated. Some of these techniques were pioneered by General Motors (GM) Harrison Radiator Division but not put in place as completely as at Nippondenso.

Radiators and alternators are clear examples of "smart products," being designed so that the challenging manufacturing strategy of conquering variety could be achieved without basic advances in manufacturing knowledge. Innovative manufacturing methods were indeed made, however. Deciding how to partition the problem into product innovation and process innovation clearly required a single team working together from the start of the project. Success would have been unlikely if process engineers had merely critiqued the product engineers' design and would have been impossible if the process equipment had been merely purchased from vendors after product design was complete.

Use of Computers in the Design Process

Nippondenso has a large CAD/CAM/CAE activity, combining their own software development and use of commercial software. The system they have developed is similar to several commercially available "frameworks" in the sense that it supports many application programs as long as they respect certain data conversion protocols, but there is no true common database. In addition to this core system, there is the typical array of CAE plus a range of software that supports production preparation and production control.

The goals of CAD/CAM/CAE are stated as

- improving the efficiency of product development
- shortening the lead time for new products
- making it easier to design product variants
- helping create smaller and lighter products

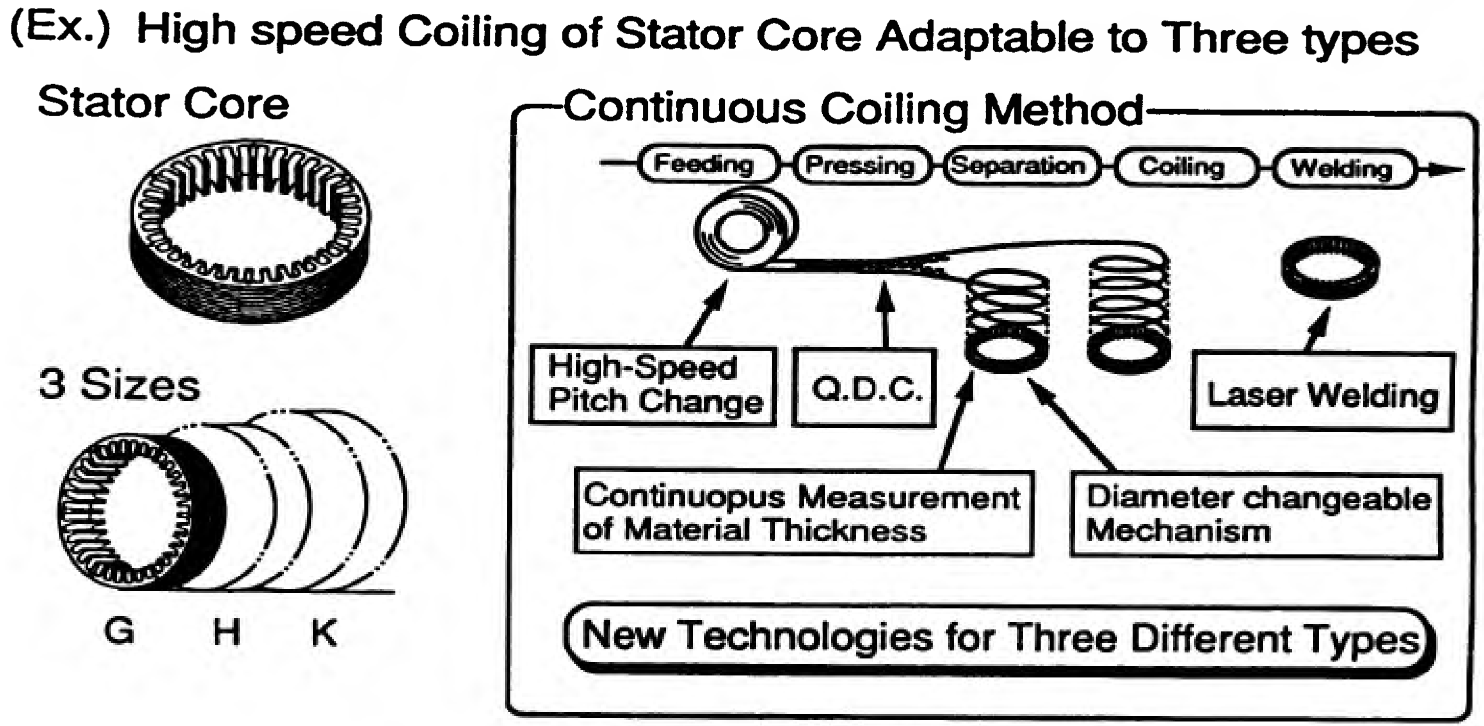


Figure 3. Example of the newly developed technology.

(Note that Nissan denied that a goal of its CAD was to shorten the lead time...) Design is supported by NADAMS (Nippondenso Advanced Design and Manufacturing System), which has been under continuous development since 1980. It is written in PL-1 with recent additions in C. Outside contractors wrote most of it under the leadership of an internal group of programmers. It runs on IBM 3090s and supports about 1,000 terminals. NADAMS supports 2D and 3D wireframe models, surface free-form shapes using Coons surfaces and rational B-splines, and solid models.

All items designed in NADAMS are in one database accessible to the designers, including those who design production equipment. Casting and molding dies, NC machine operations, robot programming, operating models of parts and products, and simulations are example applications supported. There is an expert system to help devise cutting process plans, typical CAE for vibration, stress and thermal analyses, mold flow simulations to aid die design, and some fault tolerance analysis software that was not explained further.

For example, the mold flow program (IMAP, developed by Toyota Central R&D Laboratories, Inc.) helped Nippondenso reduce the weight of its air conditioner case and avoid having a hole develop during molding. The number of actual prototypes needed was reduced by 66%.

The metal cutting expert system is based on Metcut's data plus 650 rules provided by Nippondenso's process engineers. The rules comprise knowledge about how to process certain geometries plus formulas for calculating feedrates and tool wear, for example. The software chooses tool material and size, cut depth, feedrate, cutting speed, and cutter rotation rate. In a side-by-side test, process engineers provided process plans for a precision surface that varied by 4 to 1 in recommended cutting speed. Only one engineer recommended a cutting speed as high as the expert system did. This cutting speed was verified in a test. The system thus has the capability to solve three problems: lack of experienced process planners, nonuniformity of their plans, and unwillingness of planners to choose aggressive plans, thus costing time and money unnecessarily.

Tour of CAE Facility

The facility I toured was a training center. It contains a wide variety of workstations but mostly IBM 5080s. I saw two demonstrations: robot offline programming and supercomputer output showing FEM studies.

Robot offline programming is supported by a wireframe 3D modeler that permits a user to build up a model of a workstation from basic shapes. A primary function of the program is to predict and improve the cycle time of the robot workstation. The computer already has models of Nippondenso's various robots (which it makes in-house). I could not find out how the coordinate data were put in so that workpieces, fixtures, and teach points for the robot could be described. Collision avoidance is done by trial and error, using the modeler's intersection capability. Straight line paths are computed automatically as a first try and the user modifies them to avoid obstacles or improve cycle time.

Several FEM examples were available. These include fluid flow in plastic injection molding, turbulent mixing and heat transfer inside the air conditioner between cold and hot air, stress-strain, and flow inside a fuel manifold. NADAMS supports pre- and post-processing, and a commercial FEM package does the calculations on the mainframe.

Developments in Assembly Technology

Two interesting activities of the Assembly R&D Group were presented by Mr. Harada and Mr. Sugito: design for assembly (DFA) and assembly technology. The Assembly R&D Group has only five members and was begun in 1985. Its jobs include interacting with the research community at home and overseas, developing ways to simplify products using their own DFA methodology, and developing ways to assemble difficult products that can't be simplified.

Assembly technology is divided into two parallel efforts: dexterous/intricate assembly and large variation assembly of simple items (Figure 4). Engineering innovation is used on the first kind while economic approaches are used on the second because they are already technically easy but too costly to automate.

For large variation products, an economic analysis showed that cost of preparing and feeding parts grows much faster than other costs as the number of variations grows. Efforts are going into various "low cost" feeding and preparation methods, including an attempt at low cost bin picking. Bin picking is being used in only one factory application, however. Other applications are under development. Reconfigurable grippers and pallets are also under consideration, along with such approaches as molding groups of parts onto one backbone and cutting them off at the moment of assembly.

For technologically challenging assembly tasks, such as fitting unwieldy, flexible, and warped items together, Nippondenso long ago concluded that "intelligent, dexterous, and adaptable" robots were too expensive or unavailable. Instead, they decided to "utilize the characteristics of the product" as well as to redesign the product so that assembly could be accomplished. This is another example of the "smart product" approach.

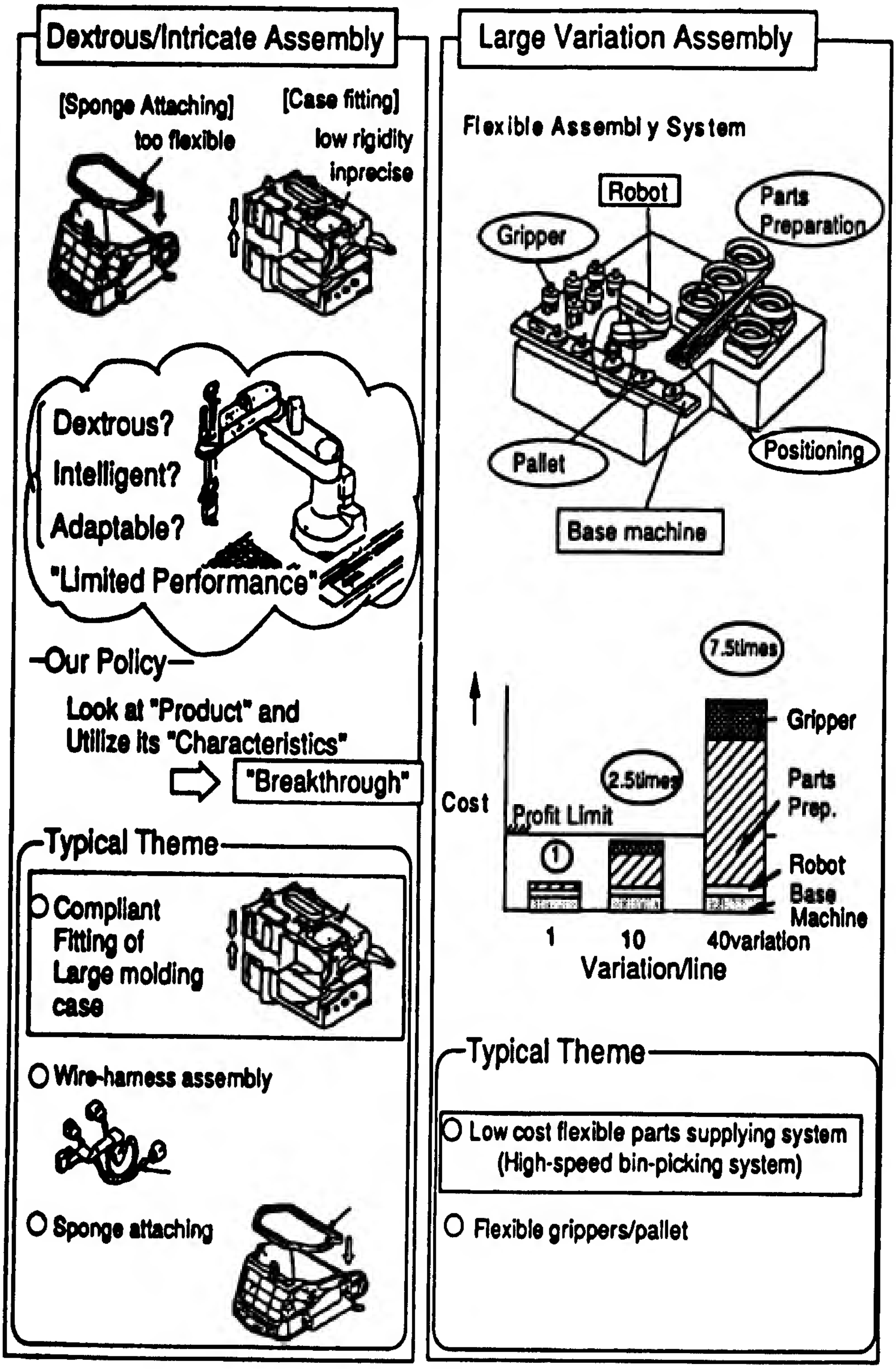


Figure 4. Assembly technology development.

A fine example shown was fitting top and bottom halves of molded plastic air conditioner housings together (Figure 5). These fit by tongue and groove around a large perimeter ("island"). Since the cases warp, the halves cannot just be pushed together. Fixturing could be used to force the halves into the correct shape but that would require costly fixtures and/or making the parts too flimsy.

The problem gets worse when the joint has a gap ("discontinuity") or two rather than covering the entire perimeter. The worst situation occurs when there are "intermediate parts" such as pivoted damper doors where one end of the hinge pin fits in a hole in one case half and the other end fits in a hole in the other half. Such doors are placed upright in the lower half but flop over to one side and the hinge pin will not line up with the upper half's hole.

People currently assemble these parts. They push and bang the case halves together, reaching inside to line up the damper hinge pins and the case holes. It is an obvious bottleneck on the production line and inherently difficult to automate.

The robot solutions have been demonstrated in the laboratory but not applied in the factory. They are elegant and involve a mix of robot angular maneuvering of the top part, redesign of tongue and groove shapes, and redesign of damper doors. This is the approach I called "smart product" above.

To fit a tongue-groove that covers the entire perimeter, the robot tilts the top half and mates the parts on one side. It then pivots the top half down gently by hinging at the initial contact point, and the tongue rolls into the groove.

When the joint has a gap, the above method is used, starting at a pivot point opposite the gap and rolling around so that the parts are mated at one end of the gap. A vision system is then used to find the top in relation to the bottom at the other end of the gap, and the robot pushes and slightly deforms the top half until the parts are aligned. Then the pivot-roll method is used to mate the parts while not disturbing the mate achieved at the first end of the gap. When there are several gaps, the one in the most flexible region of the case is mated first, then the next most flexible, and so on.

When there is one damper door, the robot pushes it upright with the top half of the case and catches the door hinge in the hole in the case. Then it repeats the tongue-groove method. The hinge pins on the damper are made extra long so that they do not fall out during the pivoting operation. When there are several doors, this process is repeated for each door, and the hinge pin of each door is designed to be longer than that of the next door so that the sequence of door mates can be controlled.

Whether this scheme can be applied reliably and at high enough speed in the factory is unclear at this time, but given Nippondenso's past record, it will be. It is a pretty sophisticated approach and represents "design for assembly" as high art.

Nippondenso has also developed its own DFA evaluation method. Nippondenso's method is broader and more sophisticated than typical DFA methodologies, which most people agree focus too much on small parts. It contains 65 points of evaluation, such as how parts must be prepared for feeding, how many variations there are in parts and product, whether a part's feeding method supports variety, how difficult the assembly technique must be, and how many parts there are (the most important item). Production engineers perform the evaluations and give advice to the product designers.

An interesting redesign activity is called variation reduction. Its aim is to reduce the effect of multiple models on the assembly processes. Methods used include modularizing the product into fixed portions and variable portions, suppressing minor variations and using more common parts instead, and using the FMS-1 technique. This topic is a subject of ongoing research and Harada is gathering more examples from around the company.

Twice a year they hold a DFA seminar to trade stories, hear advice from both product engineers and process engineers, and teach the method. Harada's goal is to create a DFA program based on a solid modeler that will help product designers evaluate their own designs. Other companies I have asked about such an approach (a subject of my own research) say that they do not believe product designers will ever have the time or knowledge to do such evaluations themselves. Harada will move to Nippondenso Technical Center U.S.A., Inc. near Detroit and will survey research opportunities from there.

Kimura noted later that both Boothroyd/Dewhurst (B/D) and Draper Laboratory research on design for assembly and simplification of products has had a strong influence in Japan. The B/D method is very popular although its limitations are recognized.

TOYOTA

31 July 1991

Background

My host was Mr. Y. Kuranaga, Head of Development Div 1 of Information Systems Div 1 in the Information Systems Division. The entire operation has 641 people plus at least 330 outside software developers. Its mission is to develop and disseminate software for engineering, business, and factory operations, plus to provide software training. Toyota has agreements with several companies such as Nihon Unisys to support and sell its CAD software to Toyota's vendors.

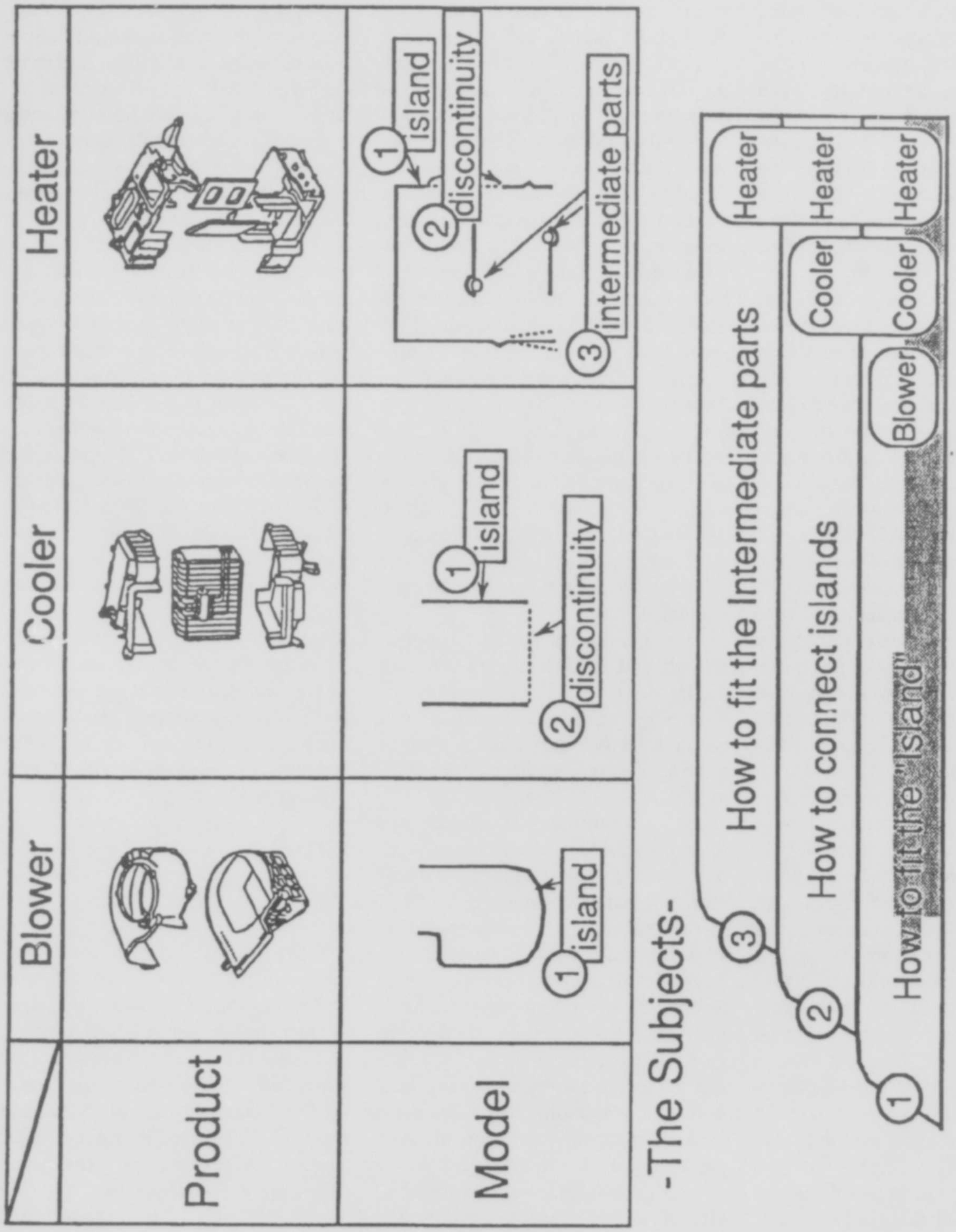


Figure 5. The subjects to realize automated assembly.

The engineering computation system consists of eight large mainframes and four supercomputers at headquarters plus other mainframes in the United States and at the various plants. Recently a transputer system was added to do color renderings of car bodies (see below). The administrative computing system also has seven mainframes.

As at Nissan, computation supports most aspects of vehicle design, including CAD/CAM of body parts, exterior and interior design (interior was not as well developed at Nissan), CAD/CAM of mechanical parts like suspension and power train, structural and aerodynamic analysis, laboratory automation, stamping die manufacture, NC programming, and machining process planning. Toyota last made a clay model as primary design data input between 3 and 5 years ago. A good summary of Toyota's computational design work is in Reference 14.

Toyota makes about three times as many cars per year as does Nissan. About five new models, plus many minor redesigns, are in the design system at any time. There are about 200 stylists and 800 body engineers. No data are available on how many mechanical, production, and tooling engineers there are. It appears, however, that Toyota has more in-house people per car design project than Nissan has.

Nissan was a little better than Toyota at presenting the full picture and giving the flavor and comprehensiveness of its long range plans. However, I'm sure that Toyota is ahead in many areas technically. The scientific depth of its work in surface representations and data structures for holding and manipulating design data are two of many examples. The effort reminds one of Nippondenso's commitment to manufacturing equipment excellence as part of manufacturing excellence: it is something you cannot achieve by buying things from vendors.

Use of Computers in CAD/CAM/CAE

Toyota has major activities in this area. I was shown demonstrations of body styling CAD, stamping die design, formability analysis of sheet metal parts, CAM of stamping dies, engineering analysis of mechanical parts, process planning of machining, and offline robot programming. I did not see anything comparable to the assembleability analysis that Nissan showed me, however.

Body Styling

The objectives of computerized body styling are stated as

(1) making higher quality surfaces

(2) reducing the required manpower and leadtime

(3) integrating CAD and CAM

Higher quality surfaces are smoother, the different sections of the body blend together better, and the final metal realization fits together better. Reduction of leadtime, interestingly, is stated as an explicit objective, something Nissan would not do. Integration of CAD and CAM is a longstanding goal of every car maker. Toyota appears to be several years ahead of other companies in realizing these goals.

The body styling activity takes the first year of the normal 4-year car design cycle. During this year, three or four complete cycles of styling and evaluation may occur. A cycle consists of making three-view sketches, converting them to 3D models and refining these, and making a one-fifth scale clay model by NC machining from the computer data. At least one full size clay is also made before the end of this year. A cycle typically takes 40 days, an impossible schedule to maintain if clay were used as the stylists' working medium and as the source of input data for computer models.

Body styling by computer dates to 1981 (Figure 6, top), with a complete end-to-end system working by 1986 or so (Ref 15). Major efforts were made to overcome well-known difficulties with designing and joining surface patches described by earlier theories. Methods of surface generation and curvature evaluation were devised that followed the stylists' methods. Control of surface curvature, its continuity, and its regularity or uniformity were found to be the most important factors. Primitive shadowing and rendering of highlight lines were possible in 1983. In the last year, extremely realistic color renderings have become possible (Ref 16).

The color renderings are computed on a parallel computer with 256 transputer elements. Computation takes into account such factors as color, type of paint, weather conditions, and sun angle at various geographic locations. A new car or view angle can be computed in 30 minutes, a new color for the same view angle in 5 minutes. Among the features available that imitates the stylists' old methods is representation of reflections from several fluorescent tube overhead lights.

The styling and rendering system is now used not only to design exteriors but interiors as well. I was shown photos of rough NC-milled clays of dashboards and center consoles (ash tray, shift lever, etc.). The design studio has 65 32-inch diagonal measure flat screen cathode ray tube (CRT) displays (2000x2000 pixels) for the purpose of designing and modifying these surfaces. They run off a UNISYS 2200 mainframe.

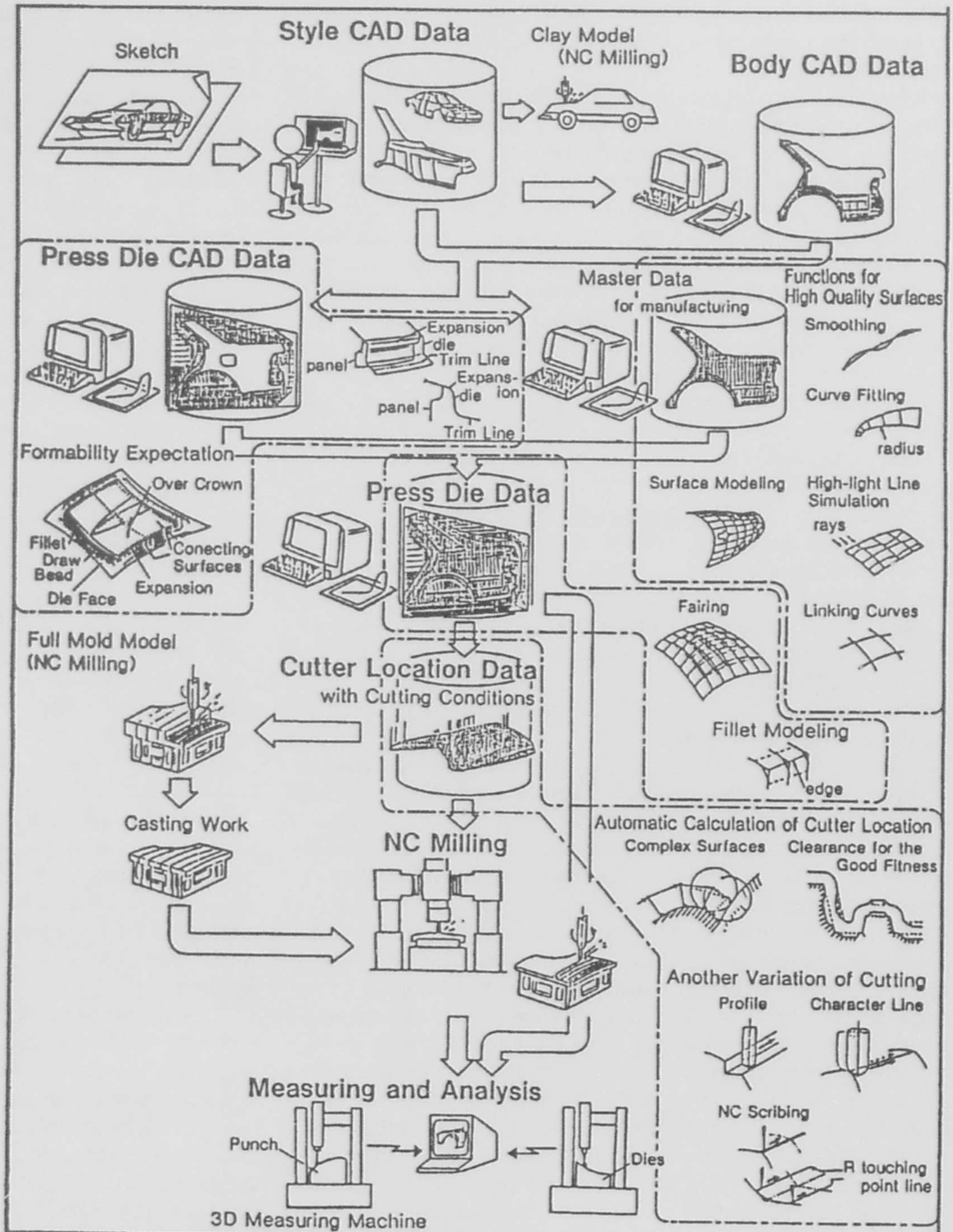


Figure 6. Body CAD/CAM.

The method of converting stylists' sketches to 3D model data demonstrates a widely felt problem, namely, that 3D modelers are too hard to use. Toyota employs specially trained computer technicians who convert the sketches into a first model which the stylist and the technician correct together. The technician interprets the shading in the sketch to obtain an impression of the intended shape, then produces that shape in a surface model. The stylist can view the realistic renderings, an orthographic line drawing, or a cross section. Curves can be modified in ways very similar to those available in Macintosh drawing programs, the most familiar being adjustment of endpoint tangent vector lengths and orientations.

These technicians are obviously rather special people since they must have both an artistic sense and computer skills. They must also provide an important part of the human interface between the stylists and the computer.

Die Face Design and Formability Analysis

Dies cannot be the same shape as the desired final metal part due to the springback of the sheet metal and friction between it and the die face. It used to take about 3 weeks to design a simple die but now with the computer system it takes only 1 week. The functions supported include direct data transfer from the styling database, addition of shape details for the final part (lightening holes, folds from front to back, locations for fasteners) and details to permit forming (flanges where the die grips the perimeter of the piece), plus formability analyses. These analyses permit the die designer to predict possible forming problems and redesign the stamping process (or occasionally ask the stylist to change the part) to avoid them.

This system is well described in Reference 17 and is credited with shortening die design time by 50%, die manufacturing by 30%, and die tryout by 30%. A major point made by this paper is that the program does not use finite element method (FEM) for stress and formability analyses. Instead, rather basic analyses are used. These include local elongation ratio, speed of deformation in local regions, shape change of grid lines, and other functions that can be computed either from geometry alone or from basic stress analysis. The goal was not a perfect system but one that would help designers find good solutions using methods they could understand and interact with.

Figures 7 and 8 contain a nice example. Here the use of the mean section length ratio is shown. Along a particular feature line, different segments are defined (sections) and their length before and after forming is calculated. The maximum ratio before and after and the rate of change of this ratio along the feature line are cross plotted. Data of this type for 10 past designs were collected and correlated with the die tryout time for each. Excessive tryout times (over 900 hours) lie above the diagonal line, providing designers with rapid feedback on potential problems months in advance. Another feature of this type of analysis is that the designers can put in their own experience, giving them a feeling of ownership and confidence in the program and allowing data to be accumulated for future use or training of new designers.

It is said that in some U.S. car companies methods like this cannot be used effectively because the stylists will not modify their designs. In one company, the stylists report to the chairman of the board whereas the engineers report to the president. In another company, a similar integrated body engineering system is being pursued but is delayed because many of the component analyses are approximate. Toyota obviously decided not to wait until perfect analyses were available and went ahead to tackle the problems of integrating the existing tools into one system. This decision has put Toyota on a higher plateau, since integration is a new learning opportunity.

Process Planning for Machining "Box-Type" Metal Parts

This system helps designers to choose the necessary machines and tools for making complex parts. An example is a complex aluminum cylinder head with pockets and holes for cam shafts, valves, valve springs, and so on. It is assumed that the part will be made on an existing set of NC machines with a continuous parts conveyor. Parts can circulate on this conveyor and visit any machine in any sequence. Thus transportation capability does not limit process planning.

The part is divided up into regions in two ways: by type of feature (hole, flat) and direction of machining (front, back, perpendicular, oblique). I believe that the software finds the features itself, but I am not sure about this. The machining system is divided into zones containing machines capable of dealing with one or more feature types and directions.

The software makes two types of calculations: finding the right zone for a group of features and planning the cutting conditions for each feature. When several zones are capable of making a feature set, the designer chooses one. He does this apparently without any consideration of workload in the zone from other parts. Each hole feature is classified by a group technology technique using such characteristics as number of steps, tolerance on diameter, need for threads and chamfers, and so on. From these characteristics, the cutting time is estimated and compared with the cycle time capability of the zone. The designer can alter the plan to correct cutting time imbalances among machines or he can try a different zone. The system then calculates the details of the plan such as cutter path and tool number.

The process plan for the valve cover took 5 days versus a month before the system was used.

Robot Offline Programming

I was shown a color 3D wireframe simulation of robots spray painting car bodies and parts. Both stationary parts and continuously moving cars were shown. The problem is to program the robot to move the spray gun over the car's surface. In the past this has been done on the factory floor by human teachers who physically grasp the end of the robot and move it while a tape recorder records the moves for later playback. The number of robots now has grown to the point where there are not enough teachers.

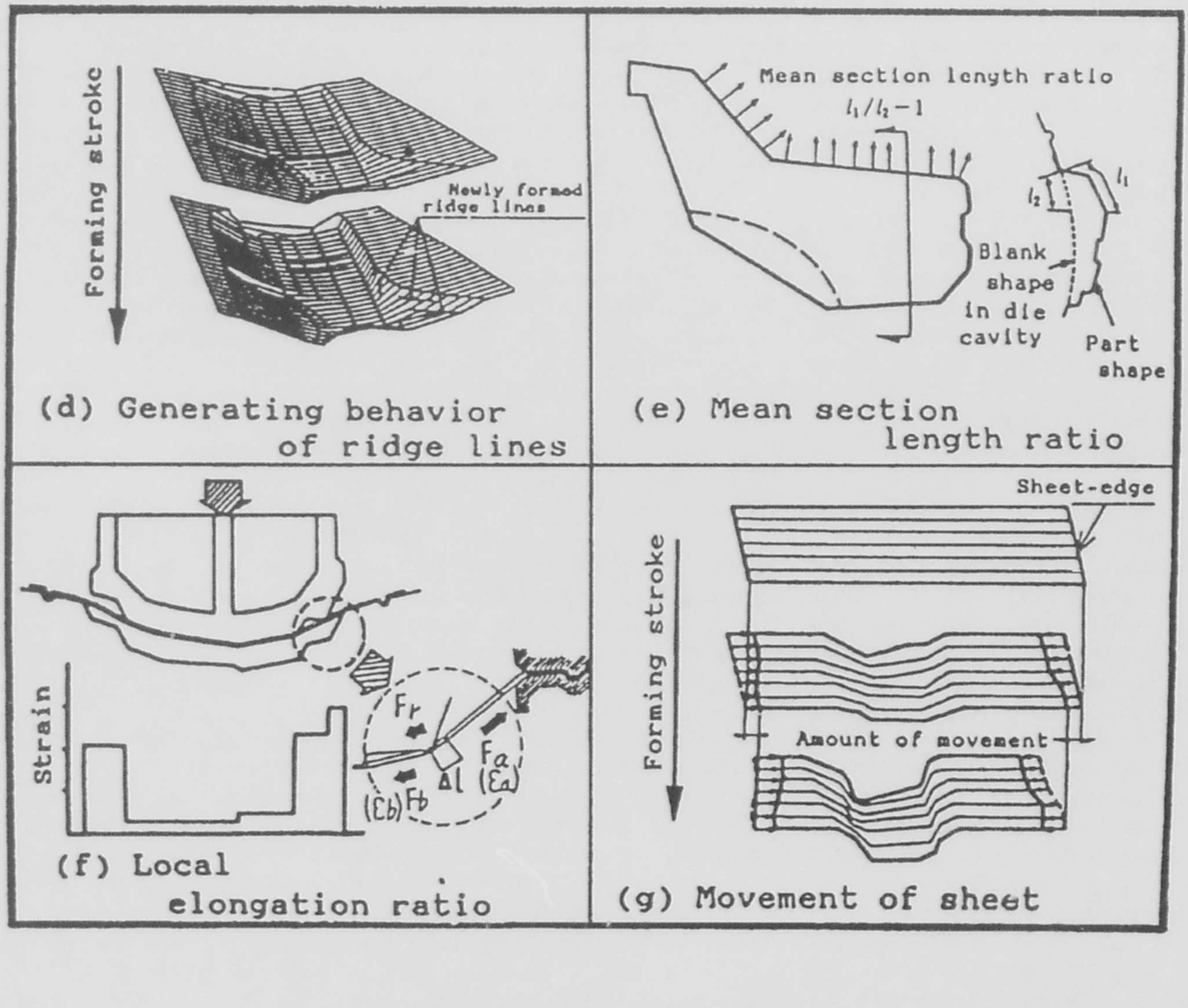


Figure 7. Use of the mean section length ratio.

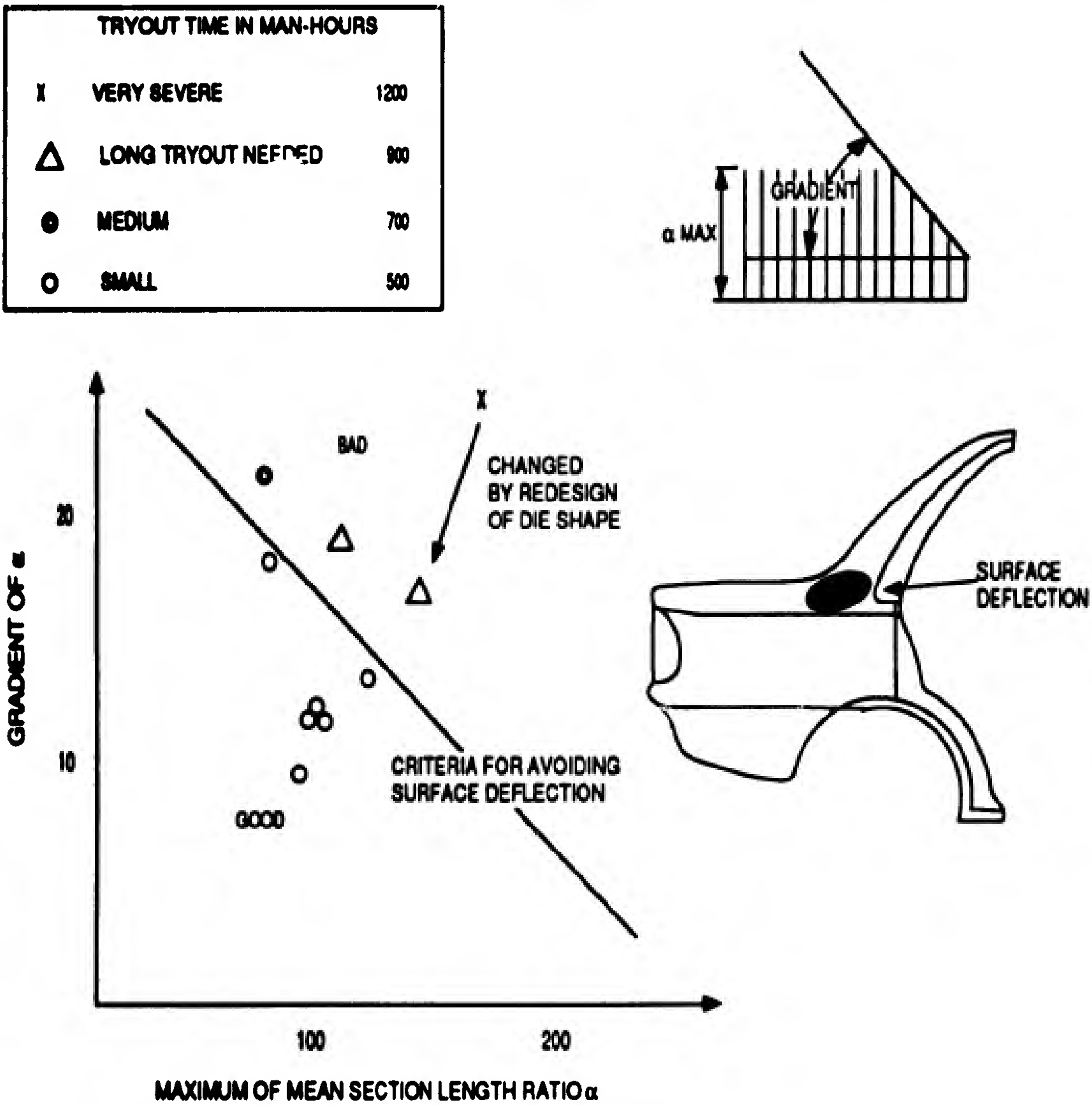


Figure 8. Criteria of surface deflection in quarter panel by the mean section length ratio. The pillar base of a quarter panel for a notch-back style car is in the shape of a saddle, which results in nonuniform forming. Therefore, surface deflection tends to occur at this portion. It is vital to check on the mean section length ratio as well as the spreading behavior of the punch contact area to avoid the surface deflection. The figure shows processed data of the formability evaluation according to mean section length ratio in 10 kinds of quarter panels of recent models. Maximum values of this ratio are plotted against gradient of this ratio and a line is drawn to separate the good designs from the bad ones according to the die tryout time.

This problem was anticipated some years ago and for the last 1.5 years the system I was shown has been in use. It is similar to commercial software available in the United States from at least two companies. The programmer moves the robot's tip with the mouse or by indicating target points on the car body and indicating offset distances from the targets to the tip. After a path pattern has been programmed, it can be duplicated and stepped along the surface so that it is "sprayed" completely. The robot's motions can then be simulated and two checks made: range of motion in each joint and interference between robot and car. The required motion time can also be calculated. Figure 9 shows the computer screen during programming of spraying the underside of an open car hood. The line of sight is from the outside of the transparent hood to the tip of the robot behind the hood. A simple path connecting target points at the edges of the hood is shown.

Curiously, even though the car body is represented by the CAD shape data from the styling system, and die faces can be machined by NC programs that are written directly from those data, the paint robot cannot be similarly programmed. The demonstrator, a Toyota programmer, said he will implement this obvious capability soon.

Another curious fact is that there is no feedback to the programmer concerning whether the robot path's velocity profile and distance from tip to part will provide a good paint finish. Possibly the software picks an appropriate profile once the target points are given.

CAD and CAE in Engine Design and Body Engineering

Typical applications are FEM studies of various types. These date from 1975 and have grown steadily until there are now 60 engineers developing or supporting such software. SDRC's solid modeler is the front end of many of these studies, but Toyota has its own pre/post-processor called CADETT. (Everyone I visit says it takes too long to prepare data for FEM analyses. Even those that have "automatic" meshers say so.) Two Crays and two Fujitsu vector processors support this work. NASTRAN, MARC, PAMCRASH, ABAQUS, and ADAMS are used along with a home-grown solid modeler called SURFES.

Engine component analyses include stress in pistons and connecting rods, temperature distributions, vibration in pipes and oilpans, and residual stress in machined aluminum engine blocks. Simulations using in-house software include piston slap, torsional vibration, oil film thickness, volumetric efficiency, and valve train dynamics. Piston temperature distribution calculations required a fuel consumption model as well as effects of coolant and lube oil on heat dissipation.

In a video I saw very accurate rollover simulations, side by side with actual cars doing the same thing, plus behavior of active suspensions and skid control systems, engine block-transmission case torsional vibrations, and acoustics of a car interior.

All of the demos I saw were either on video or in the software development and training facility so I could not tell how extensively they are used. However, it is obvious that most of these capabilities are in daily use and many have been for 3 to 5 years or more.

Future Needs and Plans

As mentioned above, I did not get a comprehensive view here like I got at Nissan. The needs expressed here are probably a fraction of what is on their minds these days. These include

(1) Better integration of databases. Right now many programs are in islands, requiring painful data conversion. This is especially true of FEM, where Toyota hopes some AI methods might be used to speed up meshing.

(2) New ways to design so that the percentage of automation of final assembly can be increased. Currently it is around 5% and they would like to see 20% or 30%. (VW estimates that it has had 25% since 1984.) One approach is to use more modules or preassembled units rather than single parts. Nissan brought up the same issue.

(3) Expert systems to help designers lay out the human factors of car interior design. These include where pedals should be located, what is a good view angle or range to dashboard items or out the window, and how much force is needed to move handles, wheels, and buttons.

(4) Artificial reality to aid interior design.

Concluding Remarks

Toyota emphasized several points that I also heard at other companies. First, CAD planning activities and implementation departments are a permanent feature of operations. These departments are staffed at least in part by former engineers. They are very conscious of the needs of users when they design new CAD tools: try to recreate the designer's previous working environment and methods and provide tools that the designers can understand and therefore trust. These ingredients are essential in getting the tools accepted and used regularly.

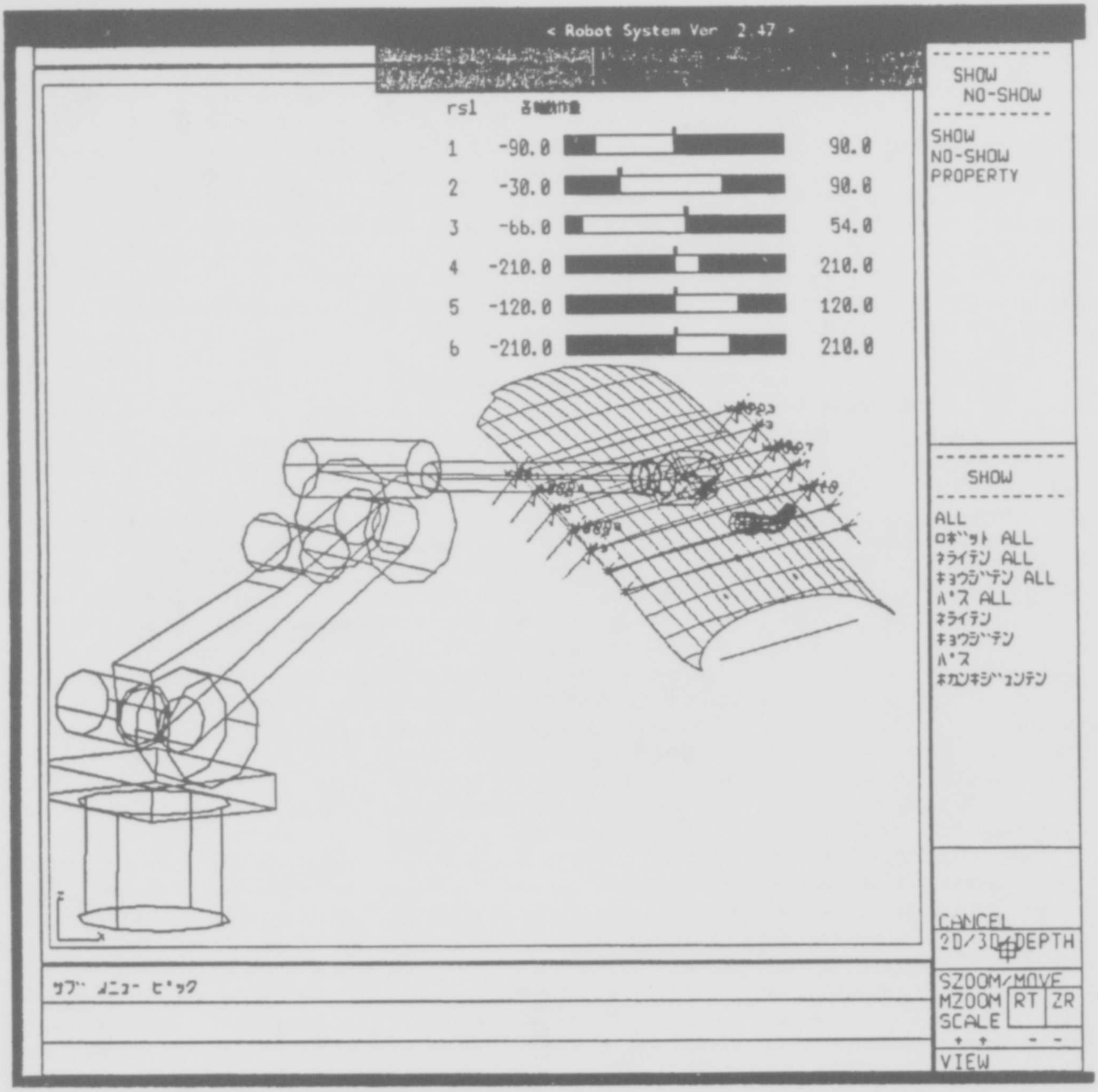


Figure 9. The computer screen during programming of spraying the underside of an open car hood.

PROF. TOMIYAMA, UNIVERSITY OF TOKYO

15 August 1991

Background

Prof. Tomiyama and Prof. Yoshikawa share a laboratory devoted to modeling engineering knowledge and design processes. While Yoshikawa is engaged as Vice President of the university, Tomiyama is in charge in the laboratory. His background is mechanical engineering, but his research approach is strongly linked to artificial intelligence (AI). It is an interesting combination with many possibilities.

The research has two related branches: design and maintenance. Each should have a theoretical basis, and he aims at providing the base via representations of deep knowledge about "how things work."

Design

This research has two branches itself: understanding the design process and understanding designed objects. The design process to him means understanding how people think, including cognitive process modeling. His route to a design theory is similar to that of researchers in the United States who, like him, use protocol analysis to determine what the designer is doing. (Protocol analysis comprises recording, often with video, what a designer does during an experiment and then analyzing the record--the protocol.) Unlike some U.S. researchers, Tomiyama tries to link the protocols to a computer simulation of the process. However, he admits that the protocols do not really tell him anything about what the designer is thinking or how the process actually proceeds.

Modeling of designed objects comprises "CAD without pictures," a term he uses jokingly but which is quite important. Like others, including myself, he feels that conventional CAD puts too much emphasis on pictures. Fascination with the pictures obscures the fact that no real knowledge has been captured in the design. The challenge is to find a way to capture "deep knowledge," by which he and other AI-based researchers describe knowledge about complex relationships among physical phenomena, for example. Deep knowledge is different from "facts," such as "every screw goes into a hole."

To capture basic knowledge, Tomiyama is using Qualitative Physics (QP) and Qualitative Reasoning (QR). The goal is to represent things symbolically so that facts can be reasoned about. This approach has the promise of creating "intelligent CAD," but in doing so appears to sacrifice many aspects of existing quantitative models. Tomiyama disagrees, saying that QP augments quantitative models because it can be the basis for generating symbolic models.

Long term, the goal is to create a meta-model (literally a model of models) that will contain the usual engineering models as subsets. Products would also be modeled in this way. Other researchers' ideas about product models are too geometry oriented for him. He would rather model where the geometry comes from. (This means that his goal extends beyond the needs of design to the needs of engineering in general. The utilitarian needs of design may not require the wheels of basic engineering to be reinvented every day.)

A demonstration system (see below) suggested how such deep knowledge might be able to find out behaviors or consequences of a design that the designer had not thought of. This would be a powerful and useful capability. To begin this effort, he put five students to work last year defining all the engineering knowledge chunks they could think of. The result was 3,000 chunks. These describe phenomena in hierarchical classes. Under "movement" one finds rotational, straight, oscillating, accelerating, and so on. For each one there is a capsule description using qualitative terms like accelerating, plus, connected to, and so on.

A moment is described in terms of two objects, one of which exerts a force on the other from a distance; if the moment is applied by one object, the other rotates. Coils and magnets can exert forces. Shafts connected to bearings can rotate. When current passes through a coil, it acts like a magnet. It also gets hot. Things that get too hot can melt. An inference engine browses through a model constructed of such chunks and finds out if the conditions for rotation are satisfied: there is an object containing a coil that can rotate, there is another object that contains a magnet, there is a source of current to the coil, the resulting force can exert a moment, etc.

Qualitative physics sits at the top (currently) of a hierarchy below which are "confluence-based (C-B) QP" and "Qualitative Simulation" (QS). QS comprises a qualitative description of the relationships between variables in equations. Typical output consists of conclusions like "if voltage A increases, current B will decrease." It has been applied by other researchers for at least 15 years to fault diagnosis of chemical plants and is used in the self-maintenance copier described below. C-B QP takes a topological description of a designed object and seeks to derive a qualitative equation description, upon which QS can operate. QP allegedly can generate the topology, but I think the designer currently must input nearly all the information from which the topology is derived. This topology comprises both the physical arrangement of objects and that of the physical principles underlying the object's behavior.

A quantitative version of all this has existed for about 30 years in the form of "bond graphs." Bond graphs model the energy flows between fairly general discrete elements like energy storers, transformers, and dissipaters. These elements can actually be electrical, thermal, fluid, or mechanical in underlying nature. The designer supplies the topology, which consists of mapping the energy flows. The equations can be derived algorithmically and are quantitative. The origin of this method is dynamical analogies, discovered when it was shown that the differential equations for many engineering systems had the same form.

Two objections can be raised to the bond graph approach. First, it cannot be reasoned about by existing AI systems. Second, it cannot easily handle logical state changes, such as that once a wire melts, the coil will not conduct electricity any more. This capability is important if one wants to capture the failure modes of a design, especially the unanticipated ones. In addition, some systems undergo logical state changes that are not failures but are merely different normal behaviors. The copier in our office senses the position of the input paper guides, decides which way the original is oriented, and selects the correct paper tray.

Tomiyama feels that these are not drawbacks but merely reflect the fact that bond graphs are meant only to model energy flows and fail to represent other aspects of physics that designers must take into account.

I was shown a demo of a QP system for modeling simple discrete physical systems--the same kind that bond graphs model (Ref 18). The item modeled is a simple one-, two-, or three-pole motor comprising a shaft on bearings carrying the coils (poles), wiring of the coils to a commutator, and two permanent magnets. Facts about magnetic attraction, moments, rotation, state change of the commutator, and rotary acceleration caused by torque are assembled by the designer into a model of the motor, a portion of which appears in Figure 10. The computer knows many side effects of these knowledge chunks and constructs its own extended meta-model.

From the meta-model the designer can elicit simulations of all effects or he can request "aspect" views, such as evolution of rotational states or thermal states. Behavior of the rotational model is started from given initial conditions on pole angle and velocity. Some states permit rotation to start and continue. The computer can deduce that cyclic state behavior exists. Other initial states are neutral; the magnets cannot exert any net torque and rotation does not occur. Instead, coil heating occurs. In the thermal model, states progress from cool to hot to melted. Operation of the motor is henceforth impossible regardless of changes in the initial state.

The dead state from which failure ensued is symmetric, a condition that is impossible for a three-pole motor. Dr. Kiriyama admitted that his system does not know the concept of symmetry and in any case could not generate the three-pole design following detection of the two-pole design's shortcoming. He said that QP is not good at such generalizations.

Maintenance Theory

The goal here is to understand how to design things so that they can fix themselves, at least to a limited degree. There are two advantages to such products. First, time and effort are saved. Second, the product may be able to fail soft. That is, degraded behavior may be available as a backup even if the failure has eliminated top quality behavior.

Two issues are involved here: how to design things that have backup modes and how to equip products to diagnose themselves and bring these backup modes into play. The latter has been explored in a self-maintenance copier. Electrical variables are manipulated to compensate for the degradation of electrically driven components. A publication (Ref 19) discusses gear-driven devices as well, but the opportunities for functional redundancy are likely to be more limited in such cases.

The central idea is self-diagnosis and generation of a repair strategy using QP. A copier in the laboratory has been augmented by a monitoring computer, a diagnosis computer, four sensors, and three controllers. One of these measures copy density. A QP model of the elements that affect copy density has been built. Degradation of the halogen lamp was simulated and the system proceeded to determine that raising the lamp voltage was a feasible fix.

The method requires the user to put in the QP model, from which the computer can derive a QS. The computer first reasons backwards from the observed sensor readings to determine possible causes, listed as voltages, resistors, and so on. It then assumes that the causes cannot be changed and identifies variables that it can manipulate, as well as the effect these variables would have given what is apparently broken. Among the available choices, some will produce side effects in addition to the desired one. The candidate with the fewest side effects is chosen (see Figure 11).

The diagnosis computer recommends a small voltage increase for the lamp, which is implemented automatically through a controller. The test is repeated, as is the recommended fix, until it cannot further improve the copy density. Either the process halts here or the diagnosis computer shifts to a second variable, the main static charger voltage, and tries to gain further improvements. This is actually a simple axis-by-axis search.

Note that all of this could have been accomplished with a quantitative linear model composed of influence coefficients relating controllable and observable variables. This method is well known and widely used in control, simulation, and optimization. The objection is again that logical state changes are not easy to represent, except by altering the coefficient matrix. However, I do not see why that is difficult. Everything that is called "reasoning" above can be accomplished using linear algebra or circuit theory implementations of it. Multi-axis solutions can also be readily found, such as simultaneously raising one voltage a lot while lowering another one a little. I do not know if QP can do this.

Tomiyama feels that linear algebra approaches cannot handle noisy sensory data, represent portions of a system that are completely broken, or permit traceability of symptoms to causes that are very subtle. He cites Three Mile Island and Chernobyl as examples of systems that failed for lack of suitable reasoning during their design. [However, the fact that Chernobyl-type reactors are inherently unstable at low power is well known and was known when it was built.]

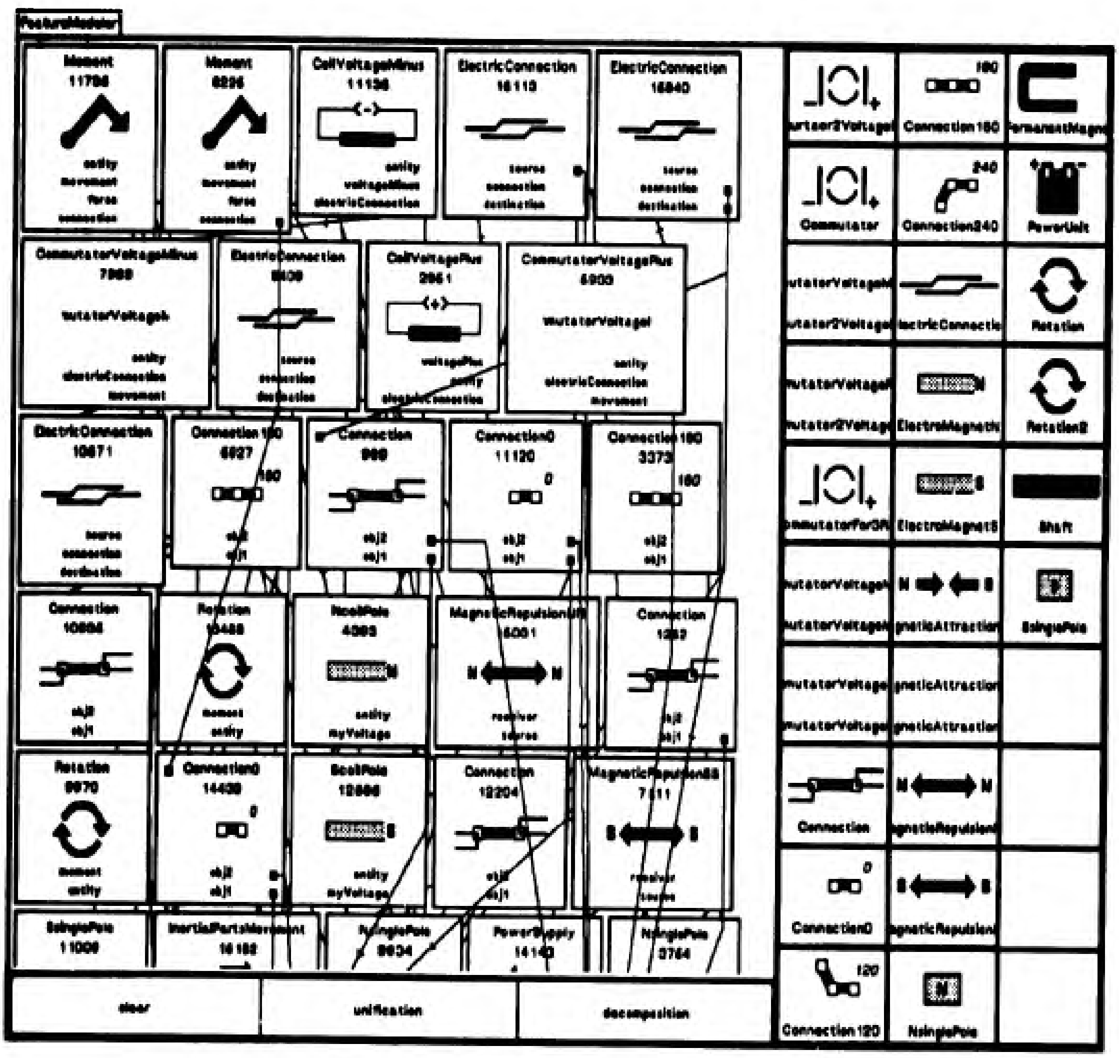
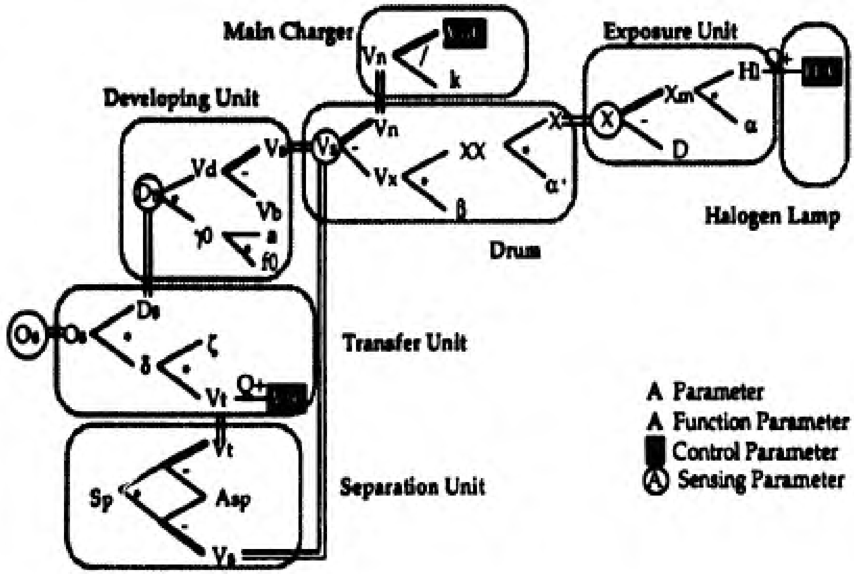
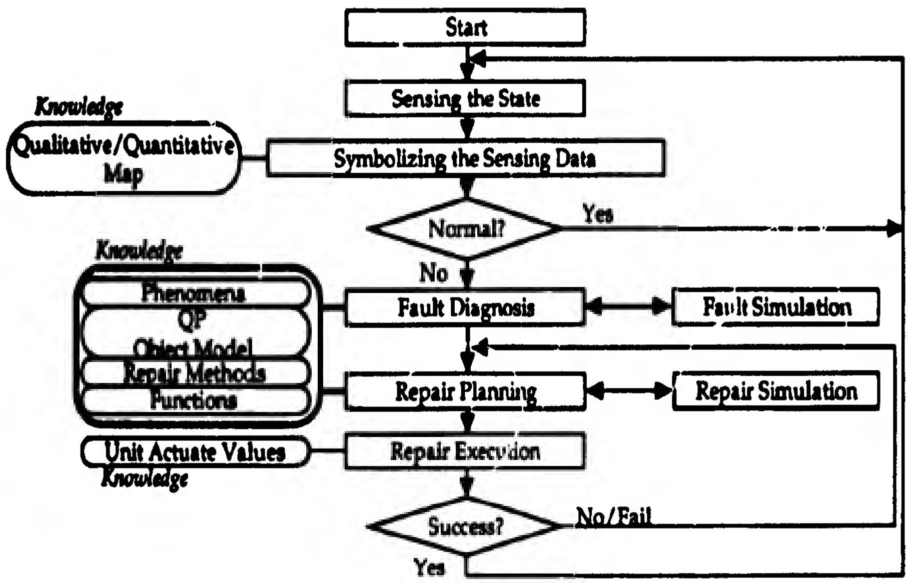


Figure 10. Primary model of a two-pole motor.



Parameter Model of the Self-Maintenance Copier



Algorithm for the Self-Maintenance Copier

Figure 11. Parameter model and algorithm for the self-maintenance copier. From Ref 19; reprinted with permission from ASME.

Comment

Qualitative models appear to have many advantages, among them being the ability to represent important behavior patterns with relatively simple models. However, it remains to be seen whether they can ever attain the sophistication and complexity of well-developed quantitative models, such as those exhibited by the automobile companies for simulating crashes, skids, and air flow. Tomiyama feels that QP not only can coexist with quantitative models but has the potential to model types of phenomena that cannot be represented in traditional models. My feeling is that augmenting quantitative models with logical state variables could increase their generality and a meeting ground in the middle might be found.

HITACHI-SEIKI (H-S), ABIKO WORKS

21 August 1991

Background

Our hosts were Mr. Kubota, R&D Center Director, Mr. Ishihara, Controls Design Manager, and Mr. Takeshita, General Manager of the Technology Development Center. Other interesting participants were Mr. Otani, General Manager of the Design Department, and Mr. Katoh, Manager of the Technical Research Department.

H-S makes machine tools very similar to Yamazaki's, but the company is about one-fourth Yamazaki's size. It is in a similar state regarding CAD and is less modern in its manufacturing facilities. However, H-S uses its own FMS for making almost every part it uses. No other kind of machine tool or system was observed. In fact, H-S uses not only FMS but also several temperature-controlled rooms for machining and assembly for the purposes of improving quality and of impressing customers. The company has 1,700 employees and makes about 3,000 machines per year.

Unlike Yamazaki or any of the "big 5" in Japanese machine tools, H-S makes special transfer lines for the auto industry. These are totally different in technology and structure from the NC lathes and machining centers which comprise 80% of its sales. Like Yamazaki, H-S has trouble selling FMS. Customers want simpler machines and systems such as the six-pallet storage machine. The pallets can be loaded in and the machine left overnight to work the parts. H-S has not yet resorted to high-pressure sales tactics for FMS the way Yamazaki has. Yamazaki even makes its own six-pallet machines look bad in economic comparisons in the hope of selling more FMS.

H-S's main business problem is managing fluctuations in demand. Five years ago the transfer line business fell apart and many people had to be relocated. Today they have 50% more design business than they can handle. "It's a big panic." Their CAD does not help them much. They work nights and weekends and take on marginally capable subcontractors whose work they must often redo. H-S is the only company to admit to me that this type of overwork hurts product quality, including design quality.

However, you can't say no to a sale, especially from a car company. They know when to buy, that is, when the suppliers are hungry. H-S notes, in a fascinating aside, that they used to be able to count on a lot of design help from the car companies' own engineers but that's not true any more. Those engineers now have only 2 or 3 years' experience and H-S ends up teaching them!

A major reason why H-S is having trouble is that they are behind in CAD and cannot utilize many sophisticated concepts such as data archiving that would permit them to use past designs more quickly. All they have is a home-made alphanumeric database consisting of part names, machine models, part size and material, and year the part was designed. It is a memory-jogger system that behaves like a library card catalog. Any way the designer can think of to help him remember a part is available to help him narrow the search. The output is a part number. He must then go to the CADAM system and punch in the drawing number in order to get a picture of the part.

They have brought in outside consultants in the hope of making their factory floor more efficient. Right now a few hours of actual cutting time takes 10 days. All they got from the consultants over 2 years was advice to group all the needed machines around the parts, which is a variety of flow shop. Such an approach is bound to be costly and inappropriate for a job shop environment. Analytical techniques exist to address this problem, but it is a tough one. The FMS was invented in the first place to address just such situations, and nothing much better has come along since. Only Yamazaki has learned how to design its parts to make FMS particularly efficient. H-S's president has challenged his people to become more standardized in their design methods. They are still in the process of interpreting this challenge and may again utilize outside professional consultants. Right now their only response is to consider more reuse of existing designs and more modularization of their subassemblies. They do not have a strong tradition of the "series method" described by Yamazaki. In general, they do not have a clear view of the importance of design methods, designed characteristics of their machines, and design technology to improving their company.

Use of CAD/CAM/CAE

H-S relies on CADAM. Ninety-five mechanical engineers access 28 terminals and about 20 drafting boards. They would buy more terminals if they were not so costly (average ¥400,000/month including the host IBM 4341). They think workstations will be their next move.

All the facilities of CADAM are used, including generation of NC data. This is sent via fiber optic cable to the factory control room.

Eight months ago they got CAEDS, the IBM version of SDRC's I-DEAS solid modeler, and they are just learning how to use it for stress and deformation analysis of machine tool beds.

Even if they get a terminal for every designer they will not abandon paper because the CAD screen is too small. Other companies have said the same thing.

Product Design Methodology

H-S has two product lines, medium size NC lathes and machining centers and transfer machines. The NC machines take about 2 years to design: 1 year for concept design, 6 months for detailed design, and 6 months for preproduction tryouts and performance documentation. This leaves out fabrication of the prototypes, but I assume it is included in the first 18 months.

The transfer lines present a totally different kind of design task, since they are made up of a linear string of standard modules. Each module drills a set of holes, machines a flat, taps a hole, or does some other simple operation on an engine block or other similar item. Figuring out what each module should do and wiring up the controls are the major challenges. Such a machine takes about a year to design and build. A set of four almost ready for delivery to Nissan were scheduled for customer buyoff the day we visited. Our hosts and I together estimated that about 112 man-months of design effort were involved in this system, which had over 75 modules. Half these man-months were obtained from subcontractors, as were many of the machines' more standard elements like conveyors.

As far as I could tell, there were no computerized methods in use for determining line balance or job assignment in the design of these transfer machines. One experienced person accomplished these essential conceptual steps in about 3 months.

To support all of this design activity, H-S has 95 mechanical engineers and 35 electrical/electronic engineers. Another 20 engineers are in R&D. About half of the engineers are in production and manufacturing. They comment extensively on the product designs but apparently do not take a large part in product design itself. About half the product designers are skilled in production techniques already. Even so, H-S agrees that there is too much delay and correction to the design drawings; about half are returned for changes or questions.

Engineers gain their breadth of experience from a short 4 months initial training plus continuous rotation until age 45 or so. After that, an experienced designer stays put. Those that do not understand production methods and new technology are "a headache."

H-S is having trouble attracting new employees. North of Tokyo is not considered "in" territory. Other Hitachi companies located in the area said the same thing.

Otani, the Design Manager, operates with a number of rules of thumb. For example, to do cost estimating, his first test is to count the parts and multiply by ¥10,000. To determine if his designers will be over- or under-loaded, he multiplies the predicted sales by 10% and compares to his shop's salaries. He can support ¥6,000M of design effort per year, so annual sales over ¥60,000M will force him to go to outside contractors or overtime.

There are few systematic design techniques in use. Tolerances are determined by reference to previous "experienced parts." Only recently have they begun to adopt the idea of the "error budget" for allocating tolerances with the aim of obtaining a final accuracy requirement. This is much more sophisticated than their current method of just using higher accuracy components.

Similarly, cost analysis is based on past data, especially since 80% of the parts are identical to existing ones or nearly so. New parts are hard to predict. The main components of cost are materials, vendor costs, and machining time, expressed in standard hours.

R&D Activities

H-S has originated a number of interesting concepts. From their own experience using their products, they realize that setup time is a major headache for customers. So they have developed novel techniques for easy setup and programming of their machines and easy in-process measuring of parts. This is based on programmable logic controllers (PLCs) that they build themselves and link up to Fanuc controllers. The PLCs do the work while the Fanuc controllers provide a familiar name and an easy user interface.

Other R&D activities include direct drive spindles (like Mazak's, I presume) and two-component casting of machine ways. These castings are cast iron underneath plus a layer an inch or so thick of steel on top, where the ways are machined. My hosts could not explain how these parts are cast.

New products include laser heat treating and machines that grind ceramics, especially for bearings. Kyocera is a big customer. Their product has half the market because it is priced aggressively, the result of its being just a modified NC machining center with some novel tool attachments.

Factory Floor Tour

This factory makes more specials and fewer ordinary machines. The "mass production" work is at another factory where five machines a day come out "right on schedule." Assembly line repetitive working conditions drive many of the employees away. They can easily get jobs nearby since the whole area's manufacturing economy is growing.

Regardless of the kind of work, the Abiko plant is fully automated in machining and partly so in material handling. No automatic guided vehicles (AGVs) are visible as at Yamazaki, however. There are several FMS lines, most about 8 years old. Rescheduling them is a problem, since it takes haif an hour. It appeared that the larger systems were not very efficient and not well utilized. At least one suffered from an old design error, namely, a single straight line parts transfer vehicle with one-part carrying capacity and no buffer positions at the machines. Moving parts around is like solving the cannibals and missionaries problem. This error was discovered at Caterpillar in the mid-1970s. The more successful H-S FMS have more buffers at each machine and a continuous flow conveyor system with parts circulating past the machines all the time. The advantage of this setup was also recognized in the mid-1970s.

Significantly, H-S plans to junk the oldest and least efficient FMS and replace them with stand-alone computerized numerical control (CNC) machines. It may arrange some of these into part-type-specific cells. One L-shaped cell for spindles has already been tried successfully.

The most interesting system would interest Prof. Okino of Kyoto University. It is called Holonic and won a prize for H-S in 1988. This system consists of a number of machine cells and continuously circulating parts. There is no overall schedule. Instead, parts are marked with bar codes that permit each machine to recognize the part and its required remaining work. A part can go to the next machine that is capable of doing the work it needs next. The operators have "human involvement" consisting of giving certain parts priority in this unstructured environment and of determining the overall behavior of the system by choosing which parts to load into it. This system resembles in both physical layout and human involvement a system build by Sunstrand for Ingersoll-Rand almost 20 years ago. It was very efficient and easy to schedule.

Future CAD Needs

I got in English only part of the long list Otani gave in Japanese in response to this question. He sees the potential of solid modeling as an input to CAE such as static and dynamic analysis. The main use for this is to shorten the 6 months of performance validation that is currently required of new designs. He also wants to be able to design one-of-a-kind machines, such as transfer lines, more efficiently than he can now. These are not money-makers in the current environment and use up a disproportionate share of his engineers. More extensive use of standard elements would be a likely outcome. He calls this "automated design."

FUJITSU TECHNICAL CENTER AND FUJITSU LABORATORIES, KAWASAKI

22 August 1991

Background

Our hosts were Mr. Fujii, General Manager of Corporate Manufacturing Systems Development, and his assistant, Mr. Asada.

Fujitsu is a large diversified company focussing mostly on computers and electronics. Its major products are mainframe and supercomputers, as well as laptops, high performance disk drives, array processors, low noise super transistors for use in space telescopes, and so on. Unlike IBM and Hitachi, Fujitsu has not suffered a drop in mainframe computer sales (although sales have been slowing for years) because mainframes are used in large communication systems and commercial systems like those for banks, automatic teller machines (ATMs), and airlines.

Fujitsu's introductory video stressed use of computers to do things "the way people do." Applications under study include neural net machines for machine translation and robot controls. Other work is on x-ray lithography at 0.2 micron line width, coherent light digital optical communication, optical memories, ceramic circuit boards with approximately 50 layers (probably for use with multichip modules although that terminology was not used), and real time image processing.

Fujii's people mostly do electronic design, so most of their CAD/CAM is in that area. He showed only mild interest in our group's work in feature-based design and modeling of mechanical assembly processes. He may have felt that I was proposing to replace the designer with a computer program, whereas I was proposing a tool to help the designer sort through many possibilities. His final judgment was diplomatic: when solid modelers become easier to use, then our work will be of great interest. However, he stressed that design is very complex and the designer considers comprehensively all the factors at once. Such a process cannot be given to a computer.

Design for Assembly (DFA)

Mr. Miyazawa gave a short presentation about Fujitsu's home-grown DFA methodology. It employs a PC to take in data from the designer about the assembly, including part descriptions, part mate types, and so on. I remarked that all of this data would be in the feature-based solid modelers of the future.

The DFA method has four characteristics: to provide a quantitative estimate of ease of assembly, to give a rough estimate of (manual) assembly time, to improve the design, and to be easy to use. Its objectives are to reduce the cost of the product, to shorten the development time, and to provide an easy way to communicate to factory personnel about assembly problems.

In these ways the method remarkably resembles Hitachi's, which they know about but have not bought. My report is sketchy since, like Hitachi, they do not want to give out all the details.

To use the method, the designer makes an assembly flow chart (presumably an assembly sequence) and types in data about the parts and mates. The computer scores 30 different characteristics, such as direction of assembly motion, part size in relation to direction, the method of attachment, whether the part is flexible, how many moves or actions are required to affix the part, and so on.

Unlike Hitachi, Fujitsu's method includes some interesting twists on part characteristics. Parts are designated as "main," "subsidiary," and "fastener," among others. Fastening methods are designated as single action, snap action, and so on.

The scoring is done separately for each class of part and a profile is made up. A perfect score would be a product with one side, one direction, single action assembly of rigid, little parts. The score is presented either as a spider chart or a profile and is accompanied by the scores of recent similar products. From these charts, obvious ways the product is worse stick out clearly: too many awkward fastening methods, too much effort to put in subsidiary parts, not enough simple actions, and so on. Using this method, the estimated manual final assembly time of a laptop computer was reduced from 6 minutes 20 seconds to 5 minutes 10 seconds.

After this presentation, Fujii remarked that DFA is part of Concurrent Engineering (CE), whose job in his opinion is merely to make the product easier to make, shorten development time, reduce costs, and reduce the number of prototypes needed. He specifically feels that CE does not (cannot?) address product quality and function. The design for assembly/manufacturing (DFA/DFM) aspect of CE makes it hard enough already for the designers, and he worries that they cannot remember everything. So he is in favor of computer tools to help them.

Aside

Several companies have their own DFA. Each shares basic properties but each has interesting additional elements that reflect characteristics of the products or of the underlying philosophy of what DFA ought to be able to accomplish. Nippondenso is the broadest, but Fujitsu is the most careful in identifying different kinds of parts and thinking that they should be scored differently. No basis is given by any company for the different emphases; they just appear obvious to the developers.

New Method for Mold Design Linked to Rapid Prototyping

The brief presentation was in Japanese with interpretation. The overheads were also in Japanese, so I could not follow too well. The laboratory tour afterwards was better.

The old method of mold design was a series of steps, each with an approval before the next one could start. The steps are, approximately: initial part design, design verification, mold design, and mold feature evaluation. Each step was conducted by an expert. Too many people had veto power, too many steps were done sequentially, etc.

The new method uses the same experts but launches them simultaneously. Significantly, it was stated that merely doing this does not save any time. In addition, the team needs some computer tools. The ones in use at Fujitsu are 3D structural design using SDRC's I-DEAS solid modeler, mold flow software, and stereolithography. The latter is implemented on a machine called SOUP (Solid Object U-V Laser Plotter) made by Mitsubishi. Input to this machine is via I-DEAS.

(Stereolithography is a technique for making rapid prototypes of solid parts. It functions by forming a part layer by layer, either from a liquid or a powder. Laser scanning is commonly used to form each layer. In the SOUP and similar machines, the laser scans the top free surface of an ultraviolet (UV) curing liquid plastic. When the layer has formed, the object is lowered about half a mm and the process is repeated. Parts with re-entrant features can be made as long as a hole is left to remove the uncured plastic. The layering gives the part a stepped outer surface finish just like "jaggies" on computer drawings. These are usually handsanded off.

Stereolithography is capable of creating the shape of a part, and methods exist for using it to make metal molds from which parts of the correct material and strength can also be made. The method permits people to quickly "get their hands on the part," including communicating to factory or subcontractor personnel in ways that drawings cannot.)

Fujitsu uses the SOUP output to make a mold from silicone rubber. Accurately made silicone inserts are used to create some mating surfaces, with the result that mating pairs of molded ABS parts assemble with surprisingly close-fitting mates.

A companion rapid prototyping facility is a Fanuc NC machine, which is programmed from a ProEngineer system. (ProEngineer was chosen specifically for its easy user interface, suitable for the technician they have assigned to operate this facility.) This machine makes smooth profile molds for items like telephone hand sets, which are also molded from ABS. The handfeel of such items can then be assessed.

The cycle from sketch to solid prototype part is 3 days, most of it taken up by 24 hour per day operation of the SOUP machine itself.

Other Uses for CAD/CAE/CAM

These are fairly routine, compared to the rapid prototyping. Typical FEM is done using NISA 2, commercial software from the United States. Vibration, deformation, and stress analyses are done on a Fujitsu workstation. Fujitsu also uses FEM5, an in-house product, and ABAQUS. The preprocessor is called Concept Station, made by Unigraphics. CADAM is used for ordinary engineering drafting.

Another in-house program is coincidentally called ICAD, but has nothing to do with the U.S. company of that name. This in-house ICAD is for mechanical design. They did not show it to me and said that it needs improvement. They are more proud of ICAD's circuit design capability, but did not show that either.

Other Tour Sites

Mr. Uchiyama hosted us on a tour of Fujitsu Laboratory's robotics activities. These included a simulator for zero-gravity robot operation, robot off line programming, precision class 10 cleanroom robots for disk drive assembly, and a space mechatronics laboratory. The latter is making experimental modules for Space Shuttle or Space Lab activities in the late 1990s. Fujitsu has about 100 of its FAROT precision PUMA-style robots in use, mostly for precision assembly and circuit board probing. These robots have about 30 micron repeatability. Uchiyama was the designer of the first prototype for this robot over 10 years ago.

NIKON NISHI-OHI WORKS

23 August 1991

Background

Our hosts were Mr. Okuda, General Manager of the Production Engineering Headquarters (HQ), and Mr. Okamoto, the Senior Assistant Manager of the CAD-CAM [computer-aided design/manufacturing] Center, a very astute person who may be ahead of the rest of the company's thinking on many issues.

Nikon is a diversified optical company with 7,200 employees and $2.2B annual sales (at ¥150/$). The main products are cameras (42% of sales), instruments (microscopes, theodolites, surveyors' telescopes - 7%), industrial equipment (mostly for making semiconductors and recently "very busy" - 32%), and eyeglasses (8.5%). Smaller divisions have less than 4% each and make electronic imaging cameras, magneto-optical storage disks, and bioengineering products, such as glass-coated metal dental implants.

The Production Engineering HQ is a corporate-level activity that makes production equipment for all the divisions. While equipment design is done at Nishi-Ohi, some of the equipment manufacture is done at the plants where it is used. Curiously, Okuda does not report directly to Corporate HQ but instead to the Executive Director (VP) of the Industrial Equipment Division, who reports to the President. There is one other Executive Director, for Consumer Products, the only other main division. Okuda says that reporting in this asymmetric way causes no problems. In any case, Nikon is generally typical of Japanese companies in making its own manufacturing equipment in a corporate-level department.

Okamoto stressed several times that Nikon is a conservative company that serves a conservative and highly professional clientele.

Product Design Methodology for Cameras

Camera technology is changing rapidly, with microelectronics being the main driver. From a mechanical viewpoint, the main change is to styling the exterior with arbitrary sculptured surfaces. This has thrown the camera companies right into the car design arena without the car companies' years of gradual buildup of experience, attitudes, and software development resources.

Altogether Nikon has about 100 camera designers, split 70:30 mechanical:electronic. (Since the optics are designed elsewhere I do not have a good view of that process. See the Ricoh report for an optics story.) There are so many design projects going on and so little time that the staff is stretched thin.

A top-of-the-line camera has about 1,000 mechanical parts. The F4 took 3 years to design and occupied 10 to 15 designers full time: 5 mechanical, 5 electrical, 1 or 2 optical, and 1 software. Lower level cameras may have 600 parts. Totally new cameras are designed every 2 to 3 years, with small changes all the time on 1-year cycles.

Another important driver of camera design is the almost vain attempt to keep the weight from growing as optics and other features are added. The main casualty of this effort has been the die cast aluminum body, which has been replaced by a set of precision molded plastic parts, usually 20% glass-filled acrylonitrile butadiene styrene (ABS). (The same material is the prime one for printer parts. See Seiko-Epson report.) Stress analysis would thus seem to be a prime concern, but neither Nikon nor Ricoh has enough solid modeling capability to use such techniques on a regular basis.

A third driver is price competition. Few Japanese companies can assemble cameras domestically. Assembly is basically manual and labor costs are high. Nikon, at the top of the price chain, can assemble in Japan, but it can (and must) fabricate only the critical plastic parts in-house. For the others, it makes use of (to us) a dismaying array of mom and pop shops scattered around town and country, working in poor conditions and subject to dismissal at any time. For this reason, among others, the influence of production engineers in the design process is not typical for Japanese companies, since they are not representing in-house people and it is difficult to predict the capabilities of such suppliers. Incoming inspection is a big effort.

The last driver is the design of a very complex and oddly shaped flexible printed circuit that holds several custom integrated circuits (ICs) and lots of little components. This must snake around to link several locations on several of the functional elements inside the camera (film drive, range finder, autofocus, autoexposure, liquid crystal display (LCD), flash, and so on.) Design of this flex circuit is tedious and not well supported by CAD.

The camera design process (same at Ricoh) begins with "industrial design" of the exterior. As many as 10 outer shell prototypes are made by hand from wood or styrofoam. Each such prototype takes a week to carve and finish. Design is difficult because hand-feel is important and peoples' hands are such different sizes. Especially U.S. and Japanese people are quite different in body size. No solid modeling is used for these explorations because it is "too slow." At least, the car company engineers tell Okamoto that! He also worries that no solid modeler could hold all the data for a camera's interior. Again, this mirrors car company opinion.

Stereolithography (SL) is not used. They have heard of SOUP (see Fujitsu report). For them, SOUP's 3 days is also too slow. (Yet they wait a week now??) But other SL machines give results in 2 to 3 hours. I was told this at Ricoh and shown the parts. They have rougher outsides than SOUP's, which is to be expected. Perhaps camera and phone designers must have the fine detail and smooth finish that take 3 days to create.

An important issue is weight and balance, which must be judged when outer shape is designed. Current and past data are both lacking on internal part weight and especially location of centers of gravity, a major shortcoming according to Okamoto. But the decision must be made anyway, usually by top management on a date set in advance on the master schedule.

When the outer shell is approved, a solid (actually surface) model is made and all subsequent engineering and preproduction prototypes are designed using CAD. "We pay more attention to feature lines than the car companies do."

The interior of a camera is divided into "blocks." We would call these subassemblies although each likely has several subassemblies of its own. The main blocks are the mirror box (for single lens reflex (SLR) cameras), the shutter block, the rewind spool and fork, and the takeup mechanism. Autofocus motor and gears are inside the detachable lenses of Nikon cameras. The size and shape of these blocks drive the shape of the interior of the camera. Dividing up the detailed functions of the camera among these blocks is "difficult" and no systematic procedure seems to exist. However, there is not too much room for change, and much of the arrangement of past cameras is copied in new ones. Each block is usually the responsibility of one designer, who rotates to another block on the next design cycle. Thus there are no "shutter gurus" and so on.

The main factors driving new block arrangements and shapes are elimination of the aluminum frame and radically new camera shapes, such as ones with vertical formats. (Videocameras in horizontal format have appeared as well.)

It is surprising to see little or no solid modeling in use to attack these problems or those of checking that all the parts will fit. Okamoto sees the potential very clearly but says that the camera companies are debating how to best approach the problem. In the meantime they make use of the ability of two-dimensional (2D) CAD to generate lots of cross section drawings, which they compare by eye with automatically generated sections of the solid model of the shell.

Once the outer shell is approved, the interior is designed and one or two engineering prototypes are built. All such design is on 2D CAD. About halfway through this cycle a co-located production tryout team joins the process. They will build preproduction prototypes before outside contractors and assemblers are launched. The designers visit the factory where the current models are made to learn about any problems they should avoid. Production people attend design reviews near the end of the design process but their comments are usually applied to the next camera. New designs are coming along all the time with so much overlap and so little major change that a phase shift of one design does not matter in applying the factory comments, or so says Mr. Sasagaki, the assistant manager of the camera design department. Major disasters are obviously prevented, and the designers learn to anticipate most other problems. Whether this approach would work at Canon with its more radical changes and faster design cycle is not clear.

They have heard of Concurrent Engineering but associate it with solid modeling, not with a different kind of design process.

Use of Computers in the Design Process

Most of the factories and other design divisions use CADAM or CATIA, running off a total of six large IBM mainframes (3090, 4341, or 9370). All the mainframes are linked by Ethernet and all the terminals in a factory or design center are on some kind of local area network (LAN).

Nikon uses Computervision (CV) for most of its camera CAD and CAM. Newer software such as a few seats with SDRC's I-DEAS level V operate on DEC or HP workstations. "Solid modeling" of the exterior parts is actually surface modeling with NURBS (non-uniform rational B-splines). Realistic shaded images are possible, though not as good as Toyota's.

These sculptured shapes are made by injection molding but, although Moldflow software is available in-house, it is not in use. Okamoto hears that it is hard to use. (Like many people in many companies, he could use better information than he can get.) The data for molded parts are converted from CV to CATIA in order that NC can be used to make the molds. The recently established Mito plant does all the mold design, fabrication, and part production for the company. CNC and direct numerical control (DNC) are used in the mold machining process.

CV's 2D drafting is used to design all the other parts, but the mom and pop shops do not have NC and usually employ hand tools.

Part of Okamoto's job is to modify commercial CAD software for internal use. This takes three forms: improving the user interfaces, creating data translation code, and integrating in-house special computer-aided engineering (CAE) software. An example of the latter is code written by Sasagaki to permit shutter kinematic analysis. It is not graphic but merely the engineering calculations. No animation is supported. They tried using IGES to transfer files but too much useless detail came along and the result was too big.

The flex circuits are designed using CV software. Okamoto says that CV is especially good at this aspect, but he admits that it does not support automatic routing or checking of node lists. These are pretty basic steps in complex circuit design that are supported fully or partly by other commercial software, but here the designer does it all by eye. All the software does is smooth the lines and check design rules like line width and spacing. The example circuit he showed had two layers and a very complex curved perimeter shape, plus about 100 parts including 6 ICs. It took "a very expert person" 2 months to design it but "visitors usually guess it took a year."

The CV software then computes a good route for the NC drill software for putting the holes in the circuit. For 332 holes, this step took about 5 minutes. Lens design is done in another department using Nikon's own ray tracing software operating on a UNISYS computer. In Okamoto's department, a simple geometric ray tracer is on hand to discover design problems like hoods that interfere with the image. He is equipped to handle customers' inquiries on such things by phone in real time.

Okamoto has some software research and development (R&D) responsibilities as well and would like to try many things that the company is reluctant to support or which he fears the designers would not use. Among these are use of solid modeling to check interferences and to support various kinds of design for manufacture (DFM) and design for assembly (DFA). Assembly planning is especially interesting but no one else seems to support him. He also wants to try artificial intelligence (AI) for helping the circuit board routing process and for converting 2D drawings into solid models. He is dissatisfied with current AI research on these topics since none of the methods appear fast enough.

The company has its own assembleability evaluation method (AEM), similar to Hitachi's, but the camera designers do not use it. The production engineers do, and complain that the designers don't. It is a manual method, not connected to CAD, though he would like to make this connection. "It will save enormous time and effort."

Other CAD/CAM

In the software R&D laboratory I was shown

- CAT [computer-aided testing; when mechanical engineers in Japan use this term, they mean computer-aided surface inspection of mechanical parts using a coordinate measuring machine (CMM)]
- CAD of eyeglass frames
- Conversion of 2D drawings to three-dimensional (3D) models
- Reverse engineering of arbitrary shapes (scan part and create computer model)

CAT has been improved by providing offline programming of the CMMs that Nikon sells. The goal was to create a computer screen imitation of the CMM's control console plus an easy graphical user interface. CAD data about the part to be measured are used to drive the software. Animation of the machine's actions and pictorial images of available measuring probes are also available. He hopes that this software will enhance sales of CMMs, which are slow.

CAD of eyeglass frames is done on a color Silicon Graphics console using a drawing program similar to many now available on the Macintosh. A very skillful woman demonstrated this. It permits lens shapes and frame shapes to be designed. Both can be colored realistically, and nice advertising-style drawings can be made. NC data for cutting molds for plastic frames are also generated. Several features of the process are dimension driven, but it was not clear if any constraints can be imposed.

Conversion of 2D models to 3D is done interactively. The user can apply some primitive feature-based design while selecting which portions of a drawing to convert. The process carries along some extra lines which the user removes with mouse clicks. This would be a useful companion to the CAT software but it is still under development.

Reverse engineering is done by using the CMM to scan a part, such as a clay model for a camera. (Ricoh uses a laser.) They have no confidence that any future CAD will permit direct camera design on a screen.

Future Needs and Problems

Okamoto is worried that Japan is falling behind. "The U.S. is 10 years ahead in use of solid models," he says. But he knows that faster and larger product variations are con ,g, and the design cycle must be shortened. The designers do not see the wave about to break over them. Just introducing solid modelers will not be the answer, because the entire design process must be thought through and restructured. There must be more standardization, reuse of past designs and data, and more systematic methods. These changes cannot be imposed from above because Japan is too bottom-up oriented, meaning that the rank and file must get behind the effort first.

As if to underscore the problem, Sasagaki says that standardization will hurt designers' creativity.

Specific future needs Okamoto sees are use of solid modeling and feature-based design (FBD) to drive a true link between CAD and production engineering, plus better ways to engineer tolerances. He comes out of the CMM world and is thus highly sensitive to tolerances and inspection. His main hope for FBD is that it will create an engineer's interface to solid modelers and make them more acceptable to designers. Overall, he has a broad view of the possibilities for integrating the product realization process.

RICOH TOKYO OFFICES

29 August 1991

Background

My hosts were Mr. Ageishi, Director of the IMS Department, Dr. Toriya, a CAD expert, Mr. Yazawa, a lens designer, and Mr. Watanabe of the Camera Product Planning Department.

Ricoh, like Nikon, is a diversified optically oriented company with the great difference that it leans toward computing and communication applications such as copiers and fax machines, with only a small presence in the camera market. It has 34,000 employees, of whom only about 13,000 are in Japan, and sales of about $5.5B (at ¥132). Office automation, including integrated document preparation, is the main product line. Ricoh has 20% of the domestic fax market and 38% of copiers. However, my visit followed the theme of cameras, making comparisons with Nikon interesting. Copiers (see below) were the subject of a brief discussion.

Ricoh also makes laser printers and the laser engines that go into them. Ricoh also has a laser printer page description language software called Ricoh-Script.

A video showed off the many technologies that Ricoh supports, including R&D on neuro-chips (one chip with 256 small neuro-chips on it), voice recognition as a user interface (any person, limited vocabulary, one word at a time), digital signal processing chips sold to Nintendo for voice synthesis, magneto-optical storage disks, conductive polymers (described by a lady chemist), and so on. The video also hinted at some problems which my hosts confirmed: the company was a pioneer in offshore camera manufacture but has had difficulty finding qualified employees and parts suppliers overseas. Ten years ago Taiwan could not assemble complex cameras for them; now it can but only after lots of on-site training and education. Also, a "restructuring" program has been underway for about a year. They are trying to improve their design methodology by overlapping design tasks, improving communication between designers and production engineers, and increasing the use of assembly automation. But total reorganization is needed first, and the project is still young.

Ricoh has about 4,000 engineers among its Japanese employees. The company worries about hiring new ones. Each of the last 2 years 300 were located, but next year looks difficult.

The visit had five parts: a general discussion of Concurrent Engineering and how copiers are designed and made, an explanation of their own solid modeling product, industrial design of camera exteriors, design of optical trains, and mechanical design of camera insides. The most interesting aspect was their first attempt to write software that will analyze tolerances in multi-element lenses.

Concurrent Engineering and Copiers

Concurrent Engineering (CE) to them means intense communication between product designers and production engineers, including some overlapping of their tasks. Ricoh has done this for years without calling it that. The main method is meetings and design reviews. In view of this, the question arises: what is the restructuring mentioned in the video? Apparently the company is aiming to reduce development time by another 50% and cost by 30% by 1993. Copiers will be attacked first. A joint team of 400 people is working this problem. The methods are cost analyses, planning of design processes, technology improvements, and more overlapping of product and production engineering. A major problem is that each division of the company has a different culture in its design methods, driven by the different production volumes and rates of product change in each. Only 15% of employees change division each year, so some differences have built up.

They (like many Japanese companies) wonder how to accomplish CE more efficiently. They think the phone and meetings are just fine and wonder how they could afford to give every engineer a PC. Communication is first, then technology. Moreover, they spoke of having to further reduce the co· ervatism of managers and interdepartmental restrictions. If these institutional barriers can be reduced, then new design technologies like feature-based design (FBD), CAD with product and process analyses, and rapid prototyping (like SOUP) will fit right in.

Copier Design

A new copier takes from 1.5 to as much as 5 years to design, depending on the complexity of the new functions and copying technology being attempted. Apparently 2.5 years is typical. On big projects the specification keeps changing because the market changes rapidly at the high end. New toners and new scanning engines are designed in parallel. There are about 550 design engineers supported by about 55 production engineers. A new copier will occupy 30 designers, while a modification of an existing design may take 10.

These numbers are typical of those obtained from most Japanese companies I visited except car makers: design teams are small and manageable, ranging from 10 to 30 (versus 500 at car companies).

Design-Base - Ricoh's Solid Modeler Product

Toriya explained this product, which he apparently spearheaded. He works for the Software Division, whose director is another lady, Dr. Kunii, whose Ph.D. is in database management from the University of Texas. She has pushed new database management products and Toriya hopes to combine them with Design-Base (D-B).

Design-Base is a UNIX-compatible system written in C that is similar in many respects to ACIS from the U.S. company Spatial Technologies. Methods and marketing are similar: its architecture is open and its engine is available for licensing to companies that want to use it as part of their own CAD/CAM work. "ACIS is our main competitor in America." D-B is the only UNIX-based solid modeler available in Japan, which says something. It has all the usual features: rendering, boolean operations, free surface modeling using Gregory patches, sections, filleting, and so on.

It also has several novel and interesting user interfaces that permit very rapid construction of shapes from simple primitives. These were demonstrated on a Sony NEWS workstation, where performance was impressively fast. (As at every company visited, the CAD demonstrator was a very skillful lady.) A PC version exists called D-B Jr. The new user interface (UI) was written in Motif, so it is easily ported to other machines. It includes ability to call forth standard primitive shapes and to detach surfaces from them and slide them easily along XYZ coordinate directions. Edges can be shifted around and can be broken up and made into curves. Such operations are entirely artistic in the sense that no "surveying," coordinate values, or dimensions are involved. So, while it is easy, intuitive, and fast, it does not really support engineering. Toriya agrees that feature-based design would not only help but might be easy to add to his existing methods.

Thirty researchers and engineers support development and enhancement of D-B, while 30 more support database management system (DBMS) work.

Unfortunately, D-B is not widely used inside Ricoh. I was told that it is so recent that there would be difficulty dislodging the considerable investment in commercial CAD, which was purchased for its surface modeling ability before D-B was available. Also, a lot of camera-specific CAE has been added to the existing CAD and they claimed it would be too hard to convert it all. Now, however, Ricoh understands the importance of solid modeling technology, and D-B is expected to be used more and more.

Industrial Design Center

D-B was demonstrated here showing aesthetic design of a new copier and a children's educational toy. The final colors of the toy were chosen by a consultant who used color printouts from solid models made on D-B. However, most of the work is done with other commercial software whose name I did not catch.

Most of the discussion here centered on camera external design. This is the first step in making a new camera. Like car design, the first step is a series of hand color sketches, followed by several clay models. Shape is the issue, not size or weight. The final clay is digitized by a laser, a CAD drawing is made, and dimensions are added to create scale and main radii. For this last, a plastics engineer adds his comments, but no molding analysis software is ever used in the entire process. From this drawing a very realistic mockup is hand made and the designers and marketing people critique it.

In a recent case shown to me (RZ 800) the market was ladies, and a major change in the shape was made, eliminating a sharp edge in front and making the whole camera softer looking. The above process (sketch, clay, digitize...) is then repeated. Data from the second version are sent to the mechanical engineers so that they can begin trying to fit their parts inside.

They had no access to the first round process.

The first round takes 3 months, the second 4 months.

Optical System Design

The optical system division designs both glass and plastic lenses. While plastic poses problems from thermal expansion, it is seeing increasing use in laser printers. These lenses are manufactured in a plant 500 km north of Tokyo. Lenses can have between 3 and 20 elements, the latter applying to complex zoom lenses. Design takes 3 to 6 months and each lens is designed by one person, of whom there are 30 in the department I visited.

Lens design is supported by both commercial ray tracing software (CODE V from Optical Research Associates in Pasadena), which operates on DEC VAX workstations, and by Ricoh's own, which operates on an IBM 3090 mainframe in Yokohama. Ricoh makes most of the equipment it uses to make lenses. This includes polishers for glass lenses and molding equipment for plastic ones. The spot size of laser beams emerging from lenses is measured for quality control purposes using equipment Ricoh builds.

The process of designing a lens starts with a given specification in terms of cost, focal length, product application, and so on. The first step is to choose a lens type and number of elements. The main construction parameters, such as geometry, lens radii and separation, type of glass or refractive index, and so on, are chosen, often using those of a similar previous design as well as patent data. Ray tracing plus trial and error are used to modify these parameters until the specification is met. The expertise of the designer is the main ingredient.

A major issue is deciding what the tolerances should be. These include all the above parameters plus those of the housing, called the cell. The factory's capabilities are represented by a Monte Carlo analysis, and many studies are run. Particular attention is paid to the "sensitive parameters." These are identified by numerically developing a coefficient table, essentially an empirical array of partial derivatives. The effect of small changes in parameters on lens performance is judged by noting the change in aberrations and the mean time to failure (MTF), a measure of image contrast.

Interestingly, the study varies only the parameters that engineers think about, such as radius of a surface, and does not consider that the ideal spherical surface might not be spherical at all. In fact, lens polishing can produce quite spherical surfaces, but this is not yet true of molding. Another surprising problem revealed at a later meeting is that the periphery of a lens cannot be held concentric with the optical axis to much better than 10 microns. In a stack of many lenses, nonaligned optical axes can seriously degrade overall performance. A more accurately made cell does not help this problem.

If performance degrades too much in the face of the stated tolerances, then they are tightened, although some attempt is made to avoid a "sensitive" design, that is, one whose performance is easily degraded if one variable varies even a little. At this point I asked if they use the Taguchi method, a technique often used to attain low-sensitivity designs. I was told that Dr. Taguchi visits Ricoh regularly and gives seminars so that the engineers by now are familiar with his philosophy and follow it in principle. However, the main design approach is numerical optimization, using a damped least-squares method.

This optimization, however, is not used to seek a low-sensitivity design. Instead, it is used to find a set of parameters that best balances a variety of conflicting aberrations, some of which get worse when others get better.

Camera Mechanical Design and Use of CAD

Use of CAD is widespread at Ricoh. In 1990, 60% of 50,000 mechanical parts were designed by CAD by 1,000 engineers using 300 networked workstations or terminals. Electronics is even more advanced: the database has 35,000 parts, and 400 engineers have access to 200 networked terminals.

Like Nikon's, Ricoh's cameras are made almost entirely from precision molded fiber-filled plastic. Typical part count is 300 to 400. I was shown the new Mirai Zoom 3, an autofocus, auto zoom, auto exposure, auto flash camera. It sells for $250 in the United States. Every part was laid out on a series of foam-core boards around the room where we met. The largest of them is the condenser for the flash. There are four motors which are either somewhat or dramatically smaller than this condenser.

The Mirai took 2.5 years to design, 6 months more than planned. There were 30 full- or part-time designers on the project: 10 interior mechanical, 5 optical and factory lens people, 10 other factory designers, and 5 assembly engineers. Considering that Nikon did not count factory people for me, the size of teams from the two companies is similar, as is the time required. But Nikon mostly designs much more complex single lens reflex (SLR) cameras. For example, Nikon uses focal plane shutters while Ricoh uses simple two-blade wing shutters in its compact cameras.

The design process has four parts, of which exterior design comes first. The others follow and are undertaken somewhat in parallel with the expected precedences: electronics, optics, and mechanical. The last is done with Intergraph systems. Electronics is supported by other CAD that does flex circuit layout but cannot support circuit simulation or analysis. Similarly, the mechanical CAD cannot support mechanism or structural analyses. Another computer is used occasionally for some FEM work.

The Intergraph system supports 3D wireframe modeling as well as external free surface shapes. If parts interfere with the case, they stick out in the picture. Design often consists of the mechanical people fighting the exterior shell people for space. However, they admit that CAD cannot adequately predict these interferences. "We can't really tell until we have the parts in our hands."

As at Nikon, camera design is done in blocks. Each block is done in parallel by a separate team that tries later to fit its block to the next team's block. The defects in this method are apparently known to them and their "restructuring" process is aimed at reducing such problems.

External parts are defined by breaking up the surface given them by the industrial design group. This is just like car design, but the camera people are not used to it. There is no strong tradition for deciding where the boundaries between sections should be, and no FEM is used to see if a choice might be bad for strength or dimensional stability.

Ricoh Optical Company makes the molds and parts from NC data provided by the above process. Typical tolerances in critical areas are about ±0.05 mm or 50 microns (0.002 inch). The parts are made from 20% glass-filled polycarbonate.

Flex circuits are also designed on the Intergraph system. Ricoh is trying to locate integrated circuit design software. I mentioned Mentor Graphics and Harris Corp.

In all, Ricoh agrees that its current CAD is an electric pencil. The main advantage over real pencils is that changes can be made quickly.

No systematic DFA methods are in use. However, the factory critiques the designs and weights ease of assembly 60% of the total. I could not find out how this is done. Sony has a DFA method that they plan to try soon.

At present, all mechanical assembly is manual, mostly done overseas. Next spring they will install a line of 30 Sony robots to assemble a shutter mechanism. I think the possibilities here are large.

Future Needs

They want better ability to predict fabrication and assembly costs, plus ways to predict the effect of tolerances on lens performance. Thus they were very interested in our assembly analysis software. They also want better solid modelers that can check interferences for them fast. Such is essentially available now. They also want ways to set tolerances automatically. No such thing exists.

Mr. Nishi showed me their early work on tolerance analysis. It has two components: identification of contact chains between parts and identification of possible detailed contact conditions between various surfaces and edges on parts. The contact chain represents the nominal situation. The possible contacts can pose a combinatoric explosion. It is not clear if his method actually investigates them all or if he is just illustrating some of the possibilities. Lenses rest against each other and determine each others' positions, but his method does not analyze the friction in these contacts or the symmetries imposed by resting spherical surfaces on each other. Thus he may permit odd contacts in his analysis that are unlikely to occur in practice. It is OK to be conservative but there are cost penalties for doing so since one may prescribe tolerances that are unnecessarily tight.

Later Mr. Ageishi told me that they recently built a machine to install lenses and check the optical alignment. The machine installs the first lens, then installs and adjusts the position of the second lens using an optical measuring system. When adjustment is finished, an ultraviolet (UV) curing adhesive is injected, which cures in 15 seconds. This is, of course, the classic tradeoff against tightening tolerances. The cost may lie in the fact that 15 seconds is barely short enough to support production.

SEIKO-EPSON

30 August 1991

Background

The plant I visited is in Shiojiri, about 2.5 hours on the train from Tokyo. It makes dot matrix printers, laser printers, ink jet printers, and personal computers. Discussion on this visit was exclusively on dot matrix printer design and manufacture. My hosts were Mr. Akio Mitsuishi, General Manager of printer design and development, Mr. Asada, a print head designer, and Mr. Mitsuyoshi, General Manager of CIM.

Seiko-Epson was formed in 1986 through the merger of Suwa Seikosha Co., Ltd., a famous maker of watches, and Epson Corporation. The combined company has 13,300 employees in Japan and 11,000 in 27 other countries, including the United States. Products include printers, personal computers and laptops, memories, semiconductors, motors and rare earth magnets and, of course, watches. The company makes liquid crystal displays (LCDs), some of which it uses in its laptops. It also makes, uses internally, and sells a line of accurate assembly robots.

Epson makes two main kinds of dot matrix printers, those with 9 pins for low end use and those with 24 or 48 pins for high end use. Heads are made at another plant using automatic assembly. Mitsuishi claims that no one else can assemble print heads automatically, especially insertion of the wires. I confirmed on one other visit that a competitor inserts its wires manually.

Like most Japanese companies, Epson has trouble finding new employees, especially software engineers. Shiojiri is not as exciting as Tokyo but "houses are inexpensive and the environment is good."

Product Development Process for Printers

The organization of the design process changed about 2 years ago when Mitsuishi introduced team design. His motto "common goal" helps the designers create the best printer, not the best print head, for example. Prior to that time, separate groups designed each subassembly, which led to problems. However, even before team design was introduced, there were design reviews in which each part was critiqued.

Design occurs directly on the computer screen with little or no pencil sketching first. They use their own CAD software for this (see below). However, they do not use any formal DFA methods, although they have considered it for 2 years. He studied the IBM ProPrinter, which was heavily publicized in the United States about 5 years ago as an excellent example of DFA. It contains many complex plastic parts whose use has greatly reduced the number of parts compared to competitive printers of that time, including Epson's. These parts snap together, reducing the need for screws.

Epson's recent printers are similar to the ProPrinter in this respect. In spite of this fact, Mitsuishi was not completely satisfied with the ProPrinter. He admires its ingenuity but worries (with some personal knowledge, apparently) that it is hard to find vendors in the United States who can deliver the complex plastic parts that such a design method requires. (Many Japanese say the same thing: high quality suppliers are hard to find.) Epson has its own precision mold making and plastic part making division for such items.

Product design, excluding technology development and print head design, typically takes about a year and involves a team of 15 to 20 people. A typical printer has about 100 parts plus at least another 50 in the print head. About five production engineers support design.

A tour of an automated printer assembly line (details below) showed that their printers have been designed so that most of the assembly operations are from above or the sides and can be accomplished by rather accurate XYZ robots ($\pm$0.03 mm repeatability). Manual intervention is needed for one turnover and to handle wires and a few tests, as well as to undo jams in the screw feeders for five screws that hold in the power supply and a circuit board. Almost all the parts are plastic, except for a sheet metal foundation for the head transport mechanism and several precision steel shafts. The plastic parts are glass-filled ABS and many are quite precise gears and levers. The division where these are made also makes lenses for eyeglasses and laser printers.

They are particularly proud of their print head design because it permits automatic assembly. The wires must pass through entry holes that are arrayed in a circle and exit through holes that are arrayed in two straight lines. To guide them from one pattern to the other, four intermediate guides are provided, each with holes in a different oval pattern. Special software was written to decide what these intermediate hole patterns should be so that the six holes for each wire lie in a straight line. Assembly then requires only the correct straight line motion.

Wires are about 0.2 mm in diameter, and the holes are about 0.25 mm. This size is typical in the industry. Each wire is about 2.5 cm long and quite straight. It is welded to an armature at one end, giving the whole thing the shape of a tiny golf putter. One of their robots inserts each wire individually by grasping the armature, using no vision or force sensing. I tried this with my own hands and poor vision and found that the wires almost fall in by themselves.

In other respects, too, the print head is a good example of DFA. All assembly is from one direction, and it is held together by a few spring clips.

In general, print head assembly appears to have many aspects in common with watch assembly, and the sophisticated expertise built up in watch assembly has been utilized in printer manufacture.

Use of CAD/CAM/CAE

Seiko developed its own CAD software for 2D drafting in 1979. Originally used on a Univac machine, it was ported to Apollo workstations in 1985 and transferred to the printer division at that time. The company now has 400 networked workstations, 250 of them in the printer division. Printer design is done by 350 people, of whom 100 mechanical designers each have their own workstation. Electronic design is done on DEC or HP computers, while software development is done using Sony's NEWS workstation. In the production engineering division, 200 production engineers are networked to the design division's database.

For the moment there are no plans to convert to 3D modeling for general product design. The reason given is the investment in special software to support printer design, such as that mentioned above for print head wire trajectories. However, SDRC's solid modeler or ProEngineer is used to support NASTRAN, MARC, and RASNA (all FEM packages) for various kinds of CAE. Moldflow software is used by the molding division to critique part designs, but the part designers themselves do not use it.

In spite of Epson's reputation for high reliability printers, I was told that no special software is used to predict lifetime of critical parts, such as the welds that join print wires to armatures, the belts that drive print heads, or the coils in the head (subject to a lot of heat). They simply test or attempt accelerated life tests. The vibration behavior of print wires is very complex, giving rise to base frequencies of 1 kHz or more plus many higher harmonics. They are attempting to simulate the physics of fatigue in such parts but they have not made much progress. Mitsuishi is willing to fund research on this topic.

Future Needs

Mitsuishi cited four areas where he would like improved computer support: tolerances, design for assembly, routine data transfer, and cost modeling.

He feels that CAD generally is just an electric pencil with the advantage that it is easier to erase electric pencil than physical pencil. Other than that, CAD offers him no real engineering support. He would love to have a way to decide if the correct tolerances have been specified.

He is aware of simple rules for DFA such as making assembly moves from one direction (not possible with his current printer designs) but he does not know of many others that are really helpful. [Note that his printers are much less complex than, say, Sony's or Hitachi's video cameras.]

Routine data transfer causes problems all the time, not only between Epson and its vendors but even in-house. The problem is most acute when transferring NC data from design to mold makers. Molds require draft angles and different vendors require different angles, depending on their skill. The base design usually has no draft angle. Keeping all this straight is apparently a big problem. Another source of data transfer problems is in tolerances, where designers may specify asymmetric tolerances (+7, -5) whereas most CAM software requires symmetric specifications.

These are not what we would call data transfer problems since they are not the result of a translation protocol failure but rather are at a higher level of design specifications and management.

Finally, he would like CAD to help him predict costs.

Tour of Automated Printer Final Assembly Line

This system has 35 basically identical XYZ robot assembly stations. The first half was installed 7 years ago and took 15 people less than a year to design and install. The second half was installed 2 years ago. It can build two kinds of printers, but these apparently differ only in the number of wires in the print head. Production capacity is 350,000 per year, two shifts.

Parts are delivered by automatic guided vehicles (AGVs) to places where people dump them into vibratory bowl feeders or place delivered pallets on racks.

A typical station has one or more feeders (two bearings, for example) and special tooling on the end of the robot that can grasp one bearing at a time and then assemble them one at a time. Some robots have more than one gripper on the tool and can grasp and install a second part or even a third one, since the cycle time is a comfortable 30 seconds.

Gear teeth are mated by slowly turning one gear; in one case the gear on the rubber drive belt is turned by a finger that stretches the belt; in another case, a blast of air is used.

Several shafts are installed by the "parallel parking" maneuver since both ends must be inserted in closed holes. These assembly moves are effortless sequences of fixed pivot tool rotations and linear robot motions.

At the end of the line, ladies handle the wires and paper needed for final testing, but packaging is entirely automatic. A curious feature of final installation and test of the print head is that the head is installed and removed five times at five different stations. It appears that only one of these removals is really necessary. No satisfactory explanation for this was obtained.

This system is a local showplace, and descriptions in many languages, including Russian, are available at the door.

MAZDA

2 September 1991

Background

Our hosts were Mr. Yoshimi Okada, General Manager, Information Systems Dept 1, and Mr. Masahiro Matsumoto, Assistant Manager, Production Planning Department. Others in attendance were Mr. Yasuto Tatsuta (Matsumoto's boss), Mr. Hideki Kita (CAE for engines), Mr. Tuginobu Tomita (CAE facilities), and three people from automatic transmission design and production: Mr. Yoshinori Kurihara, Mr. Haruto Kurihara, and Mr. Susumu Ihara. Matsumoto did most of the talking due to his command of English.

Mazda has about 30,000 employees and sold 1.42 million cars in 1990, of which 833,000 were exported. Sales in 1990 were $16.3B. The headquarters and main plant are shoehorned into odd-shaped and separate pieces of land around Hiroshima's waterfront. Use of space and arrangement of material flow must be done carefully. Like Toyota and Nissan, Mazda has an Information Systems Division that creates advanced CAD/CAE systems for body engineering and other applications. However, Mazda cannot yet design cars directly on computer screens. They see additional computer capability as essential to improve product quality, shorten product development and preproduction lead time, reduce the cost of prototypes, and enable more alternatives to be investigated.

Product Development Process

Mazda has about 4,000 car design engineers and 1,800 production engineers. Typically about 20 car design projects are underway at any one time, of which half are major product specification changes and the rest are face lifts or partial redesigns. Two-thirds of the designers work on body and interior, while the rest work on power trains. As at Toyota and Nissan, many components are purchased from suppliers such as Nippondenso, and much of the production equipment is made in-house. However, Mazda has spun off its machine tool division to form the subsidiary Toyo Advanced Technologies, Inc., and is using the resources to "in-source" many high value-added items, thus evolving toward the structure of U.S. car makers. This is "the road to survival" in their opinion. Mazda is having problems finding people to do the engineering, especially software people. As at many companies, women are being increasingly recruited into engineering, drafting, and design tasks.

Kita passed out four confidential charts from which he explained the overall product development process. While confidential, these charts did not show anything really different from what other Japanese car companies do, including the overall time required from beginning of exploratory styling to start of production.

Product planning and development are two separate stages, and design is governed in both stages by a series of design reviews. Production people take part in the reviews in both stages. A mechanical prototype to test engines and transmissions is built during the planning stage and uses an existing car as the platform. Preliminary drawings are issued at the beginning of product development, and tooling design begins immediately. (However, some preliminary tooling design begins even before preliminary drawing release.) A prototype is built from the preliminary drawings. Following tests, the final drawings are made and issued and a prototype is made from these drawings. No final prototype is made. Instead, the last prototype is used as the basis for final revisions after which pilot production models are made at the factory. They acknowledge that this method is risky and involves changes. Die design is affected the most, since engines and transmissions are designed ahead on a much longer cycle. Die change affects outside suppliers who now provide most of the dies.

Later Tomita, in explaining this process again, remarked that car design takes "too long" in the United States and Europe. When I asked him why, he said, "That's a good question." (Before moving to the CAE department, he spent 3 years in car design.) His reply was that Japanese car design is so competitive that all the companies struggle to design faster just to keep up with each other, essentially ignoring overseas competitors.

He says that small cars are easier to design and build, and it is easier to change their design. When I replied that small cars present severe space allocation problems, he replied that years of making small cars have given Japanese car makers the required know-how to attack the space allocation problem inside the car, especially in the engine compartment. When I asked him for examples of this know-how he could not provide any. The older engineers merely teach the younger ones what to do.

However, Mazda has developed a number of "design manuals" or "design standards" that give criteria and instructions for design of parts and components, and young engineers can learn from these. Each item, such as a radiator, cylinder block, or piston, is evaluated according to a set of criteria such as stress, strain, producibility, clearance around it, serviceability, and so on. Each criterion has a stated reason, an important point since the reasons probably contribute to resolving conflicts and educating young engineers. Among the producibility evaluation criteria are: justification of tolerances for function and surface finish and access for assembly. These are presented in the form of a manual checklist. No formal producibility or assembleability evaluation software is used. Instead, lessons learned from previous designs are written up according to formal Production Requirements Procedures and sent back to the designers for use on the next design. A database of these writeups is starting to be made.

The design manuals are going to be the basis for an effort to create "automatic design." This apparently means taking the steps in the manuals and programming them into a question-and-answer (Q&A) interaction between a designer and the computer. Mazda hopes to integrate such programs into one large program that coordinates the activities of many engineers, launching their work, receiving their replies, passing those replies to other engineers, and so on. Naturally, a lot of analysis of the design procedures and information flows will be needed before this integration can be achieved.

Longer term, their objective is to further reduce the need for mechanical prototypes by the process of "design-stage verification." The tools to be applied to achieve this goal are more design reviews, computerization of design standards and creation of standards for more items, and use of reliability analyses (failure modes and effects (FMEA) and fault trees (FTA)) in cases where conventional design analysis techniques are not sufficient or a conventional product technology cannot be adapted.

In this regard, I asked them about a joint program they had with a U.S. company several years ago. Due to my own experience, I knew that both companies shared production responsibility for a certain automatic transmission, so I asked if they made any modifications to the drawings that the U.S. company gave them. The answer was that they loosened a number of tolerances and clearances and relocated some datum holes to improve producibility. Then they manufactured the parts by holding 99% of the parts to within 70% or less of the allowed tolerance range. Matsumoto emphasized that smaller variance than the stated tolerance was often achieved. These modifications and procedures led to the mistaken conclusion that Mazda had tightened the tolerances. This erroneous conclusion has even been published in widely read journals.

Use of Computers in the Design Process

Mazda has three supercomputers and three IBM 3090s linked together in a backbone LAN. They support over 1,000 terminals, workstations, and PCs in the R&D Center, the Test Laboratory, and the Design Center. CAE applications include typical linear and nonlinear FEM, PAMCRASH, MADYMO for simulating behavior of dummies in a crash test, ACOUSIS for analyzing engine noise (Japanese software), ADAMS for kinematics, plus software for modal analysis, heat and fluid flow, combustion, aerodynamics, molding, sheet metal deformation, and structural optimization. A number of these programs are from Japanese companies, including some in-house work by Mazda.

In a CAD room I was shown demonstrations of various CAD and CAE applications. Mazda uses its own 3D surface and wireframe CAD system, which it introduced about 10 years ago. Body design data are transferred directly to the CAM department for conversion to NC data. NC data for prototype mechanical parts can also be generated from these models. Engine compartment parts are assembled into whole compartment drawings but no automatic interference checking is done.

Crash test data are created from a rough automatic mesh of the car body which must be augmented manually to create the final model. Twelve hours of Cray time are needed for a model with 30,000 elements.

Interior design is also supported by wireframe models. Car "package" design can be studied using standard human body size data. On the screen I saw a study of driver's eye position with respect to the "A" pillar (driver-side support for the windshield) and another study to see if the steering wheel interfered with visibility of the instrument panel. Front wheel motion inside the wheel well when the steering wheel is turned can also be simulated. I was told that multi-link suspensions can be studied by computer but did not see any demonstration of this. ADAMS can surely support such studies.

Future Computer Design Needs

Tomita would like better fluid flow, combustion, and structural optimization software. Their world-wide search has not turned up anything that suits their needs so they will probably write their own. This software is intended to help them meet the 1995 CAFE requirements, about which all the Japanese car makers expressed concern. The CAFE rules may force a big change in the way cars are designed, he says. Kita says that at present transmission design is supported by typical FEM software plus their own calculations for deciding gear ratios and dimensions of gears, plus clutch plate calculations like heat, durability, quantity, and size. Solid modeling is used for design of the moving parts of engines and for the transmission case. Mass properties are calculated. Fuel tank capacity is also determined using a solid model.

Some parts are designed using parametric descriptions. A few key dimensions are put in and the rest are determined by the software. This speeds up design of such items. Apparently the Q&A method is already in use for such parts. However, parametric design is not yet used for critical engine parts such as piston, crankshaft, and connecting rod.

They are in the process of extending parametric design to assemblies of parts, such as engines. The designer inputs a rough layout and the computer asks for or fills in key dimensions based on answers to its requests for material properties. I did not see a demonstration of this and the state of its development is unclear. However, it appears to be a first step toward "design automation" discussed above.

Tatsuta would like better computer support for production engineers. The most basic need is for a database of production process information and verified process plans. Such data would include times and costs, step sequences, when to make inspections, and so on. Such information is pretty basic and other companies appear ahead in this regard. He would also like better CAE for stamping die simulation and verification, mold flow for die castings (they have it for plastic injection molding only), and ways of determining the noise generated by transmissions based on gears, running clearances, and the way these vary as the case deforms under various loads.

Tour of 323 Engine Assembly Line

This line is largely manual with typical automatic transport of parts from one station to the next. Of interest to me was assembly of pistons, cranks, and cylinders. Selective assembly is not used when mating piston, connecting rod, and wrist pin. However, selection is used for pistons and cylinders. There are three sizes of pistons. The cylinders are measured and one size piston is chosen for all four cylinders.

This is a very crowded line, with parts delivered within a few feet of the assembly line. The people are busy essentially the whole time, practically never stopping body or hand motions. Such an arrangement is typical of Japanese car manufacturing and is generally more intense than U.S. practice. Just as in engineering, the result is that fewer people make more cars.

HITACHI IMAGE AND MEDIA SYSTEM LABORATORY (I&MSL)

3 September 1991

Background

This meeting was a follow-up to the 11 June visit and was arranged by Mr. Ohashi. Attendees were his PERL colleagues Mr. Okamoto and Mr. Matsuzaki, plus Mr. Hayakawa from the CAE Systems Laboratory and four I&MSL people. The general subject was how are computers used in the early design of complex tape handling mechanisms for videocameras, and what is difficult about such designs.

The Tape Transport Design Problem

The tape transport mechanism is very complex and very small. Its job is to carry a section of tape from the cassette to the read/write drum and wrap it more than halfway around. It must adhere to remarkably close tolerances in those places where it positions the tape against the head: since record tracks are about 10 microns wide, the tape must be positioned within a micron or so. There is a guide ridge on the base of the drum for this purpose. As a result, the main requirement is that the tape be gently pressed against this ridge and no wrinkles develop in the tape. In addition, the tape is skewed in space with respect to the spin axis of the drum. In Hitachi's design, this requires that the tape be skewed in the read-write position with respect to its stored position in the cassette (see Figure 12). The tape transport mechanism must therefore carry the tape from a straight horizontal condition to a skewed condition wrapped around the drum (see Figure 13). The path the tape follows in space is also important, especially as soon as the first portions of the tape begin to contact the drum.

The transport mechanism consists of several stationary guide posts and freely spinning rollers which are mounted on moving or hinged metal pieces. These posts and rollers pull the tape out of the cassette and toward the drum. Linkages and gears provide the motion, driven by a motor and several belts. The transfer from horizontal to skewed is provided by several precision plastic cams which lift the roller carriers as they move. The linkages and gears are arrayed in several horizontal layers on the bottom of the mechanism, plus a few parts on two sides. The top hinges up to allow the tape to be installed and thus has no moving parts on it. There are about 240 parts in this mechanism including about 50 screws and rivets. Very few parts are provided as subassemblies to the final line, which has about 100 automated or semi-automated stations.

Design of such an item requires planar mechanism synthesis, cam design, spatial path planning, and stress-strain analysis of very thin material. Especially interesting was the use of FEM to predict the shape of the tape after the drum begins spinning; friction and skewness combine to bend the tape slightly in its own plane. This will cause it to wrinkle unless the guide rollers are positioned slightly differently from purely geometrically determined locations.

The main tools available are 3D CAD (Hewlett-Packard ME 30) plus SDRC's I-DEAS and associated FEM software, plus Hitachi's own drafting software.

Design Procedure

The description of the procedure was confused between how the current product was designed and how the latest one is being designed, since ME 30 was acquired in the middle of the last design and not used during design of the first prototype. So the procedure outlined below is really how the next one will be done.

First, a concept is generated that includes defining the specifications and architecture. Then a layout of the tape transport parts is attempted and basic dimensions such as hole spacings and slot sizes are determined. The mechanism parts are then modeled and displayed in 3D CAD so that the motion and interferences can be checked. This is a painful process now since ME 30 does not support the necessary constraints or animation. I-DEAS Level V, which they have, might be able to support this. At this point about half the required parts are represented.

The 3D model is converted automatically to 2D, and drafting is done to create information from which prototype parts are made, usually by hand. These are assembled into the first prototype, mated to a drum designed by others, and tested. Results are fed back, the layout is revised, and the cycle repeated for a second prototype.

During the previous design cycle, the first prototype was not designed in such a neat sequential manner, although the second was.

Producibility and assembleability are considered during the first prototype for a few key parts. Also, because of size restrictions, low profile fastening methods were mandated from the start. This means either staking and riveting, or use of very small flat head screws. Fastening big parts like motors is a problem when such small fasteners must be used.

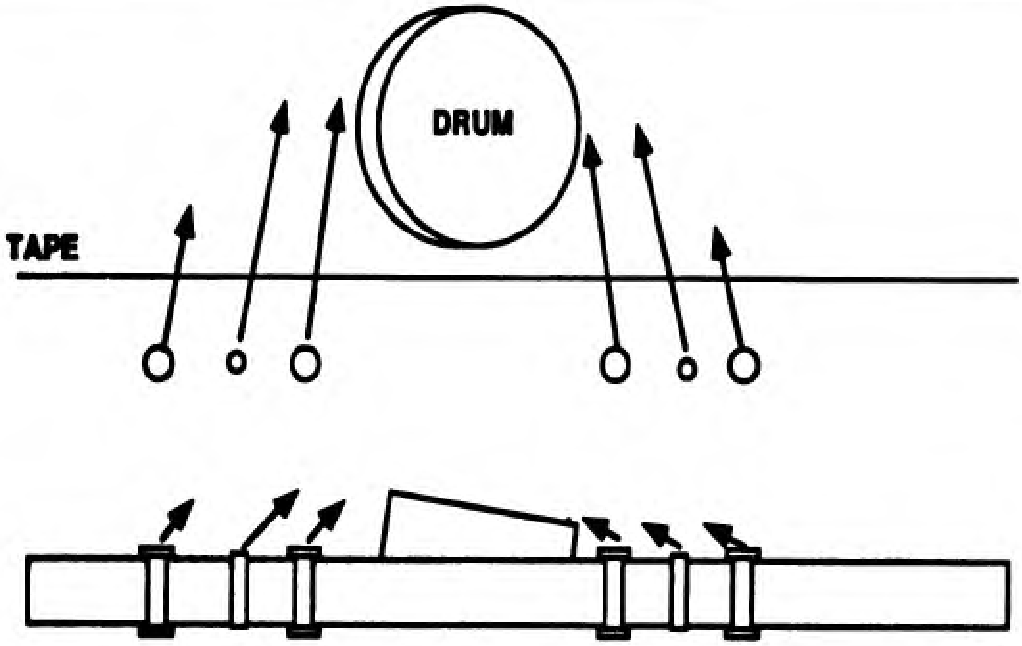


Figure 12. Tape before threading onto drum.

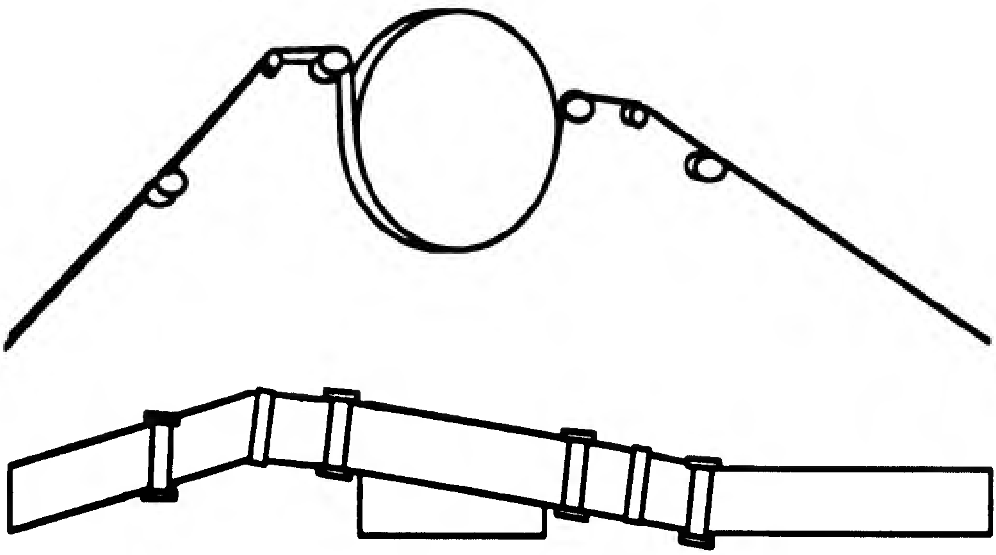


Figure 13. Tape after threading onto capstan.

Critical decisions like tolerance assignment are done manually according to the designer's experience. There are no cost-tolerance models, and the simulations do not take tolerances into account. The main factors determining tolerances have been discussed above.

Future Design Tool and Methodology Needs

Two areas stand out: increased use of parametric design and "rationalization of the conceptual design process."

Parametric design means having an equation-driven design process in which one can input certain parameters and have the computer adjust others to suit. This method seems appropriate to what is normally called variant design but not to what the Hitachi I&MSL people have been doing, which usually requires all new parts and part shapes. Often when I asked companies if they used past design data they said no because new designs are so different. Thus I cannot be sure why Hitachi is emphasizing parametrics in the case of VCRs for videocameras.

Rationalization of the conceptual design process means raising it above the level of sketching and cosmetic design illustration. Mr. Matsuzaki seems to recognize the potential for feature-based design to provide some of the needed structure. As it is, conceptual design of novel products is undisciplined and results in odd-shaped parts. More generally, standardization of the design process is needed.

He is currently reviewing his department's use of Concurrent Engineering. What else is there besides weekly meetings, he asks? What is the potential for computerized CE, especially for companies with a long tradition of close communication and small design teams? He is actively afraid that computerized CE will spoil Japan's ability to design.

I asked if this means he does not think computers can help product-process design. His reply indicates an important area of potential confusion that I met at other companies: they want CAD/CAE/CAM so that they can improve product-process design integration with focussed engineering tools. "Computerized CE" means computer tools strictly for communication between designers, a very special case. The latter is unpopular, but the former is essential.

NISSAN

4 September 1991

Background

This meeting was a followup to the one held on 8 July. The subject was engine and power train design. My hosts were Mr. Jun-ichi Kobayashi and Mr. Masataka Hidaka. Kobayashi directs CAD planning and spent many years as a manufacturing engineer. His contacts in that department stand him in good stead as he thinks about Nissan's future CAD needs. Hidaka joined Nissan 6 years ago and spent 4 of those years in new engine design. Now he has joined the R&D department to develop new computer tools to help engine design.

Like all new hires at Nissan, both Kobayashi and Hidaka spent several months working on the assembly line as part of their initial training. "I learned about assembly insertion force," said Kobayashi. "It doesn't show up on the drawing." I told him our group did research on predicting insertion force. He apparently didn't know it was possible. Insertion force and access to the assembly point strongly influence the time required for assembly, which directly affects the cost. Until these matters are modeled, attempts to predict assembly time and cost will be of limited usefulness.

The point is made here because the tone of the entire day's discussion was about the contrast between the relative ease of predicting engine performance compared to the difficulty predicting assembly cost (of cars as well as engines). At the same time, early prediction of cost is becoming more and more important. If good cost models of production can be made based on concept designs, then the real tradeoffs can be evaluated. "That's the theory of concurrent engineering," says Kobayashi. Right now, the specification for engines is set too early, based on performance only. Too many specification changes are needed after the first prototype is built, presumably to reduce the cost.

Engine Design Process

Hidaka showed me data on engine development times that are confidential but that are not too different from what other car companies showed me. Basically, new engines take somewhat longer than new cars, but adaptation of existing engine designs to new cars can be done at the same pace as car design. This does not prevent problems from arising, but Nissan has never delayed a new car introduction due to a late engine design. They just do whatever is necessary to get the design done in time.

The engine department has sections for performance planning, project development, parts design, and advanced technology and CAFE. The project sections handle different types of engines (4 cylinder, 6, V8, diesel), while the parts sections focus on different kinds of parts (external parts, lube-head-valve parts, fuel system and controls, emission controls, turbochargers, and so on). Each project section is given responsibility for adaptation of an existing engine to a new car, while the advanced technology and performance sections investigate new engines.

There is also a "simultaneous engineering" department. Its job is to study and develop new design methods and materials which require new manufacturing technologies, such as injection molding and the associated simulation software. Note the difference in philosophy here between Nissan and Nippondenso. The latter feels it must integrate new process creation with new product design.

Transmissions are designed in a different department that has a similar structure. However, communication between engine and transmission design is not as good as it should be. This is partly due to a natural conflict that arises in front wheel drive cars: there is never enough space between the front wheels to fit both engine and transmission. Styling wins most of these conflicts since it sets the wheel spacing. In sporty cars, engine design forces the wheels farther apart, but in other cars, engines and transmissions must fight it out for the given space.

I was shown their engine lineup. Some designs are 8 to 10 years old; others are new last year. Many are revisions of earlier ones. Currently they make 64 different engines, compared to 70 for Toyota, 22 for Mazda and Honda, and 30 for Mitsubishi. They showed me a graph of the trend of engine types offered by all these companies, plotted every year from 1978. Over that span, the number of engines offered by each company has increased by a factor of 3 to 4 times. Production rates for engines can be as high as 50,000 per month.

Engine design is a process of designing, building, testing, and evaluating prototypes. The number, their timing, and the overall design time are confidential. Manufacturing engineering begins right after the first prototype is built. But, beginning 3 years ago, production engineers attend design reviews and offer feedback during design of the first prototype. In future years, this participation will be pushed farther upstream, or at least Kobayashi wants it to be. This will ultimately mean participation in new technology development or evaluation. As things stand, there is considerable task overlap between the cycle of prototypes and development of production systems.

To support the trend to earlier participation, Nissan will need new attitudes as well as new computer tools. Right now the critiques are limited and detailed, such as where certain holes should be located or what direction their axes point. To illustrate, he cites some "quite distinctive" differences between the new engines Nissan and Toyota produced for Infiniti and Lexus. Nissan's engine has an intake manifold with eight separate chambers, one for each cylinder. Toyota's manifold is a single casting, illustrating more concern for ease of assembly in his opinion but possibly causing some sacrifice in performance. When I asked if specific performance compromises had been identified in Toyota's engine, Kobayashi said no. Apparently they are uneasy about being unable to explain such obvious differences.

Kobayashi also noted that Toyota's strength includes large numbers of manufacturing engineers. They can throw people at a problem. Nissan cannot do that, so it needs better computer tools.

Hidaka then showed examples of CAD/CAE in engine design. Several are typical stress analyses and simulations of crank motion. More interesting are mathematical models of engine performance. One inputs the bore, stroke, valve timing, intake volume, and other parameters, and the computer returns a graph of torque and power vs rpm. The basis for such calculations primarily is historical data. While some parameters can be predicted well, factors such as "driveability" are more difficult. Such parameters are dynamic, involving acceleration, whereas the above-mentioned chart is static and the data can be obtained on a simple test stand. Nonetheless, their existing predictions are so accurate that they discount the need for major improvements compared to the backward state of producibility analyses.

The different parts design sections have different attitudes toward CAD. Big parts are designed in 3D but little ones are done in 2D. Reconstruction of 3D information is required for moldmaking and CAE. The designers of small parts resist the complexity of 3D modeling, and the large part designers utilize only the software's ability to represent the outer hulls of parts, omitting the interior details. Moldmaking thus reduces to hand carving of models made from reconstructed 2D drawings, a distinctly awkward and old-fashioned method. The problem arises because of the legacy of the software: it was originally designed for body stylists, who design simple parts with no interiors, just complex surface shapes.

Yet "complex" is a mischaracterization, because in fact body parts do not have many details or features in their surfaces compared to connecting rods or other mechanical parts. A con rod is essentially a large collection of fillets, joined in complex ways by surfaces with shallow draft angles on them. The real requirement is thus for complex filleting, not arbitrary surfacing, and no one's software can provide this. Toyota made the same comment. Many car companies have evaluated Ricoh's Design-Base, which is supposed to have superior filleting capability, and all have so far rejected it. The same thing has happened to ProEngineer, except that its constraint capability and easy interface are still attractive and companies are beginning to adopt it for less fillet-oriented design.

Yet there are problems as designers begin to adopt 3D. The inability of solid modelers to handle all the data and the inability of wireframe models to convey the design visually to manufacturing people have been discussed before. In addition, there are design errors. In the old days, designers took pains to insert check or reference dimensions to discipline themselves and others. Now that habit is disappearing and errors are occurring at an increasing rate.

The manufacturing engineering department responsible for making forging and casting dies for engine parts has responded to shortcomings in existing 3D CAD by developing its own 3D modeling system. Other departments have done the same and now several modelers exist. The manufacturing department's program is called F-CAD and was introduced in 1988 as the result of a Ph.D. by one of its engineers, Mr. Suzuki.

F-CAD's main strength is its ability to handle arbitrary and complex fillets. But it can't support revision, so a problem occurs because many dies are changed during tryout. As a result, the drawings are not updated to a data file.

Future Needs

The opinions expressed here are those of my hosts, who are trying to convince their management. Whether Nissan will adopt their ideas is unknown at this time.

New engine designs promise to be quite different from existing ones. An example is modularity, in which two cylinders can be added to a four cylinder engine to make a six, for example. Interior and exterior engine parts will be different from current ones. More commonality will be needed, and engine performance must not be allowed to suffer because of it, due to the need to meet the CAFE requirements. Kobayashi wants 3D modeling to be adopted throughout engine design.

He also wants better cost prediction methods early in design that can analyze complex parts, not just screws and brackets. He does not know the proportion of engine cost that goes into assembly. One reason is that so many components are purchased. He feels that part count should be reduced. When I asked if that might increase the cost of each part more than the amount saved in assembly cost, he replied that representatives of Boothroyd & Dewhurst claimed not. But apparently the cost-complexity issue is still open. (Sony says that their parts are so simple that combining them does not increase the cost.)

In addition to encompassing modular engines, new CAD must account for several engine designs at once. This is because cost pressure will force reuse of parts and production equipment. The cost saving opportunity requires that new parts be designed so that the cutting capability or assembly capability of old machines is still applicable. Deep knowledge about cutting conditions is needed.

Any time cost, performance, and manufacturability must be considered together and traded off, accurate cost estimates are needed. Normally these are available when the manufacturing engineers do their planning, which now occurs too late to help the concept design tradeoff process. Therefore, manufacturing planning needs to occur earlier; the approximate data available at that time should be sufficient, he says.

Estimating assembly time/cost is harder than estimating machining time/cost because the human element is more important. If a person cannot see where the part is going in, if force must be used, or if the person's body is bent, then more time is needed. If the line is planned for too little time, the workers rush, and quality falls. Then more inspectors and repair people are needed.

To support this kind of design does not require new kinds of DFA like Boothroyd & Dewhurst's but rather more of the old fashioned kind of manufacturing engineering applied earlier in the design process. This requires more manufacturing engineers, not more computers. "And I'm in charge of CAD planning!"

Getting him to focus on the difference between computer communication and computer-aided engineering tools has been difficult, but finally he agreed that CAE for manufacturing and assembly is feasible. Until he saw my video about feature-based design for assembly a second time he did not understand it. "I thought features were only for machining," he said.

He feels that in general relations between Nissan and university researchers are weak. The university research generally does not address industry's needs. On the other hand, advanced methods like Taguchi's are just now starting to be investigated.

SONY

5 September 1991

Background

This visit was a followup to one on 1 July. Our hosts were Mr. Tohru Fujimori, General Manager of the Robotics Division of the FA Department; Mr. Yasuyuki Yamagiwa, creator of the DAC assembleability evaluation system; Mr. Junichi Kuzusako, Assistant Manager of the CAD/CAM Group; and Mr. Hiroshi Harimaya, Manager of System Development in the Production Technology Development Group. We were joined for lunch by Mr. Juzo Akiyama, who developed the first Sony robot about 10 years ago. A description of his strategy for developing Sony's family of assembly robots may be found in Reference 1.

The main subjects of the meeting were DAC, Sony's preferences for CAD capabilities, early design methodology for videocameras, and robot assembly of precision mechanisms.

Design of Videocameras

A new camera requires about 30 to 50 mechanical designers, whereas a modification of an existing design requires about 10. All these people are university graduates and there are no assistants like draftsmen. Sony is the only company visited that has more applicants than it can hire. The exception is experienced manufacturing engineers, who are not produced by universities.

CADAM, a 2D drafting program, is used for 80% of the parts, while CATIA is used for the rest, to produce cosmetic designs of camera exteriors. Sony's own surface design software called FRESDAM is also used, along with a small number of seats of Pro Engineer and Design-Base.

According to Kuzusako, 3D systems are simply too hard to use, having about 100 commands compared to 10 for CADAM. They are also much too expensive, costing as much as ¥60M per seat (clearly he has made a factor of 10 error here, since ¥60M was $444,444 at that time) with all the features. So 3D is used only when the shape is too hard to make in 2D, or if stereolithography will be used to make a rapid prototype, to check interferences, do CAE, or teach robots offline. If 3D systems were simpler to use, say because feature-based design ("a very important idea") were incorporated, not only would many designers use them but their output would be understandable by the manufacturing people. At present, design and manufacturing people are separated and communicate by passing drawings back and forth.

DAC Assembleability Evaluation and Its Use in Fine Mechanism Design

Videocamera and tape recorder mechanisms can be very complex (see Hitachi I&MSL reports). Much simpler cassette tape recorder/players were used as the example in this meeting. A design consists essentially of a base with parts stuck onto it from both sides The direction of approach for the parts thus dominates the assembly design evaluation. Fastening method has next priority, while part shape is lowest.

A new design often starts with a goal such as to cut the number of parts by a factor of 2 from the previous design, or to cut the cost or weight. "By half" is the division's motto. The previous tape recorder design had a metal chassis and a circuit board. Most of the parts were attached to the chassis, including the motor. Wires were therefore needed between the chassis and the circuit board. Sony's next design used the circuit board itself as the chassis, allowing the motor to be attached to it directly and eliminating almost all the wires. This made assembly so simple that the unit is made in Malaysia by simple pick-place robots.

Detail design consists of making pencil sketches of multi-part mechanisms in exploded view form. At the early stage, many such sketches are made, and the assembly evaluation is one of the main criteria used to choose one concept over another. This makes Sony's DFA approach different from any of the others observed during this study. The part sketches are remarkably detailed. Thus fairly good DAC judgments can be made. Since one person accounts for 50 parts, he can make a significant portion of the design and evaluate it himself.

Sony's design methodology may be different from other companies', too. The common practice is to start with an assembly drawing or assembly sketch showing the final locations of all the parts in a unit. Sony's practice as illustrated to me is that the designer starts by making an exploded view of the parts. This is consistent with a remark Fujimori made at the 1 July meeting, that designers consider assembly method and sequence during concept design, a remark I found hard to believe at that time.

Yamagiwa made the point (commonly quoted in the United States) that 75% of the cost of a product is determined by early design decisions, and DAC is therefore aimed at this stage. Fujimori said that Sony has no data to back up this estimate, merely their feeling and an informal survey of their engineers. This is interesting because no one else has any data either; but everyone quotes this number!

One designer may be responsible for as many as 50 parts. At various times in the meeting, some people called this a reasonable amount for one person while others said it was "too many to remember." The conflict is between the older people who do not want anything to block the designer's creativity and the younger people who see the need for computer tools to replace the sketches.

Fujimori points out that Sony has a database for common parts like screws and springs but not for any of the important parts. These are radically different for each new design. Past designs are of little or no use in providing design data such as parts of nearly the desired shape. Since I had given a talk on feature-based design, he remarked that Sony's lack of part data "may be a shock to you."

Design evaluation has several facets: ease of assembly, precision of the resulting part mate, and cost. Often these conflict, and precision may dominate, especially for shafts and capstans that guide tape. The parts of the tape recorder are all rather simple, and Fujimori claimed that combining them to reduce part count and create "multifunction parts" does not create any cost penalties due to increased part complexity. Part count reduction, therefore, always yields a net savings. I gathered that the assembly cost estimation method in use is not very sophisticated.

Details and Demonstration of DAC

DAC means "design for assembly cost effectiveness." It is at least 7 years old and was originally a pencil-paper procedure because at that time few computers were available to designers, except for drafting. Even now, it can be used by referring to a single sheet of paper that lists a series of keywords describing the points the designer should keep in mind.

These 35 keywords are in three classes covering part shape, method of attachment, and direction of assembly. Direction includes considerations like space for fingers or tools. Method of attachment includes what kind of fastener (if any), how far the part must be pushed or twisted (if at all), what kind of screw head, and so on. Part shape includes general descriptions like "flat" or "cylinder," plus the largest and smallest dimensions, the weight, and whether the part is rigid or flexible. Other information in a general category includes whether lubrication or cleanliness is needed, whether the part is fragile, or whether a wire is attached to the part.

Fujimori points out that "precision" of assembly is a critical factor. This really means how perpendicular a shaft will be to the base in which it is inserted. This is often more important than the exact location on the base. Press fits are deemed the most precise for their cost, although a shaft with a wide base fastened with four screws is more precise but more costly. Press fits are notoriously hard for people to accomplish and ordinary robots do not have the strength, so special high cost robots are needed. The ones in use are descendants of the first ones Akiyama developed.

A more recent chassis design had a very thin metal base to save weight. Here press fits could not be used, so the shafts were riveted instead. This indicates that ease of assembly is unlikely to be the main criterion in many of these assembly steps.

Yamagiwa demonstrated the DAC evaluation using a program on a NEC personal computer. There are several windows onto which the designer enters data about each part in the 35 categories. The computer calculates the score and keeps various running tallies like total part count, average score, and estimated assembly time for each part. One can input various goals such as "no need to turn the product over" or "less than four screws." The computer will then prompt the designer if a goal is not achieved. Wide differences between assembly times are noted as "poor line balance." The fact that two short tasks in sequence could be given to the same robot or person is not taken into account.

Robot Assembly of Complex Mechanisms

Sony began robot assembly about 10 years ago with its own robots and now has several hundred in its plants. It also has a business selling robots and complete systems to other companies, including such rivals as Hitachi. Remarkably complex assembly moves are made by these robots in less than a second or two. Examples include threading a small rubber belt around several pulleys or inserting coil springs that need to be wound up during assembly to create preload.

Fujimori points out several problems in such systems. Teaching the robots these intricate tasks takes time and can be positively dangerous since the parts are small and the programmer puts his head a few inches from the tool. Assembly cycle times are now as short as 2 seconds, so the loss of even 0.3 second at one station on a line can spoil the efficiency of the entire line.

So he would like an offline programming system driven by solid model data. His dream: "It works the first time." The problem with this is that the data are probably not detailed enough. The robot's dynamics, not easily modeled, plus the friction and inertia interactions between the parts, will make offline teaching too inaccurate.

His other dream is to have some kind of artificial intelligence built into the robot, its sensors, and its controller so that it could gradually learn a faster way of doing the task. An example is a shorter motion path that comes closer to an obstacle than originally taught. Another is a different assembly sequence. (Up to now Fujimori had claimed that the product designers think up the best sequence, so software like I demonstrated for generating alternate sequences is of no particular use...)

As a first step toward both goals, Sony is developing a "computer-based manufacturing system." It will contain vision and robot tool changing, plus a top level control system run by Sony NEWS workstations. Vision will be used to aid the teaching process, while tool change will be used to permit a robot to do the work of another one that breaks down (requiring a different assembly sequence?). In the future, force sensing will be added to permit assembly the way people do it.

TOYOTA

6 September 1991

Background

This visit was a followup to the one on 31 July. Our hosts were Mr. Kuranaga, Manager of Information Systems Div 1, Mr. Takatoshi Negishi, Manager of the CMM Group in Body Production Engineering, and Mr. Yasuhiko Ichihashi, Project Manager in the Chassis Design Department. Other attendees were Mr. Kato (CAD/CAM systems for suspensions), Mr. Sasano (body engineering CAD), Mr. Hatano (engine engineering CAD), Mr. Kobayashi (power train engineering R&D), Mr. Shimizu (formerly engine design, now in CAE), Mr. Yoshida (power train gear parts design), and Mr. Iwase (Info Systems Div 1, planning new CAD/CAE/CAM systems). The general subjects were the overall vehicle design process and use of computers in engine and transmission design. Afternoon plant tours covered die design and manufacture and Toyota's in-house manufacturing equipment building division.

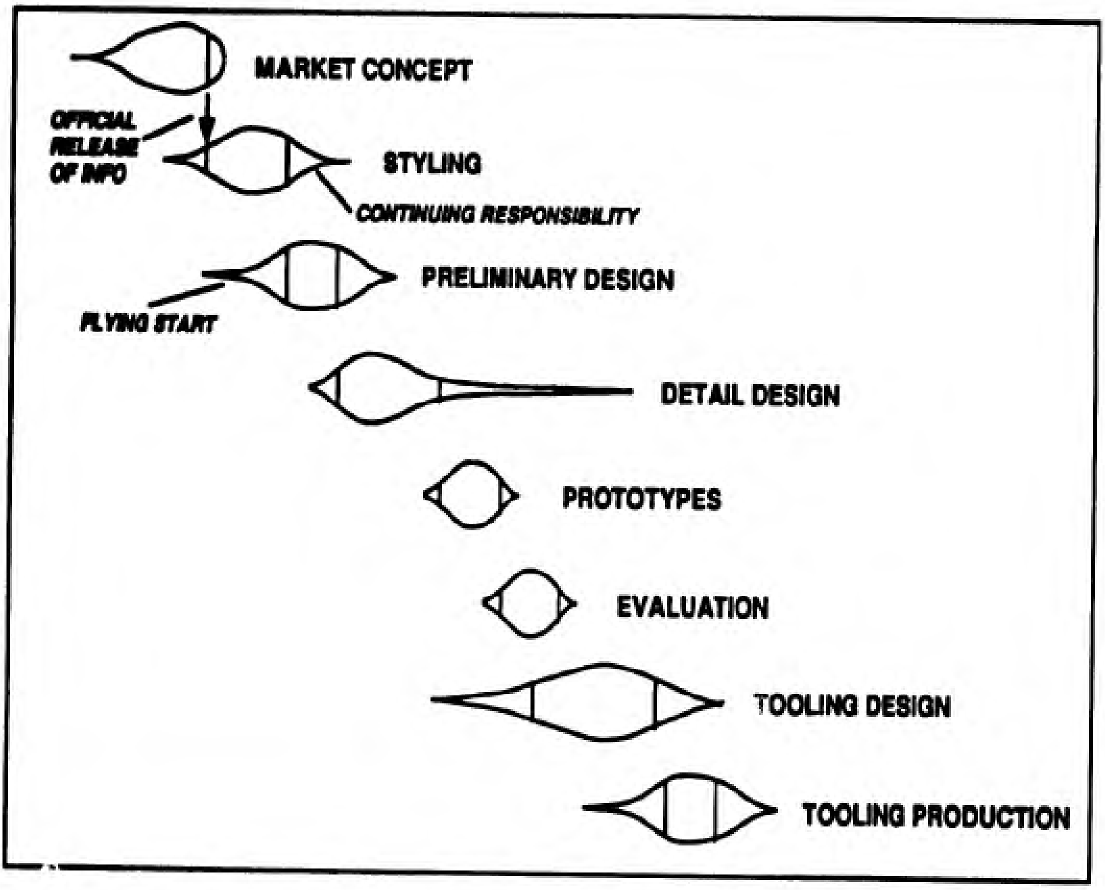


Figure 14. Overlapping design tasks. In this figure, the leftmost vertical line in each balloon indicates when official information is received from the previous balloon; the rightmost line indicates when official information is passed on to the next balloon. Preliminary information is released earlier than the official release so that the "flying start" can occur. Activity in each balloon continues after final release of information to take care of downstream problems ("continuing responsibility"). Courtesy of Toyota Motor Corp.

Vehicle Design Process

Sasano presented Toyota's car design methodology. He said that, overall, it takes 3 years from start of concept design to start of production. New technologies and power trains take longer. The concept, styling, and preliminary design take the first year; detailed design, prototypes, and evaluation take the second year; and tooling design and production take the last year. Later he amplified this breakdown with Figure 14, which shows that several of the processes extend over more than 1 year.

He used Figure 14 to make the point that European and U.S. car makers take longer to design cars because of a different attitude toward "responsibility and competence." In Toyota, designers have responsibility for their own designs, updating them where necessary due to the needs of downstream processes like tooling design. Sasano thinks that in Europe and the United States the downstream designers take over responsibility and can change the design. It is not clear why this should make the process take longer but clearly Toyota's method will cause the designers to learn downstream problems and avoid them next time.

The two important features of Figure 14 are the "flying start" and the "continuing responsibility" or downstream followup. Flying start involves two processes: an essentially free check of the design by the tooling people and a costly/risky early start on design and construction of the tooling itself. The vertical arrows in the figure denote official drawing release but there are clear cases where flying start extends back almost to the beginning of the previous task or even two previous tasks.

Table 2. Computer Support for Concurrent Engineering

Issue	Now	Future
Database	CAD model of structure: 3D wireframe, surface, or hybrid	CAD model Bill of materials Part attributes[a] Documentation
Communication	Data conversion Distribution to downstream processes	Universal communication network

[a]Attributes include weight, material, thickness, spot weld locations and their tolerances, and other tolerances.

Flying start information is not informal and is not transferred freely "among friends" (my terminology to indicate unsanctioned transfer). He was very firm on this point and it seems to contradict Prof. Fujimoto's description of a process that depends on long-term personal contacts. According to Sasano, there are various levels of approval, but all information transfer is approved. Final release has top management approval, but intermediate release of incomplete information can be done with departmental approval.

"Incomplete" can mean preliminary and subject to change, or it can mean that main structure is shown but details are omitted. How is the timing and content of these intermediate transfers worked out? What was the history of its evolution? "Difficult questions." The answer was typically Japanese: Our engineers are highly educated and have universal experience (i.e., they do not have a few narrow skills). They must harmonize with their job environment. Sometimes information is offered, sometimes it is requested. The correct action is a common subject of discussion among themselves.

Die design, power train design, and chassis design all utilize similar principles. The whole process is controlled by the Chief Designer (what Fujimoto calls the Heavyweight system). He is responsible for launching the effort and deciding all the tough technical issues.

Among these is allocating space for wheels, engine, and transmission in a front wheel drive car. Styling sets the spacing and the power train people fight it out for the space between. To catch problems early, Toyota starts engine compartment layout as soon as early styling sketches are available because many of the "hardpoints" (fixed dimensions like wheelbase) are determined at that time. A special cross-functional working group chaired by the Chief Designer is formed to handle this problem area. Wireframe 3D computer data are used to aid the decision process. Often its meetings are short because design consists of choosing an existing engine-transmission pair. When a totally new engine and transmission are used, car design can take longer than the 3 years cited above.

Computer Support for Concurrent Engineering

Sasano showed a chart (Table 2) delineating the two most important issues, databases and communication, showing the present status and future goals. For current data representation, there is a CAD model of the car in the form of a 3D wireframe or surface model, plus some parts that are modeled in a hybrid of wireframe and surface representation (the latter for complex surface regions). Communication is currently supported by data conversion software and by means for distributing data electronically to downstream processes. No mention was made of communication upstream. Since electronic data now consist mostly of geometry, a lot of attribute data are still issued on paper. Therefore, Sasano seems to think that electronic data representation is merely a change in media. Several of us in the meeting disputed this and he relented.

Hatano pointed out that in fact only body data are in 3D while all the rest are in 2D. The result is a lot of conversion to 3D to permit interference checking. This is painful and in fact the checks are done semi-manually. Multi-color wireframe computer drawings are projected onto a big TV screen in a meeting room and everyone talks them over. It is an awkward process and Kuranaga asked them if they plan to switch to all 3D in the future. Their answer is the typical one, namely, that 3D takes too long and the designers like 2D.

In the future, Sasano says that the database will be a combination of CAD models, bill of materials, part attributes, and documentation like process instructions. The future communication system will comprise a universal communication network. This will create "integrated engineering."

Prof. Kimura says he has heard Toyota people talk about this future dream system before but he feels they are still debating its details. It appears to be less developed than the ideas outlined by Mazda. Neither company seemed to have made explicit provisions for passing information back upstream. The issue came up at Toyota during a discussion of assembly planning. I had given an example of alternate assembly sequences for automatic transmissions, indicating that one sequence required mating several gears at once while another mated them one at a time, distinctly easier. The example was intended to show that there is more to DFA than just reducing part count.

Their reactions were several. First, manufacturing engineers work out the assembly process. They critique the detail design as well, pointing out opportunities to use existing tooling by recreating the hole spacing from a past design, or increasing spacing between holes so that all the bolts can be tightened at once. All this is based on past experience and data in people's heads. Second, so many meetings are held that 95% of all the assembly problems are discovered and eliminated. "Drastically speaking, our production engineers are our software," says Kuranaga. This confirms Nissan's view that Toyota can throw people at a problem and solve it. It also supports the view that many Concurrent Engineering activities that we would account for individually have become second nature at Toyota, and no need for specific efforts or additional software is seen.

Toyota uses CAD models to check tool access during assembly. Models of both tools and human hands are available in the database. Also, designers of transmissions and engines take into account the need for chamfers on parts, that a worker has only two hands, that assembly should occur from one direction, and so on. Transmissions are assembled manually. However, engines are assembled by a mix of manual and automatic methods. No formal design methods are used for taking these different assembly techniques into account, as far as I could tell.

As a result of its many meetings and universally experienced engineers, Toyota has no use for traditional DFA and feels that companies that use it must have poor communication and experience. The fact that both GM and Ford have made much of their success using DFA only confirms to Toyota that their competition is weak. They are apparently unaware of the innovative uses that companies like Sony and Nippondenso have made of DFA methods, where communication is simply not the issue.

It is possible that Toyota makes too much of communication and, like Nissan during my first visit, felt that I was interested in how computers can support communication. Since few Japanese companies think such support is necessary, I usually hear at first that computers are not essential to the design process. Only later did it emerge at Toyota that Iwase's new CAD project will indeed contain as much process engineering computer support as he can obtain or create, including that for asseml 'y.

I also learned that Toyota is actively investigating new workstation-based CAD software, such as ProEngineer. Negishi is quite impressed with it. However, all CAD systems he has surveyed, including ProEngineer and Ricoh's Design-Base, are unable to represent the complex fillets he wants for modeling connecting rods and other similar parts. While I originally thought CAD vendors' boasts about their filleting capabilities were self-indulgence, this remark by Negishi shows that some weight-critical parts can be essentially all fillets. Thus filleting can be crucial in certain situations.

A final point. My hosts at both Toyota and Nissan were CAD support people responsible for providing computer capability to engineering. The computer people are distinctly ahead of the engineers in their thinking and often propose capabilities or practices that the engineers see no need for. However, the history is that the capabilities are eagerly used as soon as they are made available.

Computer-Aided Engineering in Power Train Design

Apparently the typical CAE applications are in use, including their own software for supporting engine and transmission design. No software is available for setting tolerances, nor is there any support for selecting the style of transmission design. "An experienced person does it." Not enough detail was obtained to make possible an interesting report on this complex and rich topic. Another visit should be arranged.

Tour of CAD/CAM of Stamping Dies at Motomachi Plant

The CAE of dies was covered briefly in the first visit report. The tour covered the CAD facilities and the machining area. Figure 6 of the first Toyota report illustrates the elements of die design and manufacture. Our hosts for CAE and CAM were Mr. Muta and Mr. Amano.

CAE of dies has been forced by the huge growth in diversity of cars and the short design cycle. Many more dies are needed much sooner than before. As long as 10 years ago Toyota foresaw needing many more skilled people and more of their time than could be provided and therefore launched the CAD/CAE/CAM effort.

The CAD facilities are centered on a large UNISYS mainframe and many terminals. Data on die shape come from body engineering. In this area, die design is completed by the addition of details, clamp surfaces, cutters, and so on. Extensive software written by Toyota then determines the tool paths so that all the die's details can be cut, usually with a 1-inch-diameter ball end mill. Smaller tools are used only when necessary.

CAM consists of two rows of four large NC machines each. The first row was built by Toyoda Machine Tool Co.

in the early 1980s and consists of five axis machines. These yield die accuracy in the ±50 μ range. Toyota decided during the mid-1980s that this was not accurate enough and developed the second row of machines, which were installed in 1988. These are three axis (a surprise) and yield accuracy in the ±20 μ range. Three axis NC has the advantages of being more rigid and of having a smaller tool socket size, reducing interference problems between machine and die. On the new system a die stays on one machine 20 to 40 hours while it receives all the necessary cuts. The shop runs three shifts and runs unmanned over the weekend.

The need for higher accuracy came from identifying quality problems in earlier cars. An example shown is surface waviness near the edge of a door. Accuracy of internal structural parts is just as important as accuracy of the outer panels. (For reference, there are between two and three times as many inner panels as outer panels. Since there are typically 30 outers, there are at least 100 total per car and some require several dies.)

The dies are machined using 5-mm pitch cuts at first, then finished with about 0.5- to 0.7-mm pitch. Very high feed rates (as high as 4 m/min, they claim) are used on the final cuts. The resulting dies look like they have been sandblasted, with only a hint of linear tool marks about 15 μ high. Before finishing, the dies are checked in a coordinate measuring machine (CMM) to be sure that the 20 μ is obtained. About 15 to 20 hours of hand stoning and emery cloth polishing by three people then converts the die to a smooth, almost mirror finish.

Mating die pairs are checked with yellow transfer ink. Where a space equal to sheet metal thickness must remain, sheets of rubber are laid on the male die and then inked. These sheets have raised patterns of different heights in fractions of a mm with a different pattern for each height. From the pattern printed on the female die, the toolmaker can see how much material must be removed.

Why is this technique needed when 20 μ accuracy is obtained? Apparently this was an embarrassing question. The answer was not entirely satisfactory: there are not enough high accuracy machines in the shop to make all the dies to 20 μ. Either they are made on less accurate machines, or they are made by outside contractors to lesser accuracy, or the time is not devoted to a final cut at a fine pitch. More hand finishing is needed, adding error. Thus some dies must be hand-fitted.

Unlike any other shop I have visited that attempts work this accurate, this shop was not temperature-controlled or air conditioned in any way. The 20 μ is clearly meant as a relative error limit, as we could tell by noting how the CMM was working. That is, it is only necessary to be accurate relative to the hard points on the two dies that bottom on each other at the end of the stroke. Most dies are too shallow for temperature excursions to make large changes in height relative to the hard points. Length and width were not being held to such accuracies.

It takes about 22 days (three shifts) to make a die, according to Muta, of which about 3 to 5 are for tryout. These figures must be averages, since tryout of difficult dies often can take much longer. I was not able to find out how long it takes in such difficult cases, but Figure 9 of the first Toyota report shows tryout times in hundreds of hours, which is many days at 24 hours per day.

Visit to Teiho Plant

At this plant, Toyota designs and makes automation equipment, some of which it sells as well as uses internally. Mr. Takano showed us local area network (LAN) equipment and associated controllers, cables, and connectors all designed to Toyota's own standard. These controllers were attached to a variety of Japanese computers, controllers, and robots. The data rate is 1.25 MB/s.

We also saw a video illustrating several pieces of factory automation designed and installed by this division. These included beam transfer handling systems for merging car bodies, chassis, engines, and axles; vision-aided robots for installing dashboards; and a system of three robots that (in a rather complex way) installed wheels on cars and then installed and tightened the nuts. The body-engine-axle merging system looks somewhat like what VW installed in Hall 54 in the early 1980s.

Kuranaga noted that the dashboard being installed was empty, that workers later must lie down on their backs in the car and install the instruments and wires. "We do not install complete tested cockpits. In fact our weak point is that only 5% of our final assembly is automated." VW claimed 25% in Hall 54, and GM has been installing complete cockpits in some cars for several years.

A tour of this division's workshop turned up two cooperative robots programmed by mutual timing to open a beer bottle and pour beer, some AGVs being tested, plus several conventional assembly and machining lines under construction. The beer opening robot contained no sensors and operated in a very conventional way available to any commercial robot. I was told that in a factory, a similar pair is at work loading balls into constant velocity joints.

The other equipment was also conventional. One machine consisted of robots and transfer equipment intended to weld together three parts for the tube and brackets of MacPherson struts. These are simple parts and such struts are undoubtedly available from any number of vendors. Given the outsider's impression that Toyota buys conventional components, I was surprised to see this machine. No explanation was available.

However, I have heard separately that Toyota is beginning to bring as much as 10% of routinely procured parts in-house so that some idea of a fair purchase price can be determined internally. This includes not only simple parts like the struts but complex electronic items.

Concluding Remarks

These two visits obviously barely scratched the surface of one of the world's leading manufacturing companies. It is clear that use of computers in the design process is growing rapidly and that it is company policy to encourage this process. The priorities are focused on design-manufacturing integration of efforts that currently take a lot of time, for which accuracy is required, or for which human experience is needed and ways exist to augment this experience.

IBM FUJISAWA PLANT

9 September 1991

Background

My hosts were Mr. Sawada from the Tokyo Research Laboratory (TRL), Mr. Tsunoda of Manufacturing Engineering, and Dr. Koda also from TRL. This visit was mostly a plant tour to see manufacture of hard disk drives (HDD) for PCs.

Product and Factory Design

A disk drive is designed by a team of about 30 designers. This total includes all support people, such as draftsmen, of whom there are few or none. Design is done at another plant in Yokohama about 10 miles away. The HDD assembly system is almost totally automatic, comprising many class 100 clean rooms, robots, conveyors, stacker cranes, and test equipment. IBM and its vendors took 9 months to design, build, and install this large system. In the future, Tsunoda notes, they must reduce the time to 6 months.

The decrease in time to produce the factory coincides with the faster pace of new product introductions. Only parallel development of product and processes will be capable of sustaining this development. This is Concurrent Engineering, according to Tsunoda, who did most of the talking during this discussion and appeared not able to answer my questions easily.

A possible reason emerged later in discussions with younger engineers. I was shown a promotional videotape that first described IBM's software vision of CIM, then showed how it has been implemented at Fujisawa. The icon of this video is a set of three concentric rings. Each ring is segmented into activities: on the outside are the factory's activities (engineering, marketing, etc.), then inside are the common support elements like computers and displays, and on the innermost ring are the architectural elements like communication, databases, and presentation software.

This icon has been associated with IBM's CIM publicity for about 10 years and it gives the impression that if one has the right software one has CIM. The video confirms this by listing all the IBM products or VAR items that make up the system (CATIA, EDCS, VALISYS, COPICS, MRP, DB2, SNA, RIC, AS, QMF, SMART, and AD/Cycle), omitting explanations of what they stand for.

It is clear, however, that behind the acronyms there are problems because in fact the communication channels between people are not as open as they should be. HDDs are very hard to design, especially high performance ones (not shown to me). IBM is not the only company I know where the design is passed on to the manufacturing system people without their being able to comment on it, much less get a head start on their system design.

The method consists of product designers at one facility making the design, passing it on to another facility where process specifications are designed, then to a third group at the second facility where the equipment is designed or specifications are written, and finally giving vendors the specifications for fabrication and installation of the equipment. For example, no IBM robots are among the 10 used for HDD assembly, test, or material handling.

This method is very much in the American style. This style prevents the typical Japanese method of bottom-up automation from occurring. The technology belongs to the vendors. Each department is a specialist. "We Japanese learn by trying, not by buying. The Japanese maker's treasure is his factory." "So IBM Japan is an American company with Japanese employees?" "Yes."

Plant Tour

This is a truly integrated factory for HDD assembly. (Procuring and installing it in 9 months was clearly quite an achievement.) Incoming parts are stocked in an automated warehouse in boxes or bins. They are called out by the assembly equipment as the need arises. This is called "Auto Pull Mode," an automated version of the Kanban system. Parts are first sent by automatic conveyor to a cleaning machine which presently soaks them in a swirling Freon bath. This bath will soon be replaced by one that uses just water. Then they travel by conveyor to the assembly area.

The mechanical portion of the product consists of about 16 parts plus 4 vibration isolators and 5 screws. Unidirectional assembly is used. A line of 10 robots builds it up, starting from a kit of parts (base-motor-spindle, head package, set of platter spacers) manually loaded into the pallet. The robots take the platters from a feeder magazine, where they sit upright, and put them gently on the drive spindle, then insert a spacer, then another platter, and so on. Finally a cap and screws are installed. Each drive then gets servo marks written and a 10-minute test. If it passes this test, an elastic seal gasket and the lid are installed using more screws, and the drive is leak tested. If it passes, it leaves the clean room for more electrical tests, addition of the logic board, still more tests, and finally packaging. Some of the equipment in this second line, especially the screw feeding and installing parts, seemed very elaborate and complex. The tour was so rushed that I could not ask about any of the details.

Only a few of these steps require human intervention. One of these is the place where TRL's force-controlled robot is supposed to plug the test connector into the drive. A second feeder robot was broken so the whole station is down. This robot uses a low insertion force connector invented by IBM. It reduces the insertion force by about half by recessing half the contacts part way in the insertion direction. Half the males and females mate early in the insertion process while the other half mate later. The insertion force history, therefore, has two small peaks rather than one large one.

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ASSESSMENT OF CARBON-CARBON COMPOSITE RESEARCH IN THE FAR EAST

Dr. Robert A. Meyer conducted this study for the Office of Naval Research between December 1990 and March 1991. His trip to the Far East included visits to six universities and seven research institutes in Japan, Taiwan, China, Korea, Australia, and India. He also attended a meeting of the China Association of Science and Technology in Beijing. This report summarizes Dr. Meyer's observations and assessments from his visits to these organizations and attendance at the meeting.

by Robert A. Meyer

INTRODUCTION

The potential for utilizing carbon-carbon composite (C/C) materials is large because of carbon's unique physical properties. For example, one form of carbon is graphite, which has high specific strength and stiffness values at temperatures in excess of 2,000 °C, zero or negative thermal expansion values between ±200 °C, and low outgassing characteristics. Thus, C/Cs, which contain large portions of graphite, are an excellent material for space applications. Another advantage of using C/Cs is the ability to change the material's physical properties by altering the type and distribution of yarns and to vary the microstructure of the matrix that exists within and between these yarns. This ability to fabricate composites with different types of characteristics enables the designer to select and obtain the proper type of material that will withstand specific adverse environments.

The United States has been very successful in translating engineering requirements and process "know-how" into C/Cs with good operating characteristics. But this success is costly. In some cases, the improvements are accomplished by means of scaling up the processing and fabricating procedures in a step-by-step developmental manner from small laboratory size samples to very large and full-scale hardware. In other situations, previous manufacturing experience is used to modify an existing process by making small incremental changes over an extended period. With either approach, the large pieces of hardware are very costly because of the materials they contain and the months of time it takes to fabricate them. Obviously, failure to properly make one of these pieces or to have it "destruct" during its operation is unacceptable. Some of these failures have been attributed, in part, to a lack of knowledge. Either the material's true physical properties were not used for defining the design criteria or the most important parameters for the control of the process were not identified to insure the desired physical properties and high degree of reproducibility from piece to piece. Furthermore, the need for improved processing control is becoming more critical because the C/Cs are now required to function under more severe operating conditions. As these requirements become more extreme, it is necessary to have a better understanding of the influence of the composition of the C/C on its behavior. Such information is derived from more research activity so that further directions for research and development (R&D) and alternative processes can be defined for obtaining the desired properties in a more economical manner.

Unfortunately, the financial support for C/C research efforts in the United States has been steadily declining for the past 8 or more years. This means the enhancement of C/C properties has and does occur in a limited way by gradually changing current processing conditions using one of the two approaches already described. Another impact of using these approaches is that of not having available sufficient research information to improve the possibilities that unique, original, and significantly large advances can be made. This also means the technology that is currently being used is derived from research data that were probably obtained 5 or more years ago.

If this situation continues to exist, the lack of research information will eventually limit the ability of the United States to develop improved C/Cs, not only for our use but in competition with foreign countries. The questions that naturally arise are: What should be done? and Is the United States ahead, equal, or behind other countries in its research capabilities and knowledge for developing advanced C/Cs in a timely manner? This assessment study and interpretive report is being undertaken for the purpose of providing information to be used in answering these questions and to assist in formulating future program plans for research efforts in this field.

OBJECTIVE

The overall objective of this survey is to evaluate the current status and to estimate the future directions of foreign research efforts that are being conducted in the area pertaining to carbon-carbon composite materials and related technologies. Based on this evaluation, a general assessment will then be prepared concerning the expected impact that these foreign activities could have on the research and development capabilities of the United States for producing advanced C/Cs in the long term.

APPROACH

The major thrust in gathering information for this report was directed towards those areas of research that are considered to have the greatest potential impact for improving the performance of C/Cs. This means first priority was given to the areas of fibers, their architecture in woven forms, processing and densification methods, the influence of matrix microstructure to physical properties, bonding phenomena, and characterization methods. Other interesting areas of research activity were also included when it was possible.

This survey is organized into two major categories: (1) the country where the research organization is located and (2) whether each organization is directly supported by a university, the government, or industry. This categorization permits comparisons to be readily made of the research efforts as well as the types of organizations that are sponsoring the research either within or between countries.

The process used for selecting the organizations consisted of reviewing the literature and then seeking the advice of senior research persons who have had interactions with the researchers from each of the organizations that were being be considered. The other factors that were important include the organization's overall research reputation, the staff, past and present publications, activities in professional meetings, and the expectation that these trends will continue in the future.

The type of information that was sought from each organization had three purposes. The first was to determine the significant directions and unique research results. This information was used to evaluate the research capabilities of the organization and to inform the reader of the types of research being conducted so that more in-depth communications could be conducted if so desired. The second objective was to understand what the organization's future research goals will be based on its interests and the types of persons that are expected to be there. The third objective was to evaluate the degree of collaboration each organization would be willing to undertake with organizations in the United States. The term "collaboration" is purposefully not specifically defined so a variety of definitions are possible, such as just an exchange of research thoughts, or a foreign country's support of its students/professors at U.S. universities, or perhaps complementary research that could be undertaken on an international basis.

Some information is also included in this report about important areas of technology that are of secondary interest relative to the objectives of this study but that were discussed during the course of the investigators' presentations. For example, comments will be included that are concerned with oxidation resistance efforts as they are applied to C/Cs.

REPORTING FORMAT

A specific format is used for presenting the information that is obtained from each organization to provide as uniform and complete information as possible so that comparisons can be made between them. The format is divided into three sections: Background, Program Status, and Assessment. The Background section is to acquaint the reader with the past and current thrusts of the organization and who the primary research leaders are in the organization. It is hoped this information will enable the reader to understand some of the reasons for the existence of the various types of research programs that are being conducted at each site.

The Program Status section contains information about the current activities of each organization. In particular, unique results or experimental approaches will be cited as well as a synthesis of the relevant discussions. The technical depth of the discussions with the individual investigators will depend on the availability of the investigators' time as well as the number of activities that are to be discussed in the allotted time for each site visit.

The third part is the Assessment section. In it the research capabilities of each organization will be discussed in terms of its current and possible future contributions to the field of C/Cs and related technology. The possible impact of these capabilities on the Department of Defense's (DOD) C/C and technology research programs will also be included as well as the possibilities and advantages of using the visited organizations' strong points to augment the DOD's own technical capabilities through international cooperation programs.

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Background

The host for this site visit was Prof. Yoshihiro Hishiyama, who is in charge of the Carbon Research Laboratory in the Physics Department at this institute. Hishiyama has been here for more than 26 years and is a senior staff member. The institute was started as an engineering school about 40 years ago when the Japanese Government expanded its educational program beyond the national university system that had been in existence before World War II. The institute is privately funded and has more than 4,000 students, of which 200 are graduate students.

Hishiyama's primary area of research is in the solid state physics of carbon and, in particular, the electrical characteristics of carbon as determined by its structure from <1.2 K to >2,600 K. His group consists of an associate professor, four graduate students, and six part-time undergraduate students. Hishiyama is considered to be Japan's best researcher in the field of magnetoresistance and in the definition of the crystalline structure of carbonaceous systems through the use of electron microscopic techniques. He also uses other electrical characterization techniques such as measuring the Hall coefficient, resistance, and thermoelectric power to help define the structure.

Hishiyama was a postdoctoral fellow at the University of Buffalo for over a year in the mid-1960s under the direction of Prof. S. Mrozowski. It was here that Hishiyama started his studies in magnetoresistivity and was the first in Japan to conduct such research.

Program Status

A current area of research interest is the electrical properties of pure carbonaceous systems. The samples are rather unique in that they are derived by the pyrolysis of scotch tape where the heating rate is 400 °C per hour to a maximum temperature of 1,000 °C. This method produces a very thin film of pure carbon upon which four very thin electrical leads are fastened to it by a gold film derived from a suspension of gold particles in a solvent that is evaporated, at room temperature, after it is applied at the junction of the wire and the sample.

Another area of research is the characterization of the crystalline structure by advanced scanning electron microscopy (SEM) methods where low voltages of ~1 kV are used with a new method of electron detection using a lens field emission electron gun that has a resolution capability down to 3 nm rather than the current value of 10 nm that is attained at 10 kV with today's technology. The use of the lower voltage has the added advantage that the incident electrons do not penetrate as much into the sample and therefore provide a more accurate representation of the sample's topography. Between the better resolution power and the fidelity of depicting the surfaces, there is a great deal more information available about the microstructure and its changes with processing conditions. This type of information is most valuable in furthering the understanding about the microfracturing behavior of these crystallites.

Another investigation is concerned with the effects of heat treatment temperatures on the electrical properties of neutron irradiated graphite crystals. The sample sizes are about 2 x 4 x 20 mm and these samples contain grain sizes between 10 and 1,000 Å. In these studies it is assumed that the grain size distributions are similar among all the samples that were measured. These studies are being conducted using annealing temperatures between 700 and 1,000 °C. The current data indicate that the changes to the electrical characteristics of the samples are due to the scattering of electrons by interstitial carbon atoms that have been displaced from their normal positions in the crystal structure by the reactor neutrons. Apparently, the electrical resistance and magnetic resistance measurement techniques are sufficiently sensitive to detect 20% changes in values with only a small amount of reactor exposure on the order of 1 million neutrons per square centimeter.

The laboratory capabilities at this institute are very adequate to support the carbon research that is being conducted. Most of the high precision and sophisticated electrical characterization equipment is in Hishiyama's laboratory. This includes two pieces of magnetic resistance equipment that operate between 1.2 and 300 K in a field of 1 T (11 kG/cm^2). This magnetic field strength can be increased by more than sixfold using superconducting magnets. In addition to the measuring equipment, there is a capability to heat treat samples to more than 2,900 °C in a graphitization furnace that is now in the process of being reactivated. To better understand the physics of these carbonaceous materials, some samples are prepared and measured with the intent of having the highest degree of perfection of the graphite crystal structure within them. Consequently, these samples can be as small as 2 x 3 x 0.5 mm because the grain size is small even with some of the largest crystals of graphite that are available. These have been derived from a special supply of Kische metal that Hishiyama obtained many years ago. In spite of the very small sizes, the samples are cut and shaped with dental tools so that they have uniform cross sections and thicknesses as well as four tabs so that wires can be fastened to them with which to make voltage and current measurements. Obviously, great care must be taken in shaping each sample, not only because of its small size but because of the very limited supply of the raw material. Therefore, Hishiyama is the only person that prepares these types of samples.

A centralized laboratory facility also exists at this institute that provides special types of analytical equipment that are very costly and would be difficult to obtain and fully utilize, on a cost effective basis, by any single department. In this manner, individual investigators have available to them special capabilities when they are needed and pay only for the amount of service that is rendered. In addition, this facility is staffed with specially trained operators who operate the equipment, prepare samples, and analyze the data. These persons are usually undergraduate or graduate students. Apparently, this method of operation is effective because in the 8 years of its operation, this central facility laboratory has never had an accident or lost a piece of equipment due to faulty operating methods. The whole spectrum of equipment includes a 60-kV, 18-kW x ray; numerous SEMs, including one with the most recently available new high resolution features; infrared (IR) spectrometers; ultraviolet (UV) spectrometers; transmission electron spectrometers (TEMs); along with other analytical tools and the appropriate data processing capabilities. This approach of having a central facility for first rate equipment is a partial answer by the university to the competition that exists between the universities and the big industrial corporations that have available the most up-to-date facilities.

In discussions with Hishiyama, some further insight was obtained about the limited amount of communication that can exist between universities and industrial organizations in Japan. This seems to be the result of fierce competition within the industrial community. As a result, companies will acquire equipment and train their own people without seeking the assistance of experts at the universities just so no one outside the company will know that this particular capability exists in the company. An example of this scenario was cited by Hishiyama. He is recognized by the research community as the expert in Japan in the field of magnetic resistance measurements and has been in this field more than 25 years. Furthermore, he has presented his findings at national and international meetings throughout these many years. Yet, Hishiyama only found out, inadvertently, about a year ago that magnetic resistance research capabilities have been developed and have been used for product development in many of the large industrial research laboratories for the past 8 years.

Assessment

Prof. Hishiyama is clearly devoted to research in the solid state physics of carbonaceous materials. His interests and the direction of his laboratory programs are to understand the causes of the changes to the electrical properties of these materials. In the pursuit of this goal he is also interested in developing and perfecting laboratory techniques and equipment that will aid in acquiring more information about the structure of these carbonaceous materials. It is expected that this general program will continue in the future in these directions at least for another 15 years or so until Hishiyama retires.

Hishiyama's research work is known and respected throughout the world. In fact, he is currently a member of the French and Japanese cooperative program that is conducting a research study on the development of carbonaceous microstructure and its influence on physical properties. He is also a coauthor of a chapter in this same area of research for the next addition of the series titled *Physics and Chemistry of Carbons*, which is edited by Prof. Thrower of Pennsylvania State University.

To my knowledge there is no one in the United States who is now conducting the type and depth of research that is being performed by Hishiyama. Therefore, it is considered important that continued awareness be maintained of his work. If possible, it is recommended that some sort of cooperative research be initiated with this group which, according to Hishiyama, would be welcomed. One suggestion of a possible area might be to investigate the potential of using electrical measurements to characterize the microstructures of graphites and carbon-carbon composites for the purpose of developing their optimum properties as is being done in Russia. The U.S. contribution could be to evaluate the applicability of this fundamental information for R&D purposes.

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Background

My host was Kozo Tanaka, who is the director and general manager of the entire Mishima Plant.

Toho was started in 1934 as a producer of acrylic fibers for textile manufacturers, and today they are still the major customer. However, Toho has enlarged its product line. In 1968 the rayon base fiber development program was initiated; in 1971 the pilot plant was started, and these fibers with high strength and strain properties were available as a commercial product in 1975. Now prepregs are available for organic and carbon matrix composites and for the densification and production of composites, including C/Cs. The production rates are 4,000 tons/mo for acrylic and rayon fibers, 170 tons/mo for carbon fibers, and 4,000 tons last year for all the fibers that were produced. It was also stated that Toho is the largest producer of fibers in Japan, with a total capacity of 10,000 tons/yr. Toho weaves about 5,000 m^2/mo and prepregs 200,000 m^2/mo of unidirectional, roving, and fabric materials. The company has about 2,000 employees, of which 25% percent are at this Mishima site. In this plant all portions of the fabrication process are performed, from manufacturing of the fibers and precursors for densification, to weaving of the preforms, to impregnation and final heat treatment steps.

General business objectives are to market the company's products world wide. To do this, Toho licenses and has cooperative agreements with organizations in different parts of the world, such as NARMCO in the United States, which buys Toho's prepreg, and BASF in Germany, where there is a joint venture concerning fibers and prepreg. Toho is continually trying to expand its worldwide market and considers Hercules and Amoco to be its main competitors outside of Japan and Toray to be the major one in Japan. Some of the areas that utilize carbon fibers include low inertia rollers, high speed spinning pots, bicycles, prestressed concrete for buildings and bridges, nickel-coated fibers for electrical magnetic shielding for laboratories and testing rooms and, of course, sportswear. The primary market that is now being targeted is the aerospace and aeronautical industry, especially in the United States, where Boeing is considered the largest user of carbon fibers. Toho is actively preparing for the future needs of the automotive industry.

Communication and interactions between industrial organizations in Japan are limited because of the fierce competition between corporations and the laws that exist as to how financial support is to be given to the university system. Toho appears to have very limited interactions with the carbon community. The only organization of which it is an active member is the New Carbon Forum. This forum is supported by over 30 of the largest industrial organizations in Japan. Its purpose is to determine applications of carbon systems in all areas of technology, i.e., aerospace and aeronautics, biology, construction, medicine, power, etc. This is a very active and costly operation that conducts studies and seminars, reports on new possible areas, provides translations, etc. The forum is divided into many committees and subcommittees that meet in some form or other on a monthly basis in a particular area. There is no equivalent organization in the United States where information is exchanged so frequently and in such a broad and in-depth basis.

Government financial support is not actively sought by Toho because the acquisition of this type of money is unpredictable and is of a short term nature of only a few years. Also, it means a lot of the technology that was obtained with corporate funds must be revealed if support is received from the Government.

Cooperative programs between companies rarely occur; if they do, they are usually between subsidiaries within the same corporation or as part of a consortium that has been formed to obtain government funds. This same attitude also exists relative to cooperative programs with organizations from other countries. At this time, there is no real interest in cooperative programs with organizations in the United States in the area of carbon fibers because Toho believes it has more information in this area than anyone else so there is nothing to exchange. Its attitude is different with respect to C/Cs, especially concerning aircraft brakes, because of its desire to enter this field and because the Japanese feel the United States is the leader in engineering and producing C/Cs on a large scale.

Program Status

Toho's overall approach toward research is to develop new products or to increase the reliability and production capability of existing products. There are two laboratory organizations in the company. The Mishima Plant consists of about 60 members, of which 20 have Ph.D. or master's degrees, 20 have bachelor degrees, and the rest are technicians and support people.

The general method that is used for the development of a new area, such as a fiber or an impregnant, is the "Edisonian" approach. This means very small changes are very carefully made to the particular process being studied and its effects are observed in the smallest detail. In this manner, the variations or "causes" due to any changes to the process are understood as an "effect" on the product even though the precise phenomenology is not understood. Fundamental research directions are used occasionally if they have the potential of resulting in the development of advanced products.

Sometimes employers support their employees who are students at the universities where they perform fundamental research studies that have a corporate goal. More often, the corporation gives the universities money for the general support of students that are studying under a particular professor or in a department where the corporation is interested in acquiring first class students. Then, the corporation expects to be given a "preferential" choice in obtaining the best students. This method of operation is utilized because the supply of well trained and qualified students is less than the demand. This system is particularly effective as, generally, all the negotiations between the students and the corporations are handled through the professor.

Fibers have been developed to meet the current and anticipated needs of the consumer. At this time the emphasis is to further identify the most desirable precursors by chemical analysis and other characterization methods that are used to assist in the definition of the optimum carbonization cycles. The Toho fibers have a variety of properties, e.g., strengths from 15,000 to 600,000 psi and modulus approaching 90 million psi. The strains available are as high as 2%. No further improvement is going to be made on this property until the customers indicate there is a need to do so. Interestingly, a curve was shown of strength plotted against modulus values and families of isostrain curves as the third variable. It appears that the maximum strain of 2% occurs at a modulus of 45 million psi with strength in excess of 600,000 psi. For strains in excess of or less than 2%, the strength and strain values are lower, independent of the modulus values.

There are no production problems concerning the manufacturing procedures related to rayon-based fibers as there are strict environmental standards and control procedures in effect.

Architecture and weaving requirements are dictated by the utilization need. At this time resin matrices are the controlling matrix dictating the type of architecture, especially as it applies to the aircraft industry. The analysis used for selecting the architecture is usually done by the customer or some other organization outside of Toho, although a general design code has been developed at Toho expense that is licensed outside the company for the use of its customers. There are a number of composites made from low cost laminates of two-dimensional (2D) material with tensile strengths from 15,000 to 30,000 psi, and there are high strength laminates made of long fibers that contain yarns that have 0.2-mm spacings. There are tubes made with wall thicknesses of 1.5 mm and outside diameters (ODs) of about 1.5 inches that are similar to the Naval Surface Warfare Center (NSWC) tubes to be used for space structures. Other laminates are made of chopped fibers, which are matted and the surfaces of the fibers are activated for use as absorbent material. The densities of these various composites can range from 1.3 to over 1.7 g/cc depending on the application. The most complex shape of C/C that was seen was a turbine wheel with thin blades that were integrally woven into the rotor. Its density was in excess of 1.7 g/cc and it had a fine weave spacing of about 2 mm. All the C/C development work began at Toho about 10 years ago.

One concern in the processing of these different composites is to increase the utili. .tion of the fiber properties that are in the composites which, at this time, is only approximately 50%. A high strength 2D composite can have tensile strengths as high as 100 kpsi at a modulus of 26 Mpsi, a density of 1.63 g/cc, and a fiber volume of 57%.

Densification methods by both liquid and chemical vapor deposition (CVD) are being evaluated at this time to find the most economical approach that takes into account the specific application that is under consideration. At this time, there is a concerted effort to determine if coal tar or petroleum-based pitches are the best for densification of the types of preforms that are being sold. One technical difficulty that Toho has found with the CVD method of densification is the inability to obtain a uniform density of deposition even with cross-section thicknesses of only a few millimeters. This, of course, is a classic difficulty that is found with all those that use the CVD method.

Interfacial bonds between the matrix and the filament are considered to be very important for composites. However, the major emphasis at this time is with resin matrix composites. Studies about interfaces of C/Cs will occur at a future time. Toho is oxidizing its fibers at 300 °C as a means of increasing the bond strength between the fiber and the matrix.

Methods for enhancing the oxidation resistance of C/Cs were begun 2 to 3 years ago. At this time the protective layers are composed of SiC and matrix inhibitors of silicon carbide or boron carbide. Toho is also looking at how to protect the fibers either by increasing the perfection of the fiber's microstructure and thereby reducing the number of sites for oxidation or depositing inhibitors on the surface of the fibers. The degree of protection is close to zero weight loss at 1,200 °C for a duration of 200 minutes. However, no thermal cycling was performed prior to this oxidation resistance test. There are two staff people working on this area of technology.

Microstructural evaluation of samples has been limited to optical examination, both with polarized and bright field illumination. In addition, the SEM has been used to examine the topography of C/Cs and their fractured surfaces. But no etching of samples has been performed for examining the various types of matrices and their interactions with the fibers that they surround.

The laboratory contains complete chemical and physical property equipment for evaluation of raw materials as well as finished products. The equipment includes SEMs, TEMs, Instrons that test samples from -60 to 300 °C, IR spectrometers, thermal conductivity and expansion testing devices, high precision electrical property measuring equipment, electron spectroscopy for chemical analysis (ESCA), liquid and gas chromatographs, and other equipment for chemical analysis. At this time these laboratories are equipped with an emphasis towards organic matrix composites because this is the area that contains the major portion of the company's product line. These laboratory facilities occupy two floors of an entire building for a total of about 80,000 to 100,000 ft^2.

Quality assurance and qualification programs are an important part of the Toho operation. A significant portion of this effort is concentrating on obtaining data to qualify the company's aircraft brake material in order to penetrate the market in the United States. The normal types of ultrasonic and x-ray equipment and other standard types of procedures are being used. In the production of fibers, real time monitoring is used on the production line.

Assessment

It is expected that the future directions of R&D will continue as they currently are for the next 3 to 5 years. Towards this end, the laboratory organization and physical facilities are excellent. It is estimated the emphasis at Toho will be on research for the near term development of carbon fibers and C/Cs for applications that are or have the potential of being used in the next 5 or more years. The small amount of nonproduct related basic research that is being undertaken at Toho is expected to be for identifying totally new concepts.

On the subject of cooperation with U.S. organizations, especially at the university level, the most likely way of determining what would be of mutual interest will be to communicate with Toho's subsidiary in the United States. It is possible to receive special fibers from Toho for certain studies where the information obtained is also of interest to the company. I got the impression that cooperative programs could be established on a case-by-case basis.

I recommend that further communications and awareness be continued with Toho based on its experience and continued leadership in this field. Furthermore, Toho is a potential source of samples that might be of special interest for research in the United States and perhaps for future cooperative programs.

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Background

Dr. Seiichi Uemura, who is the general manager of the Advanced Materials R&D Division, was my host for this visit.

The research at this laboratory is directed at the development, improvement, and cost reduction of current products. But clearly there is also an emphasis on investigating and identifying advanced concepts and alternative ways of utilizing carbon for the future. In general, the senior staff members initiate research that is undertaken for selecting future programs.

C/Cs are being emphasized by the Japanese as the Ministry of International Trade and Industry (MITI) is supporting the national aerospace plane, in which C/Cs will be used as a major component. With this support it is expected that Nippon Oil will continue research in this area for at least another 7 or 8 years. In this regard, there is a cooperative effort with Mitsubishi Heavy Industries and some other corporations that have formed a consortium to develop plans for building the aerospace plane.

Since this is an oil company, there is a primary drive to find ways of utilizing pitch fibers in all sorts of commercial applications. Therefore, all three major types of composites are being investigated that contain organic, metal, and carbon matrices.

Program Status

R&D of C/Cs started here about 8 years ago. It was stated that these R&D efforts will continue at least for another 8 or more years and probably longer. At this time they are learning how to economically process the preforms with the desired properties. In order to acquire expertise outside of Nippon Oil's laboratories, there is a policy of sending three staff persons each year to either a university or an organization within or outside of Japan to work with an expert in an area of research that Nippon Oil believes will be important in the future. Nippon Oil pays the employee's salary and expenses as well as the organization and the expert for their time and facilities. For example, this type of arrangement occurred in 1985 at Rensselaer Polytechnic Institute (RPI) with Prof. Dieffendorf, who is considered one of the world's experts in CVD methods for the densification of carbon fiber preforms. In general, the research that is being conducted here covers most of the important areas that influence the properties of C/Cs. For example, fiber surfaces are being processed both by oxidation and chemical treatment methods to enhance their bonding properties to the surrounding matrix. No particular details were presented concerning the treatments, but the general intent is to find the type of bonding that will give the proper degree of bonding that is neither too strong nor too weak so that the fiber properties can be best utilized in each type of composite.

Studies have been conducted to determine the effects of high temperature heat treatment on the mechanical properties of pitch and polyacrylonitrile (PAN) fibers. No detailed data were given other than the strength and modulus of the pitch fibers increased with temperature and then remained constant as the temperature reached more than 2,000 °C. In contrast, PAN-based fibers showed a decrease of strength but an increase of modulus followed by stabilization at the higher heat treatment temperatures. This laboratory is capable of producing 50 tons of prototype fibers in a year. Nippon Oil produces 50 tons/yr of high modulus fibers that are derived from pitch and 500 tons/yr of low modulus fibers. According to the company, these are the largest quantities of pitch fibers produced in Japan. But these are relatively small amounts compared to the quantity of PAN-based fibers that are produced. It is estimated that more pitch-based fibers will not be used until the cost of their production decreases another 25% to 50%.

All sorts of weaving capabilities exist in this organization, including three-dimensional (3D) preforms that are 6 inches long by 4 by 4 inches in cross section. There is a unique ability for forming tapes of fibers that are used to produce aluminum and ceramic matrix composites. The fabrication process is performed by first spreading the fibers within yarns and then plasma spraying coatings on to them. Next, the coated yarns are stacked and hot pressed into final composite shapes.

Densification studies are underway to determine the best process for densifying preforms either by liquid pitch or CVD. In the latter case, there is concern that CVD may take too long (up to a year) to obtain the proper microstructure in a C/C preform. The predictability of the processing time is also difficult to estimate to know if the process is economical. The alternative process for densifying preforms is to infiltrate the preforms with liquid pitch. There is autoclave equipment available for high pressure impregnation [hot isostatic pressing (HIP)] of preforms to over 14 kpsi. This enhances the ability to increase the billet's density with fewer impregnation steps by increasing the carbon yield by 10% to 15% for each impregnation cycle, thereby reducing the cost of densification and fabrication. In a smaller autoclave it was found that the pore sizes can be decreased if the preform is subjected to about 28 kpsi gas pressures. This smaller autoclave can reach temperatures of 1000 °C, which also results in a smaller amount of preform shrinkage.

There is not much research underway on evaluating the microstructure of the matrix, although it is recognized that this could be an important factor in controlling the properties of C/Cs.

Oxidation protection for C/Cs is being investigated whereby protection is derived from layers of SiC or boron carbide that are vapor deposited on the surfaces of the C/C substrates. There is a concerted effort to find a method of minimizing the problem of cracking of the ceramic coatings due to the differential thermal expansion mismatch between the C/C substrate and the oxidation protection layer. The general approach is to vapor deposit six or more layers that each have a different coefficient of thermal expansion (CTE). These values are adjusted so that there is a transition of expansivities that is compatible with both the oxidation protective layer and the carbon substrate. This is called the functional gradient materials (FGM) method, which was successfully developed some years ago by Nippon Oil to form ceramic-to-metal seals. The principle is to adjust the porosity of a particular layer in the transition zone by selecting the proper mixture of gases and temperatures while the layer is being deposited. For example, the carbon content of a gas mixture with SiC can result in different degrees of porosity and variations of CTEs from 1 to 4 by 1/1,000,000 per °C. This is the first definitive and more fundamental approach that has been presented by any of the European or Asian organizations that have been visited on this assessment study up to this time.

Laboratory equipment and facilities are extensive and occupy three floors in one building and one floor of another building for a total floor space that is estimated at more than 80,000 ft^2. There were the usual types of equipment for performing chemical analysis and characterization of the precursors and finished products as well as for determining their electrical and mechanical properties. Some of the outstanding equipment included: electron probe, electron spin resonance (ESR) with a special probe that can operate at 600 °C, in-situ or real time fractography as viewed with the SEM, 130-keV TEM with a resolution capability of 2 Å, Fourier transform infrared (FTIR) spectroscopy, nuclear magnetic resonance (NMR) with a superconductivity magnet that produces a magnetic field of 9.3 T or over 80,000 G/cm^2, other NMRs that can be used for measuring solids up to temperatures of 450 °C, high precision mass spectrometer, Instrons for testing composites at up to 2,000 °C, hot presses that can be used at 2,300 °C, CVD furnaces that can be top or bottom loaded, equipment for measuring thermal expansion up to 700 °C, ultrasonic equipment to detect defects in the C/Cs, and a finite element code for predicting the stresses and strains in polymeric and metal matrix composites. Capital equipment can be bought by the director up to $70,000; otherwise, it must be approved at the corporate level.

Assessment

Concerning the interchange of information with the United States, Nippon Oil feels that years ago the United States was ahead of Japan in the technology of C/Cs and would not talk to people outside of the country. However, now there is more equality of knowledge between Japan and the United States; therefore, Nippon Oil believes that there should be more exchange of information than there is now for the benefit of both countries.

There is a strong possibility that some form of cooperative program can be worked out between Nippon Oil and organizations in the United States so long as it involves research that is being sponsored by the company. Even samples might be exchanged. But if the work is being sponsored by the Japanese Government, then a whole set of new approvals must be obtained from all the parties in the consortium that are involved in the work. Clearly the outcome is not as predictable.

It appears there is more extensive research going on at Nippon Oil than at many other Japanese industrial organizations. Therefore, it seems prudent to remain in communication with this company with the thought of either obtaining further information or perhaps forming some form of cooperative programs in the future.

NIPPON STEEL

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Background

The host for this visit was Dr. Ken-ichi Fujimoto, who is the general manager of the chemicals research laboratory, and the arrangements were made by Nabuhiko Narita.

The development of C/Cs began here in 1982 for developing a fabrication process for automobile brakes. Governmental financial support for this work started about 5 years ago. Prof. Yasuda of the Tokyo Institute of Technology, who has been an advisor to the R&D Laboratories, started his research in this area about 10 years ago. So far brakes for cars are not a commercial item because of the cost to fabricate them. So there is a significant effort directed toward finding ways of reducing these fabrication costs. Nevertheless, a significant amount of R&D in the general area of carbon and C/Cs has taken place, especially in the area of aircraft brakes. At this time there is only a small market in Japan for this material. The plan is to perfect the fabrication process, establish the market in Japan, and then take it abroad in the future.

The laboratory effort in the C/C area consists of about 10 persons, of which half are professionals and half are for support. Additional persons are doing developmental, prototype, or processing studies in connection with production.

Program Status

Pitch-based fibers are being processed at Nippon Steel and sold only in Japan at a rate of about 40 tons/yr; the fibers have a modulus of 600 GPa (87 Mpsi) and a strength of 3.5 GPa (505 kpsi). In addition, about 60 tons of fibers with lower property values are being sold where the modulus is about 75 Mpsi and the strengths vary between 35 and 140 kpsi. Some of the fibers are chemically etched to improve their bonding strengths for use with the different types of organic, metallic, or carbonaceous matrices and even in concrete.

A major emphasis during these discussions was the research efforts on developing the most effective and efficient methods of densifying carbon/graphite fiber preforms with an appropriate carbonaceous microstructure that provides the desired physical properties. Generally, three types of preforms are used: unidirectional, 2D, and randomly oriented chopped fibers. For densification purposes, two impregnation processes are being used, gaseous CVD or liquid pitch followed by pyrolysis and additional heat treatment steps.

The CVD densification method was discussed in some detail, especially with respect to the processing conditions and the resulting characteristics of the C/Cs. One of the major factors being evaluated is the weight change or carbon uptake as a function of the deposition time. Nippon Steel has had some success in modeling the deposition phenomena so that the predicted weight gain as a function of deposition time correlates well with the experimental values for randomly oriented fiber samples that are relatively thin, i.e., ~2 mm. For unidirectional samples that contain 55% by volume of fibers, the agreement between theoretical and experimental values is good for the initial part of the process. However, after about two-thirds of the predicted weight pickup has occurred, there is a saturation effect whereby no more weight gain occurs in the experimental samples. Now the investigators are evaluating the changes to the pore structure of the matrix with the processing time because this effect appears to be caused by a premature closing of the pores. This effect is not accounted for in the model as the assumption is made that there is uniform diffusion of the methane throughout the sample during the entire deposition period. For an open structure, like that in the randomly oriented chopped fiber mat, the diffusion coefficient will probably be nearly constant for the 200 or more hours of deposition time as the pores remain relatively open during most of the process. But in the case of the unidirectional samples, the pores are smaller and variable in their cross sections. This means the carbon, which is being uniformly deposited on all the surfaces of the pores, will first close the narrowest diameter pores and prevent further diffusion of the vapors into the remaining pores. Experimental determination of the pore diameters, by the mercury porosimetry method, verifies that this premature pore closure phenomenon is occurring at the end of the impregnation cycle. Consequently, the weight gain will be terminated before the samples are fully densified and the experimental values will be less than the predicted values. It also explains the density gradients that are being observed by these investigators. Therefore, the predictive model must be changed to account for these effects. This work will continue in order to obtain the best and most uniform matrix densities at the most economical cost. These results using CVD are being compared with the liquid impregnation method of densification.

A combination of phenolic and pitch precursors is being used to densify the substrates, which contain either unidirectionally or 2D oriented fibers. In all cases the fibers are prepregged with phenolic. These are then laid up into stacks of plies, which are carbonized at about 1,300 °C. Next, the preforms are further densified by multiple impregnation cycles of pitch, then carbonized at about 1,300 °C and graphitized above 2,200 °C. Frequently, CVD is used as the final densification step. This has an advantage because the vapor can enter smaller diameter pores than the liquid, so the density of the C/Cs will be increased further. In addition, the mechanical strengths will be improved because better bonding strengths will occur because of the more penetrating vapors. The densities of these pitch and CVD impregnated samples can be in excess of 1.8 g/cc with only three impregnation cycles at about 7 kpsi or 500 atm of pressure above 250 °C. At this time the preferred impregnation method is liquid pitch, as CVD takes too long and therefore is too costly.

The physical properties of these C/Cs vary with the processing conditions. For example, Nippon Steel has found that the maximum bending strength of unidirectional samples is 1,300 MPa (188 kpsi) at a CVD deposition time of 70 hours. Beyond this time, the strength begins to decline continuously to 300 hours of deposition time. For ribbon type samples a maximum strength of 250 MPa (36,250 psi) is attained at 170 hours. The cause for this maximum strength at an optimum deposition time is not understood and investigations are continuing to identify the influential parameters. Data indicate that the bending strengths of 2D composites are 10% to 20% higher than those that have been densified by the liquid pitch method even if the latter samples have a slightly higher density.

Nippon Steel's research shows that the microstructure of the as-deposited CVD matrix is important in determining the final type of microstructure in the matrix after final heat treatment of the C/C has occurred. So if it is desirable to have a highly graphitic structure matrix, the as-deposited matrix must have a rough laminar type of microstructure and the final heat treatment temperature needs to be in the range of 2,500 °C. Also, the strength of such samples is reduced by the high temperature heat treatments.

Oxidation protection layers of silicon carbide and other unidentified coatings are being deposited on C/Cs by the CVD method. Studies are underway to minimize the differential thermal expansion problem that exists between these oxidation protection layers and the carbonaceous substrates. One approach that is being employed is similar to that which is used for making ceramic-to-metal seals, namely, a number of layers are being deposited on the substrate that contain different values of coefficients of thermal expansion. In this manner a transition region is formed that accommodates the differences of expansion that exist between the C/C and the protection layer, reducing the mechanical stresses and cracking of the protective layer. This approach is similar in concept to the FGM one that is being studied by Nippon Oil.

Nippon Steel is the only organization that was visited in Japan or in Asia that is conducting research on the creep characteristics of C/Cs. This is being done using unidirectional samples to determine the influence of temperature, stress, and geometry of the sample. A negligible creep effect was found when four-point bend tests were used below 1,500 °C.

A brief laboratory facilities tour was conducted with particular emphasis on the special equipment that is used to prepare the laboratory samples. There is a graphitization furnace for heat treating samples as large as 100 mm OD and 30 mm thick in a nitrogen atmosphere to >2,400 °C. The CVD equipment is used to prepare the above-mentioned samples, which incidently, have a geometry that is similar to that of brake disks. It also appears that these laboratories are well equipped to perform evaluations of these materials as there are SEMs, TEMs, laser Raman interferometers, and x-ray units, as well as the standard types of laboratory equipment needed to do chemical analysis and measure thermal-mechanical properties of materials. During this tour various types of materials were evident, which indicated the diversity of applications being investigated in which carbon fibers or composite materials are evaluated for their applicability and marketability, such as for the Japanese space plane where the top use temperature may be 1,700 °C, brakes for high speed trains, fibers (~4%) in concrete to strengthen it, complex shapes of C/Cs for high strength and temperature applications such as for dies or fasteners, and thermal insulation where strength is required.

These laboratory facilities are extensive, as they take up three floors of space with an estimated area over 80,000 ft^2.

Assessment

Collaboration with U.S. organizations is definitely desired by Nippon Steel, according to Dr Fujimoto.

Future directions of C/C research efforts will probably remain the same for the next 8 to 10 years. Fujimoto also noted that 29 organizations are currently developing methods of fabricating C/Cs so they will not be left out of the race if this material suddenly becomes needed to fill a big commercial market. But in the next 5 or more years, this number of companies will be sharply reduced to a few when it is clear that the market is much smaller than was originally predicted but the development costs continue to be high. Thus, only the big companies will remain. This same sequence has occurred in the past, for example, in the area of carbon fibers, where 20 companies are now 5 to 7. Similar declines have been seen in the areas of mesophase pitch, intercalation of carbonaceous materials, and the diamond surfaces.

It is recommended that communications be continued with this organization because of the diversity of the R&D programs being conducted here that have resulted in a broad spectrum of applications using carbonaceous materials. Nippon Steel's strongly expressed desire to consider cooperative programs with the United States may be useful in the support of research programs at universities in this country.

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Background

The host of this site visit was Prof. Mototsugu Sakai, who is the head of the ceramics and carbon materials effort at this university. In addition, he is internationally known for his research in the field of fracture phenomenology and theoretical analysis. His staff consists of 2 assistant professors and 15 graduate students. The major research emphasis of this group is in the areas of the rheology of mesophase pitch and understanding the science of microfracturing of ceramics and carbonaceous materials.

About 80% of Sakai's group is working in fracture behavior and mechanics. These efforts are about equally divided between carbons and ceramics, in which the latter has been growing more rapidly than the former in the last few years. The other 20% of the effort is concerned with the rheological characteristics of mesophase pitch. Thus, the carbon effort consumes about 60% of the total effort in this group at this time.

In general, Sakai is interested in the "scientific" aspect of this field and will only take financial support from industry if they are also interested in these aspects. Sakai's general impression is that industry does not readily use the talent at the Japanese universities in order to maintain their confidentiality status with respect to their competitors knowing what they are developing. But industry is very eager to obtain his best students.

His experience has shown that 95% of the undergraduates and graduates are employed by industry and the remainder go to the universities or government laboratories.

Program Status

The general philosophy of the research here is to study the fracture physics from which the fracture mechanics is subsequently derived. Specifically, the breadth of possible causes is very impressive and ranges from the influence of atomic and molecular bonding to the overall strength and work to fracture of these materials and how these forces are being modified by stress shielding and crack wake effects. Fracturing phenomena are being evaluated on the basis of energy considerations. Sakai believes that 80% to 90% of the energy that is consumed in fracturing is caused by fiber pullout, 15% to 10% is due to fiber bridging, and the remaining energy is consumed by cracking of the matrix. But it should be remembered that this assessment is based primarily on current data that have been obtained with C/Cs that are composed of carbon rather than graphitic matrices. Fiber pullout tests are being conducted to determine their bonding characteristics. Single yarn bundles, 0.1 mm in diameter and 1 mm long, are being carved out of unidirectional samples. This operation is done with a razor blade with lots of patience and a steady hand. Then, the bundle is gripped and pulled out of the unidirectional C/C sample.

The other major area of research at Toyohashi is the viscoelastic studies of different pitch systems. The transition of molten pitch from an amorphous to a liquid crystalline or mesophase state is of primary interest in order to understand the kinetics of how pitch enters and diffuses throughout porous materials that are being densified or how pitches possess the ability to be drawn into fibers. Therefore, the phenomenology of this transition is being investigated by heat treating different types of pitches at 400 °C to advance them into the mesophase state. The viscosities of these various pitches are determined as a means of studying their flow characteristics. It has been found that if the mesophase concentration is less than 60%, the flow characteristics are Newtonian, whereas if it is greater than 60%, the flow has viscoelastic characteristics. The flow measurements are taken between 250 and 300 °C in order not to advance the pitch while it is being measured.

There is interest concerning the influence of matrix microstructure, but as yet the group's experience is with carbon matrices as they are just beginning to work with samples that have been heat treated to graphitization temperatures. In general, their microstructural examinations are performed using optical methods. The SEM is used only to evaluate fractured surfaces. Crack growth is measured by optical means. As a result, there are problems in identifying the initiation point and specific growth rates of cracks in C/Cs.

The C/C samples from Nippon Steel are unidirectional with a phenolic prepreg and three to four pitch impregnations, where each cycle is heat treated to 1,000 °C. This type of material is specially made for Sakai and consists of laying up fibers and then forming them by hot pressing into plates that are about 1 cm thick. Test samples can then be cut from these plates. As yet no samples have been made in this group's laboratories as there is not the equipment nor the person power to perform this type of work. Just recently sample material was received from Schunk that is 2D layups of cloth densified with pitch and heat treated to 2,100 or 2,400 °C. These 2D layups are the first samples that will be tested in this laboratory that contain a graphitic matrix. The carbon matrix samples have been tested in tension with a notch cut in them and at different orientations according to the ply layups. As expected, there is a difference in the energy to fracture with the least amount occurring when the root of the notch is in the plane of the layup and a maximum energy occurring when the root is perpendicular to these planes. A special three-point bend test has been developed here so the fibers in the C/Cs are only subjected to tensile loads. This in done by using a steel pin on the compression side of the bend sample. Through this type of test it has been found that the size of the yarn diameter is critical in determining the type of failure that occurs with the fibers. If the yarn diameter is less than the critical crack size, there will be a lot of fiber pullout, whereas if the diameter is more than the critical crack size, the fibers will break with very little pullout.

Assessment

The quality of the research is excellent under the leadership of Prof. Sakai and it is expected that this will continue for a number of years in the future. This is one of two organizations in Japan doing fundamental research in the area of fracture phenomenology of C/Cs.

The laboratory capabilities are adequate to do the type of research that is being conducted here. Much of it is designed explicitly for the experiments and it appears a lot of imagination and creativity were used in developing the techniques.

There was an excellent response to the idea of having cooperative programs with organizations in the United States and especially with the University of California at Santa Barbara (UCSB). Collaboration could take many forms, from discussions about data to having an exchange of students and even several week visits between faculty members from Japan or the United States.

Based on the above observations it is recommended that further communications be continued and that consideration be given toward determining the possible areas of common interest for establishing one or more collaborative programs that would be of mutual interest to both Prof. Sakai and organizations in the United States.

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Date: 8 Jan 1991

Background

Dr. Mitsunao Kakuta, the general manager of this laboratory, was my host. The main purpose at this laboratory is to develop products from heavy oils and pitches that are derived from the company's refineries. These products include cokes, special carbonaceous materials, and pitch-based fibers. C/C composites were being developed for about 7 years when this effort was terminated 3 years ago. This decision was made because it was estimated that there would be a limited market in Japan for C/Cs and there were too many other organizations competing. At this time a major effort is being directed at the development of pitch-based carbon/graphite fibers. High quality fibers, having >100 Mpsi modulus of elasticity values, are being produced on a prototype production basis. The major technological problem is to determine procedures for manufacturing these fibers at a lower cost. It is necessary to reduce this cost by a factor of 2 to 2.5 in order to be competitive with PAN-based fibers. This development effort is expensive as the production plant requires five persons per shift, three shifts per day, and 7 days per week of continuous operation. It is expected that a decision will be made in about 3 years on whether to continue this aspect of Koa Oil's developmental program.

The are 38 people in the carbon R&D group, of which 10 are staff members and the rest are support, including those who are on the shifts for the fiber prototype production line. In addition, there are three managers who are responsible for the new materials efforts, which are fibers from mesophase pitch, elastic graphite, and sensors from carbonaceous materials.

Program Status

Research has been ongoing for about 7 years in the area of pitch-based fibers. The spinning process occurs between 400 and 480 °C with a light molecular weight oil that is on the alkaline side with toluene insolubles in the range of 70 to 80 ppm and quinoline insolubles from 30 to 35 ppm. It has been determined that better spinnability, which means more spinning time without fracturing a fiber, and a higher degree of anisotropic orientation of the molecules within the fiber are attained with precursors that have molecular weights in the range of 500 to 1,400. Apparently, the larger values of the modulus of elasticity and the strengths of fibers vary inversely with the molecular weight.

The heat treatment temperatures can be as high as 2,800 °C in order to obtain a modulus as high as 113 Mpsi, which is comparable to the values attained by Amoco. At this time a new and small 2-micron-diameter fiber is being developed. Although it is possible to process 2-micron fibers, their diameter has a variable cross section that must be controlled.

Another research effort has been directed toward the development of an "elastic graphite." This is a material with a very low density between 0.2 and 0.5 g/cc and a surface area of 10 to 30 m^2/g that is composed of spherical particles that are 10 to 300 micrometers in diameter. Each one of the spheres is hollow with a wall thickness that is approximately one-tenth of the particle's diameter. The microstructure of the walls is very unique and gives this material its unusual properties. TEM observations show that they are composed of a graphitic structure where the a-b planes are oriented in a circumferential manner, like onion skins. In general, this material is formed by dispersing the mesophase in an alkaline aqueous solution that is heat treated at about 300 °C to form the material with a final heat treatment at 2,400 °C to obtain the graphitic microstructure. It is this special type of structure that allows the material to be compressed to <50% of its original thickness with a pressure of 5,000 kg/cm^2 and to return to its original dimension when the pressure is released. This recovery can occur because microcracking takes place in the walls of the spheres as pressure is applied, which allows the walls to be flattened and still retain their integrity. When the pressure is released, these microcracks close and allow the spheres to return to their original shapes. Thus, this material can be recompressed innumerable times without losing it original shape. There are many possibilities for applying this material, such as for gaskets, absorbers of vibrational mechanical energy, catalytic and chemical absorptive surfaces, dry chemical cells, and other uses where a low density, compressible, and high surface area material can be used.

Other R&D efforts have resulted in unique types of carbonaceous materials that are being evaluated or marketed, e.g., 200-micron-thick carbon paper and electrodes or moisture sensors for the water content of different types of atmospheres that are used in chemical processing steps. In both applications, the electrical resistivity of the material is altered, adjusting the degree of the feed stock's acidity in order to adjust its process procedures to provide the desired characteristics. For example, the resistivity of this material can be made high, which means small currents will pass through it. But if moisture is absorbed into the material from the atmosphere, the electrical resistivity will decrease, the current will increase, and a change of humidity will be indicated.

A laboratory tour was conducted of the R&D prototype production facility for pitch-based carbon fibers. This facility has a capacity of 20 kg/day and it was installed about 5 years ago. In addition to the spinning facility, whose temperature is controlled within 1°, there is a stabilization furnace through which the fibers are oxidized in air at between 200 and 300 °C and a graphitization furnace that can operate up to 2,800 °C. Other laboratory facilities were visited, and it was evident that equipment is available to test for the physical and chemical properties of the precursors that are used in the various processes and to characterize the finished products. These facilities included an SEM, an NMR for the characterization of organic substances, and a laser diffractometer to measure the diameter of fibers.

Assessment

This organization shows that it is capable of using information that is derived from fundamental studies to develop new and different types of carbonaceous materials. Furthermore, it is one of the few remaining organizations that is developing advanced types of mesophase pitch-based carbon fibers with both improved properties and lower production cost. Whether these costs can be reduced sufficiently to be competitive with PAN-based fibers is still a question. It is expected these R&D directions will continue for the next 3 to 5 years. It is interesting to note that 5 to 8 years ago there were more than 15 companies in Japan involved in the development of methods for the manufacture of pitch-based carbon fiber. Now this number has been reduced to three or four.

The question of possible collaboration between Koa Oil and other U.S. organizations was discussed. In general, there is very little collaboration with any organization or individuals in Japan. However, there might be the possibility of a limited amount in the United States on the basis of programs that are of mutual interest to both parties. In addition, there would have to be strict controls on how the derived information is communicated outside of Koa Oil.

It is recommended that further communications be continued because this organization has shown the capability of developing new concepts in the development of materials, including pitch-based fibers.

SHIKIBO LTD.

1500-5 Shibahara
Minami, Yakaichi, Shiga 527, Japan
Tel: 0748-25-1732
Fax: 0748-25-1763
Date: 10 Jan 1991 and 16 Mar 1992

Background

My host for this visit was Tokuzo Kadotani, the director/general manager of the research department of the

Industrial Textile Division. My contact was Takeshi Tanamura, who is in charge of the processing R&D. The third person in this discussion was T. Hirokawa, who is in charge of R&D of composite material, including C/Cs.

The primary C/C effort at Shikibo is to weave carbon fiber substrates of all shapes and then to densify them. The initial patent for the weaving methods was bought from the Research Institute of Polymers, which is located in Tsukuba, Japan. Using the principles of the basic method, other weaving variations and improvements have been made. In addition, processing procedures have been developed to densify these preforms. Shikibo does not take any money from the Government, so its techniques do not have to be divulged. The C/C development group consists of about 10 persons, with half of these having university degrees. This operation has been going on for about 7 years.

Program Status

The general concept of the Shikibo weave is that the x and y yarns are woven into a cloth, which is laid up and stacked to form the third dimension. These layers are held together by a continuous yarn that is threaded in the z direction between the x and y yarns. Consequently, the z yarns form a loop on the outside of the preform as it exits and reenters the preform. No z yarns are broken as they are in France or the United States. Furthermore, no x or y yarns are broken as they are by the Societe Europeenne de Propulsion (SEP) method of piercing the fabrics in order to tie them together. Apparently the Shikibo method can produce preforms with a maximum fiber volume of 60% and with yarn spacings of less than 1 mm if 1K yarns are used. Also, the weaving procedure is capable of placing the yarns at different orientations of 0°, 45°, and 90°. Both PAN and pitch fibers are used to weave different shapes including L and T cross sections or turbine rotors, where the blades are an integral part of the hub. To do this a fourth and a fifth yarn are introduced so that the thickness of the blades can be increased as the radius gets closer to the hub. Block-shaped preforms have been woven as large as 4 by 4 by 16 inches or plates 6 by 6 by 2 inches thick. The possible geometries, including cylinders and cones, are not limited by the weaving procedures. At this time it is estimated that it costs about $200 per pound of preform and it is Shikibo's goal to reduce this by a factor of two.

Currently densification of the preforms is accomplished by both liquid and gaseous impregnation methods. The combination of prepregging followed by multiple liquid impregnations is the preferred procedure because it is faster, more reliable, and less costly to attain a given density of the preforms. An autoclave with a maximum pressure of ~1,400 psi at a temperature of 650 °C is being used to obtain 3D C/Cs with densities of about 1.8 g/cc. It is recognized that the CVD method of impregnation is most useful in filling very small pores. Its main disadvantage is that the deposition times may be hundreds of hours to prevent density gradients through the thickness of the preform. This prolonged procedure obviously increases the fabrication cost. Mr. Tanamura is now investigating whether the CVD method can be effectively used as the last impregnation cycle to fill the smallest pores and possibly increase the mechanical properties of the preform. A representative value of the bending strength of a 3D preform is ~24,000 psi (162 MPa), where the loading direction is in the x direction and the fiber content is 41%, 50%, and 9% in the x, y, and z directions, respectively. This range of values is considered to be comparable to what other investigators are attaining. Shikibo is interpreting its data as suggesting that C/C mechanical properties are primarily based on the fiber architecture.

Although I didn't tour the laboratory, I was informed that equipment is available for making all the thermal-mechanical property determinations that are necessary as well as the chemical evaluations of the precursors. There is also a close cooperative program with the GIRI Osaka laboratory where high temperature equipment can be used if it is not available at Shikibo.

Assessment

Shikibo has demonstrated a unique capability in Japan for weaving 3D preforms and densifying them. Shikibo seems to be innovative in its approaches for developing advanced materials. It appears that the research being conducted here is closely tied to the development phase of its operation. The company is certainly interested in collaborating, especially if it could supply material that would be analyzed for its fracturing behavior in the United States.

It is recommended that communications be continued with this organization, especially as it may relate to advanced weaving techniques.

KOBE STEEL, LTD.

3-18, Wakinohamacho 1-chome
Chuo-ku, Kobe, Hyogo 651, Japan
Tel: (078) 261-4601
Fax: (078) 261-4671
Date: 11 Jan 1991

Background

My host was Dr. Mitsuo Suzuki, who is the general manager of this research center and an advisor to the technical development group of the corporation. The contact was Katsunori Shimasaki, who is a senior researcher in the Chemical Technology Research Laboratory.

This center is primarily directed toward the development of processes that will enhance the reliability of existing products and the invention of new products. The approach is to use data that are obtained from carefully selected and controlled laboratory experiments. Other data come from closely monitored runs that are being used to manufacture material for sale to the public. A small fraction of the total C/C effort is for fundamental research to define and select alternative paths for future developments.

The efforts at this center are divided into different categories, namely:

- New carbon products that include woven carbon fiber composites. A primary target for this activity is the development of C/Cs for the Japanese space plane. The efforts in C/Cs started about 1985, although it was not known outside the company until 2 or 3 years later.

- Nonwoven or randomly oriented products such as brake disks for high speed trains. Some of this material has a relatively high density of 1.6 g/cc. Included in this division of effort is the production of paper thin sheets of carbon that are composed of 5- to 10-micron-diameter carbon particles. This material is also used in brakes and for self-lubricating applications.

- The development, production, and sales of high pressure impregnation autoclaves to be used for HIP operations for the densification of C/Cs. Most of their units are sold in Japan, although a few units have been sold abroad, such as in the United States. The maximum operating conditions for such units are in excess of 2,000 atm pressure and 1,000 °C. Each of these units costs about $100,000 including the controls.

The carbon development group has about 30 persons, with two-thirds of these having university degrees, of which 10 have Ph.D. degrees. The others are support persons. Of this, the team that is performing R&D in the area of C/Cs consists of 10 researchers and 12 technicians.

Program Status

One of the topics of discussion was the procedures used to densify C/Cs by the high pressure method of infiltrating preforms with liquid pitch. The purpose of doing so is primarily to reduce production costs by minimizing the number of impregnations that must be performed so that the preform can attain a desired density. Data show that for five impregnations, a 30% higher density can be obtained in carbon fiber preforms than if the same type of preform was impregnated at 1 atm of pressure. Kobe's research indicates getting the pitch into the preform is no problem. The challenge is to keep the pitch in the preform while it is undergoing pyrolysis. This is because the pitch is generating gases that want to escape from the preform. This action, in turn, tends to push the remaining pitch out of the perform, thereby reducing the efficiency of each impregnation operation. Therefore, much R&D time has been devoted to determining what parameters must be considered to improve the HIP cycle. One of these parameters is defining what temperature the pitch should be when the autoclave pressure is first applied to force the pitch into the preform. Apparently, there are two boundary conditions to consider. One is to keep the pitch outside the preform as long as possible while it is being heated to prevent the gaseous products that are being generated from accumulating in the preform. But as pyrolysis is occurring, the viscosity of the pitch is increasing and it becomes more difficult to force the pitch into the small pores of the preform, especially as the preform's density is increased with multiple numbers of impregnations. The Kobe studies have shown that applying the pressure at about 150 °C above the pitch's softening point will usually result in the maximum carbon yield in the preform for each densification step. The HIP process is also useful for impregnating preforms with compounds or elements that are not in a carbonaceous state. Additional studies show that preforms impregnated by the HIP process have mechanical properties that are more isotropic. The range of tensile and flexural strengths of some of Kobe's multidirectional C/Cs is between 300 (~43,500 psi) and 200 MPa (~29,000 psi). The usual heat treatment conditions for the processing of C/Cs are 1,000 °C for carbonization and between 2,400 and 3,000 °C for graphitization. Measurements of the modulus of some C/Cs show an increase of the effective modulus of the fibers after being heat treated at these maximum temperatures. It is not clear whether this is due to changes of the fiber's modulus because the C/C heat treatment temperature exceeds that at which the fiber was processed. Another possibility is that the matrix has been graphitized and is sufficiently bonded to the fibers to raise the effective modulus of the fibers. More research is being performed to try and understand what is happening.

It is expected that the developmental efforts concerning C/Cs will continue until at least 1997, which is the time the support by MITI for the development of the Japanese space plane is scheduled to end. In an unofficial manner, some of the targets of the C/C properties that are to be achieved for this project were presented. For example, at a temperature of 2,000 °C, the tensile modulus should be 200 GPa (~29 Mpsi) and the strength equal to 700 MPa (>100 kpsi) with a strain of ~0.4%. Furthermore, this C/C material is to operate without any loss of properties for 200 hours. Several interesting C/Cs are being made for this project. One is a <2-mm-thick cylinder whose diameter is to be 300 mm (~12 inches) with a length of 600 mm (24 inches). The other material is thin (~2 to 3 mm) wall panel to be used for thermal insulation that contains flanges that are to be about the same thickness.

An R&D effort on the development of oxidation resistance methods has just been started. Consequently, there is no information to report nor were the research approaches discussed.

The laboratory tour showed all the necessary equipment for conducting any type of chemical analysis or physical property test that might be required in the course of performing R&D investigations. This is the only industrial organization that I visited that has a small research effort in the field of fracture mechanics.

Assessment

The research, development, and production efforts appear to be well directed and coordinated with long range objectives. The Kobe efforts probably encompass the widest span of interests in the field of carbonaceous materials of any industrial organization that I visited. This is because they are in the business of not only making novel materials, including C/Cs, but selling HIP equipment for processing these materials. Consequently, there are many areas of common interests and possibilities for collaboration.

Collaboration may be possible with Kobe Steel, according to Dr. Suzuki. He will recommend to the Corporate Technical Development Group that such arrangements should be made if there are technical areas of mutual interest between organizations in the United States and Kobe. It is most likely that if any efforts were started, it would be organized through Kobe's laboratory that is located in Palo Alto, California.

It is recommended that communications be continued concerning the R&D efforts at Kobe Steel to be knowledgeable about their results and to determine if there are areas of technology that would be of common interest and a basis for starting a collaborative program.

GOVERNMENT INDUSTRIAL RESEARCH INSTITUTE (GIRI), OSAKA

Inorganic Materials Department
1-8-31 Midorigaoka
Ikeda, Osaka 563, Japan
Tel: 0727-51-8351
Fax: 0727-54-1931
Dates: 12-13 Jan 1991

Background

My host for this visit was Dr. I. Souma, who has recently become the head of the C/C section in the Materials Department. This laboratory has the distinction of being the place where Dr. Sindo developed the process for making the first PAN fibers many years ago. During my last visit here in 1985 I met Dr. Sindo, and he explained the activities of the laboratory at that time. Currently there are four researchers involved in the C/C effort, but there are no support people, which is the situation at all GIRI facilities.

In general, there is more collaboration between the GIRI laboratories and industry than there is with the universities. This situation is partially brought about by the fact that the charter of these government MITI funded laboratories is to be the intermediate laboratory between the bench scale and the full scale production phase. About one-third of GIRI Osaka's budget is derived from the industrial collaboration projects. The situation is further complicated by the fact that the universities are funded by an entirely different source, the Ministry of Education, which means there is another set of ground rules and barriers similar to those that exist between the Department of Defense and the Department of Energy in the United States.

Program Status

The major research activities in C/Cs are being pursued by Dr. Narasawa and Mr. Tatsumi. Their areas of interest include the use of nondestructive techniques, such as ultrasonics, to study the fiber/matrix interactions while the sample is being stressed. Special unidirectional composite samples are being prepared to understand the fracturing behavior. The densification procedures for these samples involve multiple impregnations with pitch and pyrolysis at 850 °C. Sometimes this temperature is raised to 1,000 °C. In either case the impregnations are conducted at 200 atm in an autoclave. Normally coal tar pitch is used because it appears to infiltrate more thoroughly into the preform, although it is recognized as not being as graphitizable as the petroleum-based pitches. Three to five impregnation cycles are used to bring the densities of the unidirectional preforms to about 1.9 g/cc. After each impregnation and pyrolysis cycle, the next step of the process is to go to 2,400 °C to graphitize the sample and open the pores. Only unidirectional samples are used in this laboratory because the investigators believe fracturing behavior can be better evaluated. Samples of this type are not made elsewhere.

This carbon effort has just been reinitiated with emphasis on C/Cs. This area is new to both of these principal investigators, Dr. Narasawa, who is trained in solid state physics, and Mr. Tatsumi, who comes from a materials science background. They have completed laying out their research program and are in the stage of getting the equipment operational. Therefore, it will be a while before there will be data and results available. However, a brief laboratory tour was conducted and it appears that there was adequate equipment to conduct their experiments and to properly characterize the samples and precursor materials for both chemical and physical characteristics. There was even equipment from previous studies to spin special fibers if the research took such a direction. Since this program is just starting, it is expected it will continue in this direction for the next 3 to 5 years.

Assessment

The current research work is just beginning so it is not expected to produce much information for at least a year. Studying the fiber/matrix interactions by nondestructive means is a unique approach that could be very useful from both research and industrial viewpoints. Therefore, it is recommended that some form of communication be maintained in the future. As far as collaboration is concerned, Dr. Souma believes that it is possible, especially on the university basis.

HOKKAIDO UNIVERSITY

Faculty of Engineering
Dept. of Applied Chemistry
Sapporo 060, Japan
Dates: 14-15 Jan 1991

Background

My host was Prof. Michio Inagoki, who leads the carbon effort in this department. He joined this faculty less than 2 years ago from Toyohashi University, where he had been for more than 18 years. Inagoki is very active in professional societies and organizations that are connected with carbon. Most recently, he was the General Chairman of the Japanese International Carbon Conference, which was held from 4-8 November 1990 in Tsukuba, Japan. Inagoki's technical interests are concerned with the chemistry, structure, and texture of ceramic and carbon systems and how these variations affect the material's properties.

The two major objectives of this visit were to learn about the carbon research activities at this university and to obtain a general view of the interactions between the universities, industry, and government laboratories in furthering the total C/C research efforts of Japan. It is important to understand how effectively this research information and expertise are being used, for the answers are then integrated into the general assessment portion of this study.

Carbon research at Hokkaido University has been in existence for more than 20 years in the Department of Applied Chemistry, which Inagoki now directs, and in the Coal and Carbon Laboratory, which has been directed for the past 18 years by Prof. Sanada.

Inagoki supervises about 12 persons and is assisted by Assoc. Prof. Shiro Shimada. This carbon group is composed of two postdoctoral research associates, three Ph.D. candidates, two masters students, and four undergraduates. The current and primary thrusts of this group are to understand the phenomena of intercalation in thin films and oxidation in carbons and the phase changes of carbides and nitrides.

Program Status

Shimada's primary area of research is to understand the development of different carbide systems (TiC, ZrC, HfC, and TaC) as they are being oxidized at temperatures up to 600 °C and pressures to between 3 and 20 kPa. One of the interesting effects that has been found is evidence, by electron diffraction patterns, of a diamond phase between ZrC and Zr_2O_2 as the ZrC is being oxidized. Also, it appears the diamond layer is well bonded to the two adjacent Zr phases. This research is being continued to determine more precisely the exact conditions that produce the diamond film. In the course of his studies, Shimada has developed a very sensitive method for detecting changes of phases through the use of acoustic emission (AE) signals. Changes of state of these systems occur as their temperatures are raised at rates between 0.1 and 20 °C/min and AE signals are continuously being emitted. However, at certain temperatures these signals suddenly increase in their intensity and this is considered to be the temperature where a phase change is initiated. Frequently these values don't agree with those published in the literature. In such cases the experiments are rerun to be sure of the data; otherwise, the differences are attributed to the increased sensitivity of the AE method over the usual differential thermal analysis (DTA) method. Special attention is given to the manner in which the temperature of the solution is measured to be sure the AE sensor is at this same value.

This AE method has been extended to be used on solids and powders up to 1,300 °C, where it detects the microcracking that occurs due to the differential thermal expansion mismatching that exists between different phases. Careful analysis of the frequency spectrums is performed to increase the sensitivity of this method. Shimada started developing the use of AE about 3 years ago and, to his knowledge, he is the originator of the technique in Japan One possible application of this method might be for use in acquiring more insight into the initiation of the phase changes that occur in pitch as the temperature is increased through the mesophase region, coalescence, and solidification stages.

Inagoki's current and primary research area is to investigate intercalation phenomena and their influence on the structures and electrical properties of graphite films and powders, but not on vapor grown carbon fibers as others are doing. The primary technical challenge at this time is to attain stability of the enhanced conductivity that is produced by intercalation so these materials can be used for switches, electric brushes, components for sound amplification systems, and other applications. Inagoki believes from his experiments that stability might be enhanced by the use of additives, like PbO.

He is also conducting collaborative research with other investigators in Japan concerning the microstructure and properties of fibers and the activation of carbon fibers and how their adsorption characteristics are being altered by precursors and processing conditions. Inagoki is the head of the Japanese effort for a collaborative program with the French on the structure and properties of mesophase-based fibers.

Prof. Sanada has been the director of the Coal and Carbon Laboratory for the past 18 years. This laboratory is staffed at this time by two associate technicians, nine masters candidates, and five undergraduate students. The principal directions of this laboratory's research program are to understand the phenomena of carbonization of heavy oils and petroleums and the liquid faction of coals and to develop methods for reducing the environmental pollution that occurs through the use of coals and oils. An understanding of how to modify crude oils will also provide an ability to optimize the feed stock for the spinning of fibers or for impregnating bulk graphites of C/Cs with the desired type of matrix microstructure. Half of this laboratory's efforts are devoted to pitch chemistry at temperatures <700 °C. One of the investigations is to model compositional structure of the coal-derived pitches by using compounds of naphthalene and anthracene and determining the influence of noncovalent bonds that are produced with a third material type of catalyst such as CF_4SO_4H. The next step of this investigation is to find a cost effective method of reclaiming this catalyst. Another portion of this laboratory's research efforts is to determine the effects of time, temperature, and pressure on the texture of the derived liquid crystal or mesophase state of the pitch.

In connection with these investigations, a special high pressure electron spin resonance (ESR) technique (<room temperature (RT) to 500 °C and <100 atm pressure in nitrogen or hydrogen) is being used to study the mobility of the molecules of interest. For example, it has been determined that the mobility of hydrogen exceeds that of nitrogen in these systems. The life times of some of these radicals have been measured at less than a millisecond, which means that the entire analysis must be completed in less than 10 seconds. Current the equipment is being modified to be able to make measurements at liquid nitrogen temperatures.

The other half of the mission at this laboratory is concerned with finding methods for burning coal with less of a negative impact on the environment. This research is most important to Japan as more than 600,000 tons of coal are used to produce energy and metallurgical cokes.

The laboratory equipment and analytical capabilities in both Inagoki's and Sanada's organizations appear to be very adequate for performing the desired studies for the research they are conducting. In addition, there is a central testing facility available that is run as a service by the university in the event that some piece of equipment is not available in any department.

Assessment

The quality of the research efforts observed at Hokkaido University is very good. This situation is expected to continue for at least the next 3 to 5 years before either Inagoki or Sanada consider retiring. The Coal and Carbon Laboratory is unique in Japan and probably in Asia. It is comparable to the laboratory at the University of Newcastle upon Tyne in England. It is expected that Inagoki's laboratory will become increasingly productive in the next few years, judging from his past record.

A specific point was made by Inagoki that it is very possible that collaborative research could occur with U.S. organizations in those areas where there is a common interest. This certainly seems likely, especially in the areas of pitch chemistry and phase changes that are taking place in the mesophase transition temperature range. It is quite possible that an exchange of graduate students could be arranged. There are precedents for doing so, as Inagoki was a postdoctoral student in Prof. Mrozowski's laboratory at the University of Buffalo many years ago.

It is recommended that the research at Hokkaido University be followed in the future with collaboration being a possibility.

The Interactions and Influences of C/C Research Organizations Within Japan

A discussion was held with Prof. Inagoki about how the collective research capabilities are utilized within Japan toward developing and applying their C/C technology. This topic was the second major reason for this visit, as the information was very useful in preparing the general assessment for this study. Furthermore, Inagoki's thoughts and opinions are highly valued because of his familiarity with carbon research and his professional activities and knowledge of the organizations that are involved in the carbon field throughout Japan.

The overall effectiveness of research efforts depends on many factors including utilization of expertise, communication, coordination, and collaboration among the different universities, industries, and government laboratories.

The utilization by industry of research information and expertise of the professional staff at the universities appears to be much less than it is in the United States or other countries, especially

France. A number of factors contribute to this situation. One factor is the decision of each professor as to how much support he will accept from industry. For example, Inagoki only accepts 15% of his budget and the rest comes from his university and different funds from the Japanese Government. On the other hand, Prof. Sanada's support is >50% from industry and the rest from the university or the Government. Some professors accept no industrial support while others take >70% at other universities. So there is a wide diversity found amongst the professors visited on this survey, and it appears to depend on the professor's desire to maintain his freedom for conducting research without the constraints that are usually imposed by industry. Another factor is governmental regulations that seem to limit the utilization of university expertise by industrial organizations. Apparently industry cannot hire a professor as a consultant if he is a faculty member of a national university. The only compensation for services that the professor can receive is funds that must be sent to the professor's university for the support of his laboratory operations or for travel. Occasionally industry may ask professors to give lectures or seminars for which they receive an honorarium. This financial restriction is a real limitation because it cuts down on the flexibility of industry to utilize the expertise at universities in the most effective manner and vice versa.

Communication methods for the transfer of technical information vary according to the type of organization. The maximum degree of freedom is through the dissemination of research information by publications, reports, and seminars, which are the usual modes used by the universities and the Government Industrial Research Institutes (GIRI), unless a particular research project is for an industrial organization. The least amount of freedom occurs in the industrial organizations that are very restrictive about the dissemination of any information, either orally or in writing, because of the fierce competition that exists between themselves. Very frequently the representatives of industrial organizations will not even ask questions at public seminars for fear the opposition will determine what they are doing. This situation seems to feed on itself because the companies can start to overestimate the opposition's strengths or competitors may be unnecessarily duplicating each other's research.

Fortunately there exists in Japan two activities that enhance communications between the universities, government laboratories, and the industrial organizations. One of these activities is called the New Carbon Forum (NCF). Its membership consists of about 30 industrial organizations including many of the largest corporations in Japan. The purpose of the NCF is to identify new applications and uses for all forms of carbon, including C/Cs. To accomplish the objective, a great deal of effort is being expended in reviewing the literature, collating the information, and conducting study groups and seminars on specific topical areas of carbon. This information is then communicated to the organization's membership through seminars and conferences. These seminars are held every 12 to 16 weeks; guest speakers present in-depth lectures and then there are extensive discussions by the attendees concerning the current and future status of the area that is being discussed.

The second means of enhancing communication in Japan is through an organization called the 117 Committee, which is a part of the Japanese Society for the Promotion of Science. This committee holds a meeting about every 6 weeks that is attended by about 40 to 60 members from the three types of laboratories: university, government, and industry. Generally, the status of different research projects that are being conducted is presented by lecturers from universities or government laboratories. However, the information is also being transmitted to the industrial representatives, who can openly ask their questions at the meeting or more discretely call the speaker by telephone at a later date.

It is generally agreed by many of those that attend both the NCF and 117 Committee meetings that they serve, at a minimum, the function of communicating the status of research but, in actual fact, the direction of research is also being influenced for all three types of research laboratories, whether it is admitted or not. Furthermore, there are indications that these meetings are beginning to convince the management of some of the industrial organizations that public exchange of some of their thoughts may be advantageous for sparking new research directions. Collecting research data is of primary importance and includes information from national and international sources. Different techniques of communication are very effectively being used in Japan and these will be discussed in other portions of this report.

Coordination of research activities of all three types of research organizations can be excellent, especially if the Government is providing the support for developing specific areas as defined by the Ministry of International Trade and Industry (MITI) or the Ministry of Education. Examples of this will be given in other sections of this report. Coordination is extensively used between universities and GIRI laboratories. If the process or product needs to be scaled up from a laboratory size to an intermediate scale prototype, this is a prime function of the GIRI organization.

Collaboration is an essential ingredient in pursuing research activities by all three types of laboratories. This is best exemplified throughout the universities, where they will pool the necessary resources to accomplish a given objective that is of common interest.

Additional Items of Interest

In discussions with Prof. Inagoki, the following points were made by him:

- The United States is ahead of Japan in the development of C/Cs because we have a lot more experience and have made larger pieces. He admits that the opinions of the Japanese might be distorted through lack of information.

- It is not clear whether Japan or the United States is ahead in the science and research related to C/Cs.

- The major work on developing oxidation protection is being done at GIRI Kyushu using carbides. However, the majority of the efforts in this regard are being done by many industrial organizations in Japan, although it is not clear what is being done because they are not discussing this work.

- Nippon Steel is making special one-dimensional samples for mechanical testing by Profs. Sakai and Yasuda. This company is pushing very hard to develop two- and three-dimensional C/Cs.

- Kobe Steel is making 8-inch-diameter disks of C/C that have densities of about 1.8 g/cc after they had been multiply impregnated using the hot isostatic pressing (HIP) process.

- Mesophase research and development is being pursued by Prof. Isao Mochida of Kyushu University, Prof. H. Yamada of Tohoku University, Kobe Steel, and Mitsubishi Chemical.

- The major technology thrusts last in Japan for 5 to 10 years, then they drop off to a relatively few companies. This sequence is also valid for the world of carbon, where fibers were being emphasized 10 to 15 years ago, then the mesophase state of pitch 5 to 10 years ago, and currently the manufacturing of C/C composites, which was started about 5 years ago. Currently there are more than 25 companies involved in the processing of C/Cs. MITI started concentrating on C/Cs about 3 years ago and will continue its support until at least 1997. Nissan is working on exit cones and nozzles, which are indicative of the rapid progress that has been made in the past 3 to 5 years.

- A large amount of excellent equipment is found in industrial laboratories because they want to do their research without the knowledge of outsiders and especially their competition. How much of these capabilities are devoted to research or development will vary from company to company, although there probably is a tendency for more research to be supported by the larger organizations. Furthermore, the research staff is heavily backed up by support people, which is not the case for the universities or the government laboratories.

- There are different approaches in the use of research for the development of materials between Japan and the United States. In the former case, research is used to build the outline of the developmental problems that are associated with manufacturing a new material. Prof. Inagoki uses the analogy that the Japanese approach is much like putting up the framing structure of a house upon which the roof is placed, after which the details of the house are filled in. But in the United States, his impression is extensive development is used to understand all the phenomenology of the material, which is analogous to building the best foundation before any of the framework is started so that the optimum framing alternatives can be selected before the roof is put on. But this approach will take longer and it will be more costly to build the house or to develop new materials.

- Cooperative educational programs on an international basis are being promoted by the Japanese Society for the Promotion of Science with the assistance of the Ministry of Education. This is a bilateral Japan-U.S. agreement for the exchange of students and provides for their support while in the United States.

SHINSHU UNIVERSITY

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Dates: 19-21 Jan 1991

Background

Prof. Morinobu Endo, who is in the Electrical Engineering Department, was my host. He is internationally known for his pioneering research on the growth of single fibers of graphite from the vapor phase. These fibers are very perfect in their crystal structure and are therefore most useful for experimental and theoretical studies such as intercalational phenomena. Endo's initial research was accomplished almost 10 years ago. In all his studies, the main theme is to use the scientific research approach to explain phenomena that can be used to enhance the properties of materials so they can be used for engineering purposes. The materials that he is generally dealing with are different forms of carbon. Endo is the head of a group that consists of 15 students (8 undergraduates, 4 graduates, and 3 from industrial organizations).

He was educated at Shinshu University and joined the faculty upon receiving his doctorate.

The financial support for this group is divided into two-thirds from the Ministry of Education and the remainder from industry. In addition, Endo has indirect support through collaboration with over 50 different companies. This means that data are collected from processing runs from a company that is having production problems but does not have the "know how" to solve the problem. These data are sent to Endo, who evaluates the data on a scientific basis to understand how the process functions. With this knowledge, he advises the company's management what changes have to be made to the process to increase production or to improve the product. In return for this service, Endo receives further support for the group and can use the data to further his research efforts. A key to the success of this approach is that large quantities of data are very carefully collected to be statistically significant. Furthermore, the type of data selected is one that will give the best insight into how the process operates. This system of problem solving is advantageous to both parties because the company doesn't have to keep someone on its staff full time just in case a problem arises and the professor gains useful information with which to continue his studies. In addition, the problems get solved faster because of the professor's expertise. As an example, Endo mentioned that Mitsubishi Heavy Industries uses his services in this manner even though it has 150 researchers in its laboratories. In the course of describing the different modes of corporate operations, Endo made the point, as others have, that the philosophy of developing a product is entirely different in Japan than in the United States. In Japan, a market is identified for a new product, a process is developed for producing an acceptable but unsophisticated product, and it is sold to the public. A portion of the revenue from the product is used to improve its performance through further R&D. In the eyes of the Japanese, the United States does the inverse procedure by identifying a product, doing a lot of R&D so a sophisticated product can be made, then trying to find ways of making it cheaper so the product can be marketed. In terms of the development of C/Cs, Endo believes Japan will know as much about how to make this material as the United States does by 1995. Then Japan will go ahead of the United States technologically by 1997 or 1998. Part of the incentive for making this advance is because of the MITI C/C initiative that was started in the late 1980s and will end by 1998. Endo also believes there will be a shortage in Japan of technical persons in the future. This view was substantiated by a *Reuter's* article on 19 January 1991 stating that a recent survey indicated that by the year 2005 there will be a shortage in Japan of 510,000 scientists and engineers because young people are not entering the field due to low salaries, poor working conditions, and long hours. As a current example of long hours, Endo works 6 days a week from 0730 until 2000. This is not unusual for any number of professors that I've questioned. The problem of getting and keeping trained persons is being compounded by a change in the work ethic by industry. Previously, when a person was hired by an organization, it was a lifetime commitment by the employee and the company. Until even 5 years ago, a technical person could not make more than one move to another company without getting a black mark. Endo says the hiring and firing practices of big corporations have changed. Now the corporations are hiring 50% more graduates than they will need in the next 3 years. This allows the corporations to screen the group, pick the best ones, and fire the lower 50%. This procedure certainly puts a lot of pressure on the beginning engineer or scientist. Another aspect of industrial practices is that they are beginning to do more applied research than they were doing in the past. This change is beginning to impact the number of graduate students and faculty members in the universities because the industrial pay is greater, the hours are shorter, and the working conditions and equipment are better.

Program Status

One of the major areas of research in Endo's group is the detection and identification of defects in fibers. He believes that by accurately knowing the concentration and type of defects, it is possible to calculate the reduction of the thermal mechanical properties from the theoretical values for a perfect crystal of graphite. Conversely, if the influence of different types of defects is known, then it should be possible to modify the processing procedures to eliminate them, thereby improving the properties of the fibers. Endo is working with Prof. Mildred Dresselhouse of the Massachusetts Institute of Technology (MIT) in this area of research. Numerous techniques are being used in this laboratory to identify the defects in fibers such as TEM, at magnifications up to 1 million, laser Raman spectroscopy, magneto resistivity and other electrical characteristics, and thermal mechanical properties. All of this information is being fed into a computer-aided system that evaluates the data in terms of the type and orientation of the defects or in effect provides an absolute image analysis of the defect distribution in the fiber being examined. This approach has been used by Nippon Steel for its pitch fiber where the specific modulus and strength values exceed :hose of PAN fibers. A major portion of the defects in the pitch fibers has been eliminated, which results in large increases of the mechanical properties. These changes are sufficiently large so that they compensate for the higher density of the pitch fiber compared to the PAN fiber and that results in the larger specific properties. No values of modulus or strength were given because of the company's confidentiality agreement. The next stage of this research program is to apply these same techniques to identify defects on the surfaces of fibers. Again, the objective is to relate the types and distributions of defects to the bonding characteristics of the fiber with its surrounding carbon/graphite matrices. In addition, the defect distributions will be compared to the processing conditions and this should eventually permit the selection of the proper processing conditions to eliminate adverse defects.

Other areas of Endo's research efforts include:

- Optimizing the orientation of the mesophase-based pitch fiber to improve its transverse strength and toughness characteristics. The microstructure is being altered by adjusting the flow characteristics of the pitch as it is extruded through the orifice by changing the pitch's viscosity and how it is stirred as it enters the orifice.

- Defining the phenomena and conditions for the transformation of the amorphous carbon to the graphitic phase. It is Endo's opinion that if the radius of curvature of the microstructure is less than 150 to 200 Å, no graphitic structure will be formed.

- Reducing the cost of pitch fibers by using the less expensive isotropic pitch as the precursor. Finding and eliminating the defects in these fibers to improve their mechanical properties and applicability to a larger number of engineering uses.

- Identifying and altering the defects on the surfaces of carbon fibers to enhance their adsorption properties and applicability as a substitute for activated carbon.

- Studying the mechanisms of intercalation processes in carbon fibers to enhance their electrical properties and thermal stability.

- Determining if real time or in-situ measurements of the electrical properties of fibers can be used as a means of controlling the processing conditions to obtain the desired microstructure and physical properties. Right now the industry is evaluating fibers by characterizing fibers that are being taken from batches at different stages of the process. The types of undesirable defects are believed to be caused by such items as chemical impurities, variations in viscosity during the spinning of the fibers, and the types of disclinations that are formed by the various processing conditions.

- Continuing investigations with the vapor grown carbon fiber, especially with respect to its applications in energy storage batteries and the field of biotechnology. The dimensions of these fibers are approximately 1 micron in diameter and 10 microns long.

The laboratory facilities are very extensive and unique, especially for the characterization of fibers. The exception is that no mechanical tests are conducted here. But this is not a problem because of collaborative programs with the producers of fibers who provide Endo with all the data that he needs.

Assessment

The research program, under the direction of Prof. Endo, is one of the best if not the best in Japan. Its depth and breadth is not equaled in any of the other laboratories that I have visited on this whole assessment trip. These investigations are directed toward the different aspects of the solid state of carbonaceous materials. The information that is obtained is used to optimize the fiber's properties for particular applications. Therefore, a wealth of information exists here. It is expected that these research efforts will continue for many years to come. As far as collaboration with U.S. organizations is concerned, Endo has for years been a co-investigator with Prof. Mildred Dresselhouse of MIT. He would like to continue and broaden the number of these interactions.

It is strongly recommended that every effort be made to continue and extend communications with Prof. Endo. If possible, more collaborative investigations should be initiated.

GIRI NAGOYA

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Date: 23 Jan 1991

Background

Dr. Kikuo Nakano was my host for this visit. He is the chief of the High Temperature and Ceramic Material Division. The research here is primarily directed toward ceramics as matrices in composites where the fibers are made of both ceramic and carbon materials. Some of the research areas include:

- Superplastic deformation of ceramic systems where 100% deformation may take only 50 seconds at 1,400°C and 29,000 psi. The systems being investigated include silicon nitrides and carbides and zirconium oxide.

- The influence of grain size (<1.0 to 20 microns), aspect ratios, and chemical composition of boundaries on the sintering and hot pressing characteristics as well as the toughness and mechanical properties of silicon nitride.

- Superconductivity of Bi-Pb-Sr-Ca-Cu-O systems. This has been under investigation for the past 2 years. The major objective is to reduce the grain boundary effects in order to increase the current densities to 10,000 A/cm^2.

Program Status

The primary research involving carbon is the incorporation of carbon fibers into composites whose matrices are composed of nitrides and carbides of silicon and boron carbide. Dr. Nakano started this work about 5 years ago to make materials that have good oxidation resistance and excellent mechanical properties of the carbon fibers. These materials will be used for the near term or until the utilization temperature is raised to >1,600 °C. The current samples are 30 to 40 vol % of unidirectional carbon fibers wound and impregnated in a mixture of silicon resin and silica powder. The next step is to hot press the preform at 1,700 °C or at 1,850 °C if boron carbide or silicon carbide powders are used. The plates that are formed are 4 by 20 cm and 6 to 10 mm thick. Pitch-based fibers are preferable because they do not react as much with the different matrices as the PAN fibers. The cause for this difference has not been determined. These materials are evaluated at <1,700 °C for tensile, compressive, and bending strengths as a function of the different types of matrices and the processing conditions. For example, the bending value of a silicon carbide matrix composite can be 600 MPa (~87 kpsi) when measured at 1,600 °C. In some cases the fiber-to-matrix bond can be too good, which results in the sample fracturing prematurely before the maximum strength value is attained due to the differential thermal effect between the matrix and the carbon fibers as the temperature is raised from 22 to >300 °C. This is because the matrix expansion can be between 3.3 and 4.5 parts per million per °C as compared with ~-1.26 for the fiber in this temperature range. The oxidation resistance characteristics of these materials are not currently known as this phase of the program has just begun. In the future it is intended to study these materials in a 3D yarn or fiber configuration. As yet no thermal cycling with oxidation testing has been performed nor has there been any creep tests. Within the next 3 years the goal is to have these types of materials function satisfactorily at 1,800 °C. Mitsubishi Heavy Industries and other manufacturers are interested in this material for use in the forthcoming Japanese space plane that is being supported by the Government.

Assessment

This organization has a high degree of technical competence in the area of ceramic matrix composites that contain carbon fibers. This is a general direction of research that will probably result in the development of the next generation of high temperature materials to operate in an oxidizing atmosphere. Therefore, it is recommended that communications be maintained with this laboratory to keep abreast of the progress and to determine if any of the results can be utilized to improve the ceramic coating used on C/Cs to protect them against the effects of oxidation.

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Date: 24 Jan 1991

Background

My host was Shigeo Yasuda, who is the general manager of the Manufacturing Division, Inorganic Chemistry Department. My contact was Akira Hashimoto, who is the deputy general manager, Carbon Products Sales Division of the same department.

This is a multiproduct company that is concerned with the sales and applications of electronic boards for integrated circuits (ICs), ceramic fibers, and other items with carbon products such as fine-grained (<1 to 40 microns) graphites for electrical discharge machining. This phase of the business has been in existence for 20 years and usually acquires about 10% of the company's total revenue in a year. In terms of C/Cs, the company's interest started about 5 years ago. It appears that these efforts are being expended so that Ibiden can tell its potential customers that it can make C/Cs in case a sudden and large market occurs in the near future such as for the space plane or nuclear fusion reactors. The New Products Division is also interested in different types of ceramics such as silicon nitrides and carbides and zirconium oxide.

Program Status

There was no significant discussion about Ibiden's research activities or the reasons for doing so either now or in the future. The initial portion of the presentation was on general information about the entire corporation. During the course of this, several samples of C/Cs were displayed but the quality was not good, as the yarn spacing was 8 to 10 mm apart and the density was about 1.7 g/cc. The pieces were cubes with a dimension of about 100 mm. To densify the material, pitch was forced into the preform at 4,300 psi and the temperature was raised to 1,000 °C. No physical properties of this material were given. From the discussion it was apparent that Ibiden was aware that the temperature at which the pressure is applied is critical, although this value was not divulged to me.

The discussion then centered on the characterization and interpretation of the data. The samples are only examined by optical microscopy methods at magnifications between 10X and 100X. Essentially, they are looking for gross cracks between the yarns and in the matrix. No higher magnifications are being used, even though they believe the matrix microstructure has an influence on the physical properties of C/Cs. Ibiden's primary concern about physical properties of C/Cs is that the bending strength and thermal conductivity values be as high as possible. No explanation was given as to the rationale for these choices, and it is not clear from the information what the applications might be. No mention was made of thermal expansion, modulus, fatigue, or creep.

The development of C/Cs is being conducted by four researchers. No government funds are being sought so their technological advances can be held by the company. No laboratory tour or description was offered.

Assessment

Compared to the previous site visits, this one was disappointing. Judging by what I observed, Ibiden C/C technology is not current with companies in Japan or in other places of the world.

It is recommended that no further efforts be expended on this organization in the future.

MITSUBISHI HEAVY INDUSTRIES, LTD. (MHI)

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Date: 25 Jan 1991

Background

This visit was hosted by Yasuhiro Yamaguchi, manager of the Chemical Research Section of the Engineering Research Department. In addition, there was a manager from the advanced composites development team and a senior engineer from the Structure Designing Section of the Aircraft Engineering Department. The total number of attendees at this meeting was eight.

Studies concerning C/Cs have been going on since 1985. Although not specifically stated at this meeting, MHI, along with other big corporations like Mitsubishi Chemical, has a large effort to develop C/Cs for the Japanese space plane that is being partially supported by MITI. In addition, C/Cs are being designed and fabricated for rocket engines in launch vehicles. A tour of the resin matrix fabrication and processing facilities clearly indicated that all types and shapes of carbon reinforced plastic composites can be made. A type of winding equipment was installed in June 1990 that is capable of winding, with 3-inch-wide tape, a whole aircraft wing to a thickness of 112 plies (15.5 mm). There are hot presses and autoclaves that operate at 400 °C and 300 psi for processing whole aircraft wing sections as the largest autoclave is 18 feet in diameter and can take pieces 51 feet long. Apparently, these facilities are being used for the fabrication of various shapes of C/Cs. For example, I was shown a portion of a leading edge section for a wing that was similar in shape to that of the U.S. space shuttle. However, the flange thicknesses in it appeared to be thinner (~3 mm) and the yarn layups were straighter and more evenly spaced. Also shown was a thin C/C, SiC coated, flat panel, 1 by 2 feet, with an integrally woven rib that was also ~3 mm thick. Apparently, the expertise that has been gained in fabricating resin matrix composites is being used to make excellent prototype C/Cs.

The carbon effort at MHI is reported to be four to six staff and five support persons and the R&D has been going on for about 5 years. It is expected, based on other information that was obtained elsewhere, the C/C efforts will continue here for at least another 7 to 8 years.

Program Status

The discussion was very directed by the MHI representatives towards trying to get answers to specific questions, such as which type of architecture was better--2D, 3D, or some other architecture? Or, what were the shear properties of the U.S. space shuttle C/Cs? But the MHI group was reticent to provide any specifics about its programs or the research in connection with C/Cs. However, as the discussion went on, some information was obtained about its 2D C/Cs. They are fabricated by stacking layers of carbon/graphite cloth that has been prepregged, cured, and polymerized in the usual manner. After the preform has been carbonized to 1,000 °C, it is reimpregnated with furfuryl alcohol five to seven times and carbonized after each impregnation. At some point of the densification process, there is at least one graphitization step at 2,500 °C. The final density of the C/C is about 1.7 g/cc, which is typical for this type of material. Pitch-based fibers are used and the bending strengths of the C/Cs are around 20 to 30 kpsi. Again, these numbers are comparable to similar types of C/Cs that are produced elsewhere. Apparently, the quality of these current C/Cs is evaluated by the usual mechanical testing procedures and optical and SEM microstructural observations. However, the discussions would indicate that MHI is not yet sensitive to the importance and the influence of the matrix microstructure and the types of fiber-to-matrix bonds on the performance of C/Cs. They do find that graphitization does increase the modulus, lower the tensile and compressive strengths, and increase the strain values.

MHI has been performing research studies for the past 10 years on approaches toward resisting the oxidation effects on C/Cs. They have been involved in two different methods of applying SiC coatings to C/C substrates. MHI finds that the conversion of silicon oxide to the carbide forms a better bond. But, vapor depositing silicon carbide provides better protection. In each case the layers are ~200 microns thick. They are also trying the combination of conversion and vapor deposition methods to form a protective coating. Then on top of this a thin layer of a high melting point metal such as Hf, Zr, or Ir is deposited. Other types of refractory metal layers are being tried. This work is just starting and the goal is to provide protection to 2,000 °C. Thermal cycling between 22 and 1,700 °C is being included as part of the evaluation procedures of the coatings. No data were provided concerning any portion of the oxidation investigations.

Assessment

It is very evident that this corporation has and will continue, probably for the next 8 years, to develop C/Cs for high temperature applications. My limited observations of the types of C/Cs that are being fabricated indicate that the quality is very good and comparable to that which is produced in the United States. This situation does point out that Japan is doing exactly what they say they are going to do. Namely, Japan will become as knowledgeable as the United States by 1994 or 1995 concerning their capabilities for processing and fabricating C/Cs. Then, Japan expects to surpass the United States by 1997 or 1998 in the technological capabilities for producing advanced C/Cs! The information that will allow Japan to gain this position will come primarily from its own research and development efforts and by better communication and coordination between the other large corporations that MITI has formed into different consortia. There probably is a great deal of developmental information available here. How much research there is that is not connected to immediate problems is not clear. MHI says that collaboration is possible with organizations in the United States. Before this can be defined, communications between us need to be improved. I think this can be achieved judging from how relatively open this meeting ended after a very guarded start.

The recommendation is that MHI is an organization with which communications should be continued and perhaps some sort of a cooperative program should be established. Another advantage of establishing a link is that this organization is in the center of the big initiative that MITI is supporting with respect to C/Cs.

GIRI KYUSHU

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Date: 28 Jan 1991

Background

The host for this site visit was Dr. Minoru Nakamizo, who is the Director General of this facility. A general review of the activities here was presented. Approximately 25 joint projects are conducted each year with industrial and other GIRI organizations but practically none with universities, due to the fact that the GIRI funds come from MITI and not from the Ministry of Education. There are approximately 70 research personnel at this site, of which 40% have Ph.D. degrees, and there are only 20 support persons, including secretaries. As has been mentioned before, the researchers must do practically all of their own equipment building, data collecting, analysis, and writing of the papers and reports. In addition, it is difficult to hire young persons because the salaries and laboratory facilities are so much better in the industrial sector. The plus side is that the researcher is allowed a lot more freedom in conducting his investigations than would be possible in industry. However, all directors of each GIRI organization have recently been informed that their staff must be cut back 5% each year for the next 5 years, which certainly limits the growth to practically zero, especially for the hiring of young people.

The research in C/Cs started about 3 years ago, but work in the carbon area has been going on for more than 15 years under the direction of Dr. Yasuhiro Yamada with the support of three or more assistants.

Other major areas of research include the development of new engineering materials, including porous metals and intermetallics; mineral processing; ceramics; processes for the reduction of environmental hazards; and other studies for the scale-up of processes that have been developed in the laboratory.

Program Status

The general theme of the research in carbon is to understand how the processing conditions influence the microstructure and how this, in turn, alters the physical properties of the materials that are being investigated. In this regard, fundamental studies on the mesophase state of the pitch have been underway for the past 6 or more years and will end in 1992. One of the most interesting results is the ability to form a matrix microstructure whose a-b planes are oriented normal rather than parallel to the surface of the fiber. This means that the high strength direction of the graphitic structure of the matrix can be used to increase the transverse and shear strengths between fibers, normally the weak link. If a procedure has been developed for obtaining a 90° reorientation of the matrix, it would be a real breakthrough for the whole C/C world. The photo micrographs that were shown looked very encouraging as more than 80% of the matrices were oriented transversely to the fiber surfaces. This research is ongoing and, as might be expected, no details of the mechanism or processing conditions were divulged other than the fibers are heated between 600 and 800 °C before the pitch is introduced into the yarns. If the fibers are heated >800 °C, the matrix a-b planes will lay down parallel to the fiber surface. This implies that some sort of a radical type of bonding may be involved between the fibers and the surrounding matrix. This is an area of research that should be pursued, for an understanding of this phenomenon will certainly add a great deal to the ability to alter the properties of C/Cs according to the design and applications requirements.

Another unique development that was devised in this carbon group is the two phase carbonaceous spring. This is achieved by codrawing, at a relatively low spinning temperature, a mixture of isotropic and anisotropic pitch through an orifice and then processing the fibers in the usual manner. This results in a fiber, which is 10 to 15 microns in diameter, that is coiled into a springlike shape that acts like a spring. The tensile strength of this type of fiber is approximately 60 kpsi. Apparently, the two types of pitches are not miscible and there is a differential contraction between them during the pyrolysis phase of the process that results in the spring-like configuration, which has a diameter of 1 to 2 mm and a length of 0.5 to 1 cm. There are numerous possible applications for this type of spring because of its inertness to the body and high temperature properties. Apparently the geometry of the coils is controlled by the mixture of the two types of pitches and the extrusion procedures.

A number of other of carbonaceous artifacts have been developed here based on Dr. Yamada's knowledge of the chemistry of the precursors and the influence of the pyrolysis conditions on the development of the different types of carbons with various microstructures and properties. One of the systems is elastic graphite, which was discussed in the Koa Oil site visit of 7-8 January 1991. At this site, the heat treatment for this material is 2,800 °C, which results in a pore size of <1 micron. Another example has been the development of fibers from various types of pitch over the past 10 years. Their tensile strengths have been in the range of 360 kpsi with moduli of 90 Mpsi or less. Another approach has been the solubilizing of the mesophase in water by sulfination, nitridization, and other chemical modifications. Such modifications have permitted the formation of unique types of carbon and coatings. In the former case, the unique carbons can be used as a sensor of atmospheric water content. In the latter case, thin carbon coatings can be applied to steel rods that are being used for medical purposes. Other unique applications are also being investigated.

Research in the enhancement of resistance to oxidation of C/Cs is being undertaken at this site. One of the approaches is to determine if oxidation stable, submicron size particles can be dispersed on the surface of carbon fibers to act as oxygen "getters." At this time, the processing procedure has successfully dispersed carbon black powder. Another approach has been the use of two newly developed processes in which the carbon is mixed with zirconium carbide and boron carbide. One method of forming this material is to hot press using the boron compounds as a sintering aid and the other is the pressureless method using a sinterable carbon powder. The carbon/ceramic composites are found to have high oxidation resistance (<0.25% in 10 hours at 1,200 °C) and excellent friction-wear properties at high temperatures (0.1 at 500 °C). In all of this they are trying to understand all fundamental processes that are causing the carbon to change its characteristics.

Assessment

This organization is certainly a leader in Japan in the development of new types of carbon systems. This effort should continue in the future, since within the past 2 years MITI has initiated a new thrust to develop C/Cs that is expected to continue at least until 1997. Dr. Nakamizo expressed the desire for collaboration between this institute and organizations in the United States. There have been such collaborations with DLR in Germany, in Sweden, and in Australia.

It is recommended that we keep in touch with this organization and possibly initiate some cooperative projects, as this carbon group has shown the most innovations of carbonaceous materials of any single group that was visited.

KYUSHU UNIVERSITY

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Dates: 28-29 Jan 1991

Background

Prof. Isao Mochida is the head of this institute. His major research interest is the chemistry of pitch systems and how this knowledge can be utilized to make them more useful. Mochida is one of the three or four foremost carbon researchers in Japan and the principal contributor in the mesophase field of research. He has been doing so for the past 15 years and is internationally known for his research contributions. Mochida spent a year at the University of Illinois as a postdoctoral student and at the University of Newcastle upon Tyne in England, which was the world center at that time for mesophase, coal, and coke research.

Mochida's institute consists of 3 assistant professors, 2 postdoctoral students (1 from Japanese industry, 1 from China), 4 Ph.D. candidates (2 Japanese, 2 Chinese), 10 master's candidates, 2 undergraduates (1 is the wife of one of the Chinese graduate students), and 3 part-time support staff. Funding for these efforts comes from Kyushu University, the Ministry of Education, MITI, and industry. There is frequently a delay in getting money from the Ministry of Education and good graduate students have been lost or research programs are not accomplished on schedule. So other sources of funding must be found to overcome these delays such as having a researcher from an industrial firm spend time at the institute doing a project of mutual interest and receiving company support.

Program Status

The research program at the institute is composed of three major areas:

- Carbon science, which is concerned with understanding the phenomena of the mesophase transformations of pitches and the application of this information to the formation of optimum structures of cokes and fibers.
- Coal and heavy crude oil refinement processes, including liquefaction and catalytic reaction phenomena that occur with these processes.
- Solid state catalysis, including pollution control through activated carbons and fibers.

About 6 years ago research began to formulate the proper processing procedures to derive mesophase pitch for the production of fibers in the most economical manner. The purpose of the research was to determine how to chemically and thermally treat the pitch so that it would have the proper chemical structure for spinning and stabilizing the fibers and obtaining the desired microstructure and the desired physical properties after a high temperature treatment. One example of such a research program involves the preparation of mesophase pitches from methylnaphthalene with the aid of HF/BF_3. This study was undertaken because it has been shown that pure aromatic hydrocarbons are excellent precursors for mesophase pitch with the aid of HF/BF_3, but clarification is needed as to the influences of the methyl group on the condensation reactivity of the aromatic hydrocarbons and properties of the resulting mesophase pitch. A number of methyl groups on the mesogen molecules are expected to reduce the softening point further and should enhance the stabilization reactivity of the mesophase pitch which, of course, will assist in the formation of fibers. Actually, the experiments did show that the mesophase pitch had a lower softening point and higher spinnability, and the desired degree of stabilization reactivity was successfully achieved. Furthermore, it was found that the methyl group changed its position between 1- and 2-work state, indicating that it is not necessary to separate the methylnaphthalenes before the synthesis of mesophase pitch. Thus, it is concluded from this investigation that the roles of the methyl group in the stabilization are as follows:

- The methyl group itself has a high reactivity against oxygen.
- Methyl group substitutes for the aromatic ring activate the naphthenic C-H as well as the adjacent aromatic C-H. Further studies are currently underway to explore better preparation conditions.

Another example of the type of research that is being conducted in these laboratories involves the improvement of the microstructure and properties of fibers that are derived from mesophase pitch. Usually, the fibers are drawn through orifii, which results in the high degree of orientation of the molecules parallel to the axis of the fiber, thereby resulting, after completing the entire processing procedure, in the high specific strengths and moduli that are characteristic of this type of fiber. Such mechanical properties are governed by the microscopic alignment of carbon planes, which inherit the basic arrangement or orientation of the aromatic or mesogen molecules. The purpose of this investigation was to determine if the mechanical properties of pitch fibers could be improved by applying external forces during the carbonization step (<600 °C) and then unloading while the temperature is raised to 1,300 °C. These carbonized bundles were then graphitized at 2,500 °C. It appears from the current data that the strain during carbonization certainly influenced the structure and properties of the carbonized and graphitized fibers, which were stabilized with an amorphous skin and an oriented core. In this core the carbon planes appeared to be aligned into an onionlike texture that resulted in a significant increase in the tensile strength of the fibers. Some change of the fiber's modulus was noted, sometimes positive but sometimes negative, without apparent reasons. So far, the tensile strength and modulus are not always improved by the carbonization of pitch fibers that have a skin-core microstructure. Therefore, more extensive studies are underway to determine if processing differences are the possible causes of these variations.

More recently there have been investigations initiated into preparing pitch systems that are specifically designed for use as impregnants for the densification of preforms. The goal is to obtain a high degree of fluidity and also maintain a large percentage of carbon yield for the pitch. The approach is to continue the molecular studies and to determine how the different pyrolysis conditions alter the structure of the molecules within each type of pitch. In some cases the carbon yield has been as high as 98%! The eventual goal is to reduce the costs of processing and fabricating C/Cs by requiring fewer impregnation cycles. Another approach for reducing costs that is now being tried is to mix chopped fibers with pitch, partially pyrolyze the mixture to drive off the low molecular weight volatile gases, but still maintain enough organic residuals so that the pitch-covered fibers are bonded together when they are hot pressed to the desired preform shape. There are two distinct advantages for reducing cost. First, it is very cheap to chop fibers instead of weaving preforms with continuous fibers. Second, allowing most of the volatile gases to leave the low density preform while they can readily escape saves fabrication time. Then, the preform is densified by hot pressing so that there is no need to reimpregnate to fill the voids that are otherwise left by the escaping gases. The disadvantage of this system is that it is difficult to properly distribute the fibers in the preform and to maintain their orientation throughout the pyrolysis stage of the process. Another unknown factor is the degree of utilization of the fiber's mechanical properties that can be achieved in the composite form. Clearly the answer will depend on numerous factors such as bond strength, matrix microstructure, and processing conditions. At this time none of these answers are available, as no mechanical property data exist. Nevertheless, it is expected that this method of fabricating cheap C/Cs will find an application where the demand for high mechanical properties is not too great.

Areas of research that are just beginning are the nature of chemical bonding between the fiber and the matrix and the influence of the type of pitch and its processing conditions on the matrix microstructure. Both areas require in-depth characterization of the chemical nature of the pitches and how they vary as processing proceeds.

Other areas of research activity at this institute that are relevant to C/Cs include:

- Characterization of ethylene tar and coal liquids by nuclear magnetic resonance (NMR) in the liquid or solid state
- Structural change of carbon during carbonization and chemical calcination processes
- Control of carbonization of pitch-based carbon fiber and preparation of novel pitch
- Preparation of liquid crystal pitch for synthetic pitch derived from naphthalene with the aid of super acid
- Acceleration of stabilization reaction of pitch fibers
- Modification of naphthalene-derived pitch for general performance
- Modification of coal tar based isotropic pitch by blending naphthalene derived pitch
- Development of carbon fiber reinforced carbon of which the matrix is derived from mesophase pitches

The laboratory capabilities for the characterization of the chemical nature and crystalline structure of all materials in any state are outstanding as might be expected at such an institution as this. There are no SEMs or TEMs at this site, although they are available in other parts of the university. Several pieces of equipment are available for determining the mechanical properties of fibers and composites. In addition, there are centrifuges for separating chemical compounds, pressure autoclaves, solid and liquid state NMR, mass spectrometer, and ESR equipment.

Assessment

This institute, under the direction of Prof. Mochida, is unique in its capabilities to provide significant information about the processes and compositions of the precursors and their transformations during processing of fibers and impregnants that are used to densify preforms. It is expected that this high quality of research will continue for years to come and that the information will be of use to the United States as well as to the world of carbon as it has for many years. Prof. Mochida is interested in collaborating with organizations in the United States. Therefore, it is recommended that communications be maintained with this group as it is active and prolific in the pursuit of research papers. Consequently, it is expected that there is a good chance that some collaboration can occur in the near future if there is enough interaction between the parties that they can determine what areas of collaboration would be most valuable.

TOKYO INSTITUTE OF TECHNOLOGY

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Dates: 5,9,10 Feb 1991 and 18 Mar 1992

Background

My host was Prof. Eiichi Yasuda, who is the head of the Very High Pressure and Temperature Section and is internationally known for his research in ceramics and carbonaceous materials. He was a postdoctoral research fellow more than 20 years ago at the University of Karlsruhe with Prof. Eric Fitzer, also internationally known for his research in the field of carbon. Now Yasuda is one of the leaders in carbon research in Japan. He was a co-chair of the last Japanese international conference on carbon that was held in November 1990.

Yasuda's section specializes in research on high temperature properties of ceramic and carbonaceous materials and the influence of microstructure. At the time of my first visit, Yasuhiro Tanabe was Yasuda's research associate and received his Ph.D. in the area of multidirectional C/Cs. It is with these two researchers that most of the time was spent in discussing the influence of temperature, microstructure, and neutron irradiation on the physical properties of C/Cs. Since 1991, Tanabe has been an associate professor and is doing research in another section on thin carbon coatings, including diamond layers on metals to enhance their wear resistance. Yasuda's section consists of two doctoral, three master's, and two undergraduate candidates. A majority of the finances that support the section come from the Ministry of Education. There are five sections in the Division of Materials Processing, which is part of the Research Laboratory of Engineering Materials that was established in 1958. The Tokyo Institute of Technology was promoted to national university status in 1929.

About one-quarter of the section's efforts are devoted to research on carbonaceous materials. The research is focused on the influence of microstructure on the fracture behavior of carbonaceous materials between room temperature and >2,200 °C. The materials being investigated have varied from measuring single carbon/graphite fibers at 1,600 °C to studying the influence of microstructure and additives on the thermal and mechanical properties of multidirectional C/Cs after they were heat treated to 3,000 °C or subjected to neutron irradiation.

Program Status

One of the current research programs of interest is determining and identifying what functional groups may exist on PAN and pitch-based fibers after they have been oxidized in air between 500 and 560 °C for different times from 1 to 48 hours. These oxidized fibers are analyzed for changes in weight, surface area by the Brunauer-Emmett-Teller (BET) method, wettability, and identification of surface groups by ESCA. Each of the differently treated fibers are then used to make unidirectional resin matrix samples. These are double notched and tested in compression with the load axis parallel to the fiber axis to determine if oxidizing the fibers changes the bond strength between the fiber and the matrix. The results of the analysis are compared to the variations of strength to identify, if possible, the factors causing the bonds to change. Some of the preliminary observations are as follows:

- The weight loss is 2% for PAN fibers and only 1% for pitch fibers after being exposed in air at ~500 °C for 48 hours.
- There are no significant observable effects of oxidation on the surfaces of the PAN or pitch fibers after 48 hours in air at ~500 °C as viewed with an SEM at a magnification of 7,500X. No deep pits or deep grooves were visible. A small difference was noted in that the longitudinal marks left by the die during the drawing operation were less distinct for the pitch fiber as compared to the PAN fiber after being oxidized.
- There is a significant difference of specific surface areas with heat treatment as the PAN fibers exceeded the pitch fiber values by almost a factor of two after 48 hours oxidation at ~500 °C and by a factor of almost three as a function of weight loss.
- The wetting angles of the fibers in water decreased with oxidation time from approximately 60° at 0 hour for both PAN and pitch fibers to about 25° for pitch fibers and 35° for PAN fibers after approximately 15 hours of oxidation at ~500 °C.
- The ESCA results indicated that heat treatment at 2,600 °C of all the "as-received" fibers did eliminate an oxygen functional group that was very evident on the PAN fibers. However, for the as-received pitch fiber there was only a slight indication of this group but none after the heat treatment. After oxidation in air, there was no evidence of any groups on either type of fiber even after 4 hours at 500 °C or after 14 hours for pitch and 4 hours for PAN at 560 °C.

- The shear strengths between the resin and the fibers seemed to be nearly constant irrespective of the oxidation time.

This investigation is still continuing as it is not clear what phenomena are occurring. At the moment, it appears that no functional groups are introduced by air oxidation treatment at 500 °C possibly because they are removed very rapidly at this temperature. The next approach is to expose these fibers at a lower temperature (~250 °C) in a pure oxygen atmosphere to determine if any functional groups can be generated. Another interesting question is why are there no bond strength variations measured between the two types of fibers after oxidation since there are differences between their weight losses, specific surface areas, and contact angles? What does this indicate about the type of fiber surface that must be generated before a significant type of frictional bond is generated?

Another interesting result and subject of discussion is the apparent increase of the work to fracture of C/Cs that have been irradiated with 6×10^{24} neutrons per square meter. It appears this effect is more pronounced if the irradiation temperature in 640 °C as compared to 22 or 240 °C. This effect is contrary to that which has been observed for graphites under the same type of irradiation conditions where the irradiation effects are reduced as the temperature is increased so the work to fracture is reduced. No clear cause or explanation of this effect on C/Cs was put forth at this time. The answer is important because C/Cs are now considered to be the baseline material for deflectors in fusion reactors.

It is evident from the our discussions that a lot of consideration is being given by this group to the interactions between the fiber-to-matrix bond and the matrix microstructure, as they influence the fracturing behavior and change the physical properties of C/Cs. This is the only group in Japan that is doing research on the combined effects of microstructure and high temperatures on the fracturing behavior of C/Cs. Another factor that no other group in Japan seems to be considering is the influence of temperatures >1,400 °C on the mechanical properties of C/Cs. It appears from Yasuda's research that the fracturing mode is influenced by the same bonding and matrix factors between 20 and 1,650 °C. But above 1,650 °C there seem to be other possible influences such as defects and dislocations. Clearly a better understanding of this phenomenon is needed if C/Cs are to be used for high temperature and impulse turbines and other applications.

The laboratory tour indicated that the proper types of equipment are available to carry out the experiments being conducted and to characterize the material before and after the tests have been performed. In particular, there are two special types of equipment available in this section but not in any other university. One of these is a testing machine with the ability to conduct mechanical tests at >2,000 °C. The other equipment is a hot press that can form ceramic samples at 2,200 °C. Also, there are furnaces that can heat treat samples to 3,000 °C, pyrolyze up to 1,800 °C, and densify samples by CVD.

Assessment

The research efforts at this institute are clearly unique both in Japan and in any other country. Important information and concepts about the parameters that influence the mechanical properties of C/Cs have been coming from Yasuda's group for many years. It is expected that this situation will continue for at least another 5 to 8 years. There is a good communication link between Yasuda and a number of universities in the United States, so a form of collaboration has already started. He is most willing to extend this as time and money permit to do the type of research that would be of interest to both himself and to us. It is strongly recommended that communications be continued and serious consideration be given to forming some sort of a collaborative effort between us.

R&D INSTITUTE OF METALS AND COMPOSITES FOR FUTURE INDUSTRIES (RIMCOFI)

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Background

Discussions were held with Hajime Nishimura, who is the executive director of this organization, and Yoshio Minoda, a director. This meeting was arranged by Prof. E. Yasuda of the Tokyo Institute of Technology. The objective was to obtain further insight into MITI's mode of operation and plans for the development of C/Cs through research. After numerous discussions with Profs. Yasuda and Inagaki, their recommendation was to visit RIMCOFI to obtain the desired information from the organization that is actually managing the R&D activities for the composite programs, including C/Cs.

There are several organizational layers between MITI and RIMCOFI that need to be identified in order to understand why RIMCOFI can reflect the MITI operational attitude. MITI has the overall responsibility and does so through its Agency of Industrial Science and Technology (AIST). This organization's general and overall technical program objectives are generated by recommendations that are made by a Program Steering Committee that is composed of representatives from industry, government laboratories, and universities. This general program is acted upon by two separate types of organizational activities. The first is composed of the six government laboratories, such as the three GIRI laboratories that I visited in Osaka, Kyushu, and Nagoya. The second activity is composed of industrial laboratories and is under the supervision of the New Energy and Industrial Technology Development Organization (NEDO). Its aim is the rapid development of basic technologies that are considered essential to the growth of future industries. The fields covered by the program include new materials, biotechnology, new electronic devices and superconductivity, and project-related R&D that extends from the time a promising new technology is identified theoretically or experimentally to the time when its industrial application is established. Under these general categories, between 1981 and 1989, 14 specific "Research and Development Programs on Basic Technologies for Future Industries" have been established. The 11th one to be formed is "High Performance Materials for Severe Environments," which was established in 1989 and will run until 1996. This program is managed for NEDO by RIMCOFI.

Purpose and Functions of NEDO and RIMCOFI

NEDO was formed in 1981 and focuses its efforts on the research and development of industrial technology, particularly in basic and leading edge fields such as new materials and biotechnology. At the same time, it is sponsoring and taking the lead in establishing large scale advanced research facilities like the Japanese Ultra High Temperature Material Research Center (visited by me in March 1992).

Through such activities, NEDO is aiming at establishing innovative industrial technology that can support future programs like space travel and the conservation of energy and the earth's atmosphere. NEDO is an implementation agency of the Japanese Government and receives its annual budget appropriations from MITI each year. To ensure further expeditious technological advances, NEDO has actively undertaken research and development projects. But NEDO has no research laboratories of its own and has no researchers on its staff. Its role is to administer, coordinate, and manage the research work undertaken by the national laboratories and industry. RIMCOFI assists in the fulfillment of this latter responsibility.

RIMCOFI is aiming towards inventing new high-temperature materials that are lightweight, corrosion proof, and abrasion proof by developing reinforcing types of fiber, matrix, and intermetallic compounds as well as the technology to integrate them into structural materials. With this information, it will be possible to design and introduce an entirely new generation of high speed transport aircraft for use in the early 21st century. To do so, it is first necessary to develop new materials that can withstand the extremely severe environmental conditions inherent to supersonic and hypersonic aircraft and space planes. The scope of the RIMCOFI program involves:

- Materials design
- Development of intermetallic compounds and reinforcement fibers
- Processing or fabrication technologies for thin sheets
- Oxidation resistance technologies
- Evaluation of thermal, mechanical, and chemical technologies

In the context of this study, the most urgent project facing RIMCOFI is to find a method of protecting C/Cs against oxidation in air. The target is 1,700 °C for the first phase that is to be accomplished within the next 4 years. At this time, the approach is to use SiC for the coating. Beyond this, the goals are to operate for ~200 hours at 1,800 °C and for one-third of an hour at 2,000 °C. Towards this end, several consortia have been formed. One consortium is Kobe Steel and Fugi Heavy Industry; they are investigating possible methods of oxidation protection where the C/C preforms are woven with Toray PAN fibers. The second consortium is composed of Fugi Heavy Industry and Nippon Steel. In this case, the fiber that is used for the preforms is pitch based rather than PAN. A third consortium that is investigating oxidation protection methods is Ishikawajima-Harima Heavy Industries Co., Ltd. and Tonen Corp. Only limited information was presented about the actual protection methods that are being investigated in the development of the coatings. In general, it appeared to be comparable to what was used for the U.S. shuttle some years ago. As expected, the results are comparable to the shuttle values up to 1,400 °C. But the Japanese test samples were only exposed to a few thermal cycles before the weight loss measurements were made. So this procedure is not as severe as they thought it should be for a proper evaluation.

Other organizations and the R&D efforts that are being addressed include:

- Production of petroleum-based fibers
  - Petoca, Ltd.
  - Nippon Petrochemicals Co., Ltd.
  - Tonen Corp.
- Processing and fabrication of C/Cs
  - Nissan Motor Co.
  - Mitsubishi Heavy Industries, Ltd.
  - Kawasaki Heavy Industries, Ltd.
  - Matsushita Electric Industrial Co. Ltd.
  - Petroleum Energy Center

RIMCOFI plays a vital role in the whole material developmental process by coordinating the activities of all these groups through enhancing the communication link between them by organizing and conducting topical seminars or progress/coordination meetings. For example, a recent seminar was held on 24-25 October 1990 titled "Basic Technologies for Future Industries, High Performance Materials for Severe Environments." In addition, there are about four to five coordination meetings held each month with one or another of the various groups. Another important aid for achieving better coordination and productivity is through the collection and dissemination by RIMCOFI of the most recent physical property data for all types of advanced composite materials. These data are collected and put into a computer system for easy retrieval by the members. In addition, the data have been compiled into a 1,000-page volume that was first published in 1990 and is available to the organization's members at no charge. However, the volume may also be acquired by the public for Y55,000 (˜$435). Data for the next volume are now being compiled.

It is the opinion of the directors of RIMCOFI that the ceramic matrix composite is the most immediate and available material for high temperature structural purposes. Consequently, more money is now being spent in this area and it will reach a maximum in 1992 because of the specialized equipment that needs to be procured to carry on the R&D efforts. However, it is also the directors' opinion that C/Cs will be the next generation of materials for high temperature applications and that C/C research must be conducted now if this material is to be available in a timely manner. It is expected that the research relating to C/Cs will continue to be supported by MITI at least until 1998 and possibly longer.

In addition to the funds received from MITI, RIMCOFI receives money from 22 industrial research supporting members and 21 public supporting members. Some of the organizations that are involved include Kobe Steel, Ltd.; Nippon Steel Corp.; Nissan Steel; Nissan Motor; Nippon Carbon; Mitsui Engineering & Shipbuilding; Mitsubishi Heavy Industries, Ltd.; Kawasaki Steel Corp.; Hitachi, Ltd.; Tonen Corp.; Toray Industries, Inc.; Japan Aircraft Manufacturing Co.; Petoca Ltd.; Pratt and Whitney; Rolls Royce; and many others.

Assessment

This visit was most illuminating as to how the MITI operation is subdivided in order to enhance technical productivity by having an organizational activity that is specifically responsible for managing and maintaining excellent communications and good coordination between the participating groups. The general purpose for each phase of the program is clearly defined, but there is also flexibility for identifying and pursuing new directions that develop in the course of the program. This approach towards the development of new materials means there is the recognition that is takes time to evaluate the viability of any approach. But in the course of the planned research there may be alternative directions that are indicated that could be more fruitful if there was time to evaluate their potential. Under the NEDO charter, which is applicable to RIMCOFI, such a mechanism exists for the pursuit of additional information. This is an aspect that is clearly missing in the U.S. system for developing C/C materials in two ways. First, there is not enough research effort and time allocated for developing advanced C/Cs. This means that instead of 3 to 5 years we are allowed 1 or possibly 2 years. Therefore, it is only possible to refine and scale up the existing processing procedures. Secondly, the budgets for research are so scaled down that there is no room to deviate from the original program and still make the original objectives even if there are strong indications that another approach might be advantageous.

Another aspect of the MITI organization and its approach is recognition that research and technology efforts and outputs can be enhanced by having organizations, like NEDO and RIMCOFI, that provide the staff for managing, coordinating, and enhancing communication between the various highly technical and diverse groups. As part of enhancing the effectiveness and communication between these groups, current physical property data about these materials are collected and disseminated on a timely basis. It appears that MITI and the Japanese Government recognize that devoting a minimal amount of nonresearch effort is necessary in order to have the research and development efforts proceed at a rapid pace. It is also necessary that the managers not be from one of the participating industrial organizations that are conducting part of the research efforts, thereby inhibiting one company from getting an advantage over its competitors.

It is recommended that further information be obtained about the pros and cons of the MITI system to determine if it can be used as a model for C/C R&D in the United States.

FENG CHIA UNIVERSITY

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Background

Prof. Tse Hao Ko was my host for this visit, and he is the head of the Carbon Fibers Research Group. His effort started over 10 years ago and is being supported by the Taiwan Government with the intent of developing methods of manufacturing fibers for this country's own use and eventually for export. He is a frequent contributor of papers at the international carbon conferences. Several years ago, Ko spent a year at the Massachusetts Institute of Technology (MIT) studying carbon fiber interfaces and their bonding characteristics to metal matrix composites.

Program Status

One of Ko's primary investigations is concerned with the variations of physical properties and microstructural changes in two different kinds of stabilized fibers. One kind is obtained from commercially available polyacrylonitrile (PAN) fibers and the other is developed from the same precursor source but it is then modified in Ko's laboratory. The purpose of this study is to understand if and how modifications of the precursor can make good quality fibers with higher tensile strengths. A special grade of PAN fiber tow was obtained from Courtaulds Ltd. that contained 6% methylacrylate and about 1% itaconic acid copolymer. The fibers from this tow were modified with hot potassium permanganate solution. The treated, untreated, and stabilized fibers were then heat treated at different temperatures between 300 and 1,300 °C. The tensile strengths, elemental impurity content, pore distribution, and crystalline structure were then determined. It has been found that the modified fibers, when compared to the stabilized but unmodified fibers, have a higher density, better preferred orientation, and 20% to 40% improvement in tensile strength. The fiber diameters are between 6 and 7 microns. The effects of different heat treatments above 1,300 °C on stabilized fibers are also being studied. One set that received 2,800 °C heat treatment temperature (HTT) had a very high modulus of 116 Mpsi and a strength of 290 kpsi.

Another major part of Ko's research is concerned with the treatment of the surfaces of fibers and the bonding phenomena that occur with different types of organic matrices. Next, he plans to study the bonding characteristics of fibers in carbon matrices.

Ko's group consists of another university staff member, three graduate students, and four undergraduate students. The description of the measurements and characterization procedures that are being performed in connection with this research indicates there is available adequate laboratory capabilities, although I did not have the opportunity to see these facilities.

Assessment

Although this research effort is not large, its directions appear to be innovative and it is expected this type of work will continue for many years. It is recommended that surveillance of these efforts be continued. Ko has indicated that collaboration with investigators in the United States is possible if there are areas of mutual interest.

CHUNG-SHAN INSTITUTE OF SCIENCE AND TECHNOLOGY

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Background

Prior to my visit, Prof. Ko gave me some background about this institute and how this visit occurred, since it was not on my original agenda. This is a paramilitary organization that is very well supported by the Government of Taiwan. It is a strictly controlled access facility where clearance is normally required. For example, Ko had never been in this institute until the day he accompanied me, in spite of his long involvement in carbon research. I was asked to come here because my vita that was sent to Ko somehow had been seen by the institute's director of the Material R&D Center. The purpose of this entire institute, of which the center is only a part, is to produce military hardware starting with the research and going through the development and prototype stages to the production phase, if necessary, of the final hardware. Apparently, all of this is done mostly without the help of any organization or persons outside of this institute. Ko says that a great deal of money has been spent here on C/Cs for over 15 years. Once inside the controlled area and during the brief drive to the center, it was apparent the institute is a very large facility with more than eight large buildings that each contain about 6 to 8 stories. Each building must be over 100,000 ft^2 in area.

Prof. Shu-en Hsu was my host for this visit. He is the director of the Material R&D Center and a professor at the National Taiwan University. It was he that arranged this meeting. A brief overview was presented by him of the major divisions that exist at the center. They are:

- High Temperature Materials, which includes ceramics both in bulk and composite form, C/Cs, powder metallurgy, radomes.
- Composites, including structural, thermal insulators, metal matrix, and high temperature polymers that are used up to 1,000 °C for very short periods of time.
- Electric Power Batteries for missiles. All electrical characterization measurements are conducted here for the center.
- Conventional Metallurgy of superalloys and castings.

- Test Group conducts the measurements of mechanical and thermal properties, chemical and crystallographic analysis, and microscopy.

- Special Materials prepared by plasma spraying, explosive and high energy electroforming, powder metallurgy.

- Solid State that includes single crystals, oxides, superconductors, diamonds, and electromagnetic (EM) shielding phenomena.

- Optical and Infrared (IR) Sensors

Approximately 500 persons work at the center: 50 have their M.S. or Ph.D. degrees, 200 have B.S. degrees, and the remainder of 250 are support people without degrees. The director spent considerable time showing me a variety of materials that had been developed and processed into hardware and different types of components for aircraft, missile systems, and other military hardware. The emphasis of his discussion was that this center was responsible for the development of a large variety of advanced materials and transferring this knowledge into procedures by which parts are made on a production basis sometimes with the assistance of industry. It certainly was an impressive display.

Program Status

C/Cs have been the subject of research here for the past 20 years according to Hsu. He says that they densify C/Cs by chemical vapor infiltration (CVI) and liquid impregnation methods and were the first organization in Asia to densify C/Cs by HIP procedures. The outer container of this 12-year-old facility is reported to be 7 feet in diameter with a working volume of 40 cm diameter and 60 cm long. They also weave one- (1D), two- (2D), and three-dimensional (3D) preforms into various shapes. This includes 1-inch-thick by 24-inch-diameter disks and 12- by 12- by 12-inch 3D blocks. The block that was shown to me had yarns that were spaced 0.5 mm apart. Its density was reported to be >1.9 g/cc and its surface texture appeared to have an even distribution of very fine pores, which would be consistent with the high density. Its high density was obtained by HIPing to 15 kpsi to a maximum temperature of 600 °C using pitch for five cycles and HTT (<2,500 °C for 24 hours for thermal stability). The gas pressure inside the autoclave is applied after the temperature reaches 250 °C, which is different than is frequently used in the United States. The director said their HIP facility was the first one in Asia. The billet contains 55 Mpsi fibers that were bought abroad from Toho of Japan. Formerly they bought their fibers from Hercules Co. of the United States. Photomicrographs, using polarized light, showed each fiber in some of the C/Cs to be surrounded by a ring of amorphous carbon. But outside of this ring is a graphitic matrix that bonds or joins these coated fibers together. This combination of matrix microstructure is used with the intention of providing a specific combination of mechanical properties of high strength and modulus without a significant reduction of the work of fracture. Apparently the fracture surfaces showed a significant degree of fiber pullout, which is desirable if good utilization of the fiber's properties is to be obtained. It is very possible that this mixture of isotropic and graphitic microstructures that surrounds the fibers might give the desired properties. No details were given about the property values that are considered to be optimum. But this research direction does indicate the importance that is placed at this center on having the proper type of matrix microstructures.

Two other pieces of C/C were shown to me that are used for a gas diverter vane and a swivel rocket nozzle for vectoring. The nozzle has a 2-inch throat diameter and the piece had just been used in a test firing. Its internal surface looked very smooth without any trace of erosion. Polarized light microscopy is used to define the type of microstructure that exists in the C/Cs. Etching by oxidation is performed on some of the samples. Another variable that is used to attain different properties is the cross-sectional shape of the yarns. Circular-shaped yarns are used if high strength and isotropic properties are desired in C/Cs. Apparently, the yarns can be packed into a higher density in the C/Cs with the uniformly circular cross-sectional yarns.

Subsequently, discussions were held with several of the younger staff members, who provided me with additional information about the status of the R&D investigations on C/Cs that are being conducted at the center. Some of the 3D C/Cs have bend and tensile strengths of 27 and 23 kpsi, respectively, and modulus of 100 Mpsi. The fibers that are frequently used come from Toho of Japan. The major success in the densification of C/Cs by the HIP method has occurred in the past 6 to 7 years. Other shapes of yarns can and have been used in producing various preforms. An unclassified article on some of the processing procedures has been published with the approximate title of "Super Alloy, Super Ceramic and Super Composites," Academic Press, 1988 or 1989, by Tien et al. Apparently, it has been found here that the best mechanical properties are obtained with a combination of CVI and liquid pitch impregnation method where CVI is used for the first and last densification steps and pitch is used for the intermediate steps. This sequence makes sense as the CVI bonds the fibers together if they are close together and penetrates into the very fine pores that are formed during the pitch densification steps. The use of only CVI results in an inferior C/C because of the density gradients that are produced inside the preforms with this method of impregnation.

Detailed discussions showed that there is a sensitivity to the importance of processing conditions and the resulting microstructure and their influence on the physical properties of C/Cs.

Oxidation protection coating research is being conducted. The best result at this time is that no loss of the C/C substrates is noted after 60 hours at 1,600 °C. The coating is multilayer, with a composition of some combination of Zr and Si with a total thickness of all the layers between 50 and 100 microns. The inner layer, next to the substrate, is put on by applying a layer of silica powder that is converted to the carbide at 1,600 °C. Then, the outer layers are formed of mixtures containing Si and Zr powder that are applied and heat treated to 1,600 °C. The entire coating is oxidized in air. Some of the C/Cs have been coated with this material and then have been thermally cycled for 10 times. Upon evaluation no noticeable degradation or weight loss has occurred. No exact numerical figures were given to me. There is concern at the center with the differential thermal expansion problem that exists between the coatings and the C/C substrates. Thermal expansion tests are being conducted on these different materials, primarily as a means of quality control of the processing conditions. Apparently there is no research being undertaken to alter the coefficients of thermal expansion (CTEs) of the C/Cs.

The C/C research group consists of about five staff and five support people. Clearly, laboratory support for this R&D effort is available as was indicated by the above description of the organization by its director.

In the future, this group will continue to develop new fabrication processes through an understanding of the phenomenology that causes the materials to behave as they do under severe environments. At the moment there are no big requirements for C/Cs for industrial purposes; thus, the research efforts at this center will continue at the present level in order to fill the military needs according to its director. An additional purpose at the center is to maintain an awareness of what is going on in the material field.

The question of collaboration with different U.S. organizations was brought up by Prof. Hsu. He wishes to do this if such joint efforts will be meaningful to both parties. Apparently there is a precedent already set; Pratt and Whitney have just completed an agreement with the center where there will be an interchange of scientists in the field of intermetallics. Also, the center has some cooperative research work with the University of Delaware. Hsu said that uncooperative actions occurred at the Cocoa Beach, Florida, meeting of the American Ceramics Society, where his man was asked to present a paper in the closed session and then was asked to leave the session while the rest of the papers were being given. Hsu considered this procedure to be uncooperative and not conducive toward improving better communications.

Assessment

In general, this whole visit was very enlightening and totally unexpected because there is very little information that is published from the center. Yet, there is a significant amount of research and development work occurring here. The time at the center was limited, so it was difficult to evaluate the type and depth of research that was being conducted as opposed to good development work. However, the pieces of C/Cs that were shown to me appear to be of a good quality and comparable to material that is fabricated in the United States. This could not have occurred without an understanding that is derived from some research. More importantly, there is good R&D being conducted here that they are willing to share. Otherwise, I would not have been invited to come and given special attention by the director for more than 2 hours. I was told afterwards that getting so much of the director's time is highly unusual. I think his motive is to show that significant work is going on at this center and that he is willing to have additional communications and perhaps collaboration with the United States. Therefore, it is recommended that continued communication be undertaken especially in the area of their optimization of matrix microstructure in C/Cs where collaboration might be beneficial to us.

NATIONAL TSING HUA UNIVERSITY

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Tel: (035) 715131 x3622
Date: 20 Feb 1991

Background

My host for this site visit was Prof. Chen-Chi Ma of the Department of Chemical Engineering, which is a part of the Institute of Chemical Engineering. This is one of two universities in Taiwan that are involved in research areas that pertain to C/Cs and the only one that is especially concerned with woven structures that use carbon fibers. The primary thrust of the research at this university for the past 10 years has dealt with organic matrix composites, in particular, the mechanisms of reactions and bonding characteristics of the fibers in different mixtures of phenolic matrices. Now this research is shifting towards carbonaceous matrices.

The effort involves two people with Ph.D. degrees, six M.S. candidates, and four undergraduate students. In addition, some assistance is being provided by three full-time engineers and two postdoctoral graduates who are part of an industrial development effort for composite materials that is being sponsored by the Taiwanese Government.

Program Status

The main thrust of the effort is to understand the influence of different mixtures of phenolic and furan, processing conditions, and resulting microstructure on the physical properties of C/Cs. They are trying to use their extensive knowledge of polymeric systems to see if there are unique combinations of precursors that may have been overlooked in the past by other investigators. They believe that it should be possible to reduce the total porosity of the C/Cs to less than 4%. Eventually these researchers will begin to study the pitch systems as a means of densifying the preforms. This research is just starting, so no results have been forthcoming nor are there any papers.

Assessment

This is a relatively new research effort, so not much information is available at this time. But it is expected that an aggressive program will continue in the future because it is being funded by the Government so that C/Cs can be produced in this country for use in the military and eventually for industrial purposes. Prof. Ma would be interested in collaborative research with U.S. firms in the future. It is recommended that in a year or two a detailed review be conducted of the research progress that has occurred at this institute.

MEETING OF THE CHINA ASSOCIATION OF SCIENCE AND TECHNOLOGY

My host throughout the visit to China (from 21-28 February 1991) was Prof. Donghua Jiang, who is Secretary General of the Chinese Ceramic Society:

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My visits to the different organizations in and near Beijing were arranged by Prof. Jiang. He was contacted when the plans for this visit were considered because we had our first discussions about C/Cs in 1983 at the American Carbon Society meeting. At that time Jiang was in charge of carbon research at the Beijing Research Institute of Materials and Technology, which is a part of the Ministry of Aero Space Industry of China. He and some other senior scientists have been involved in the R&D of C/Cs since the early 1970s. As with those of us in the United States at that time, the formal training and background of all the Chinese scientists and engineers was in fields other than carbon, such as ceramics, metallurgy, chemistry, etc. In general, all of these people did their graduate work in Russia. Now the graduate students are usually trained in China as there are enough experts available in the carbon, materials science, and other various science fields.

Background

This meeting, held in the Friendship Hall, Beijing, on 22 February 1991, was chaired by Prof. Jiang and attended by more than 55 persons from at least 10 different organizations that included:

- Shaanxi Nonmetallic Material and Technology Institute
- Northwest Chemical Power Corp.
- Beijing University of Aeronautics and Astronautics
- Journal of the Chinese Ceramic Society
- Chinese Ceramic Society
- Nanjing Fiberglass Association of Research and Design Institute
- Beijing Institute of Chemical Technology
- The Ministry of Aero Space Industry of China
- Institute for Astronautics Information (Technology Dept.)
- China Academy of Launch Vehicle Technology
- Institute of Polymeric Materials
- Beijing Institute of Chemical Technology

Discussion

The purpose of this meeting was to discuss C/C research and related technology. The general question prior to this meeting was: Is there a technology for producing C/Cs and significant knowledge available in China for obtaining the desired thermal-mechanical properties of C/Cs based on R&D activities that have been conducted here since the early 1970s? In other words, has the research information that has been reported at past technical meetings been derived from only small-scale laboratory work that was performed in China? The discussion questions and information obtained from this meeting are presented according to the different topical areas listed below.

Fibers. Programs are being conducted to determine the best methods for producing pitch- and PAN-based fibers on an industrial scale. Apparently, they are still undecided as to which type of fiber should be the primary industrial product. In general, the fiber diameters range from 5 to 10 microns in diameter. Pitch-based fibers with a 6-micron diameter have a maximum modulus of 700 GPa (102 Mpsi), which is 10% to 15% higher than the modulus for the PAN fibers. But they have tensile strengths of 3.2 GPa (464 kpsi) compared to 3.0 GPa (435 kpsi) for pitch fibers. Production lots of PAN fibers can have strain values as high as 1.8% compared to 1.2% for pitch fibers. The current emphasis is to develop processes for the domestic production of pitch fibers. Until recently, the precursors for the fibers as well as the PAN- and pitch-based fibers have been obtained from Russia. But China is developing methods for producing its own pitch precursors. No information was made available to me about domestically produced PAN precursors.

Weaving and Architecture. There is general agreement among the participants of this meeting that the fiber/yarn properties and architecture are very important ingredients in the determination of the properties of C/Cs. One of the questions was, "What type of yarn distribution will be best for maximum resistance to erosion and ablation?" This started a general discussion amongst the participants and their conclusion was that better resistance is attained by having the yarns/fibers as evenly distributed throughout the preform rather than as discrete groups of yarns that are displaced from each other. The weaving capabilities are still being improved and they have the question whether 3D or 4D is a better architecture.

Impregnation and Densification. Densification of preforms is by chemical vapor deposition (CVD) or liquid impregnation methods. The pitch that is used has characteristics that are similar to the U.S. 15V pitch. Billets are usually impregnated five times. It appears, although not specifically stated, that both organic and pitch types of impregnants are used, as it was stated that the last two impregnations are usually with coal tar pitch. Of the five impregnations, only four receive graphitization heat treatments (HT) as the last impregnation has a HT at < 1,000 °C. This is to minimize the amount of open porosity that remains in the preform. The densities of the preforms are between 1.85 and 1.9 g/cc. The CVD impregnation method does have density gradients in thick samples of between 0.1 and 0.2 g/cc at a depth of 3 cm below the preform surface. Pyrolytic graphite from CVD or CVI is the preferred matrix for aircraft brakes.

Processing Conditions. Processing temperatures between 400 and 700 °C are considered to be the carbonization range for mesophase-type pitches. Their research indicates that this temperature range is where the molecular order of the microstructure is first defined. The pressures that are used during impregnation can range from 300 to 700 psi and even, on special occasions, as high as 23,000 psi. The thermal and mechanical properties can be altered in coal tar pitch densified C/C preforms by varying the heat treatment between 2,400 and 2,500 °C, which means the amount of graphitic structure can be changed to fit the application requirements. Furthermore, for comparable amounts of graphitic matrix, the HT temperature is lower for pitch than it is for phenolics. Depending on the type of precursor, there is an optimum graphitization heat treatment for a particular desired maximum value of mechanical property. This optimum HT processing condition has also been found in Germany at Schunk. Another method for altering the properties of C/Cs is to treat the fiber surfaces of the yarns by electrolytic oxidation or by coating them with silicon-based oil sizing followed by a pyrolysis HT. Apparently these procedures will increase the degree of fiber-to-matrix bond strength.

Microstructure and C/C Thermal-Mechanical Properties. It was indicated that the fiber-to-matrix interface bond is very important in determining the C/C's work of fracture, strength, and modulus properties. If the bond is very strong, the compressive modulus and strength will be high but the strain values will be low. But under tensile loads, it has been found that a reduction occurs of strength and strain values with an increase of the modulus. Their experience is that C/Cs with the highest work of fracture values and reasonably good strengths contain PAN fibers and graphitic matrices. Higher thermal expansion values are obtained with high fiber-matrix bond strengths and amorphous carbon matrices. The sheath effect has been observed in these studies where the graphitic a-b planes surround each of the fibers similar to rings in the trunk of a tree. This type of microstructure is considered to have an influence on the effective modulus and strength values of the fibers.

One of the most interesting points was their discussion about the transverse orientation of the graphitic a-b planes between fibers. This means the normal of these planes is parallel to the fiber axis rather than perpendicular as it is for the previously mentioned sheath effect. Under proper processing conditions the microstructure is predominantly transverse, which results in a >25% increase of the transverse tensile strength and a 10% to 20% reduction in its longitudinal strength. Further studies are being undertaken to determine the optimum distribution of oriented microstructure, which will give the proper transverse and longitudinal strengths. Their description of the processing conditions that are used to get this transverse orientation was limited to a statement that the surface of the fibers is treated to obtain a random orientation of the fiber's surface structure and the carbonization pressure is 15 kpsi. Studies are now underway to determine if the same structure can be obtained at lower pressures. The type of fiber surface may be similar to that which was described to me at the GIRI Osaka laboratory in Japan, which also produces transversely oriented matrix microstructures.

Quality Assurance (QA) Techniques and Testing Methods. Mechanical testing of composites is being conducted between -196 and 2,600 °C and the data are used both for engineering design and as a gauge of the influence of different processing conditions that are used for developing advanced C/Cs. Thus, these physical property data, along with microstructural observations, are being used in an iterative manner to find the optimum processing procedures for improving these materials. At this time, no quantitative microstructural analysis research is being undertaken as they feel the problem is too complicated.

Methods for conducting QA include x ray, ultrasonic, thermal and electrical resistance, and computer tomography. They believe that the main unresolved problem for obtaining reliable QA predictions is the inability to define the type, number, and distribution of defects that will cause the physical properties of the C/Cs to significantly degrade.

Miscellaneous. Oxidation resistance work is taking place at the level of the shuttle technology, where silicon oxide is deposited on the C/C substrate and subsequently converted to silicon carbide. Only single layers of coating are being applied, but there are plans to investigate multiple layers.

Assessment

This meeting was very informative as it clearly answered the general question as to whether China was knowledgeable about the technology of C/Cs. Their information and answers to my questions were forthright and knowledgeable, which left me with the impression that many years of research and development effort have and continue to be devoted to the general area of developing C/Cs. I surmise, although it was not specifically stated, that the primary uses for this material are for military and aerospace applications such as for exit cones, nozzles, nose tips, etc. No emphasis was placed on industrial uses or the exportation of C/C products.

SHAANXI NONMETALLIC MATERIAL AND TECHNOLOGY INSTITUTE

P.O. Box 72
Xian, Shaanxi, China
Date: 23 Feb 1991

Background

This meeting, held at the Ceramic Society building, was composed of four persons from the institute and Prof. Jiang. The senior engineer of this group is Mr. Kang-li Wang, who stated the major purpose of the institute is the production and exportation of materials for the civilian market. One of their major goals is to become the major supplier of aerospace and aeronautical materials in Asia. This includes carbonaceous materials such as chopped carbon fiber composites that are densified by CVI for brakes; 2, 3, and 4D woven C/C nozzles and hot structures as well as high density graphite for electrical discharge machining (EDM) applications; low density felts for insulation; and metal-impregnated graphite for motor brushes. The members of this group are primarily involved in the R&D efforts that are related to the processing of C/Cs.

Program Status

The major portion of this discussion was concerned with the densification of woven carbon fiber preforms. Their method of densifying is primarily by using liquid pitch to impregnate the preforms. If their densities are required to be in the high density range of 1.8 to >1.9 g/cc, the impregnations are carried out at high pressures in a HIP facility. Then, the preforms are contained in a metal can that is placed inside an autoclave. The can is partially filled with pitch and the temperature and pressure of the system are raised at a predetermined rate to a maximum temperature of 700 °C. In general, the temperatures and pressures are increased to plateaus and held for predetermined times. These temperature plateaus are normally at 250, 400, and 700 °C and the increase of temperature is at a rate of about 15 °C per hour. The holding times at each plateau vary, too, from as short as just reaching thermal equilibrium to holding >10 hours at about 400 °C. In this case the long time is used to advance the pitch toward the carbonaceous state at a slow enough rate to allow the gaseous products from it to diffuse out of the preform without blowing the pitch out of it. They believe the major difficulty in the densification of C/Cs is getting the pitch into the preform and that keeping the pitch in the voids is no problem during the pyrolysis steps that occur between about 350 and 500 °C. This finding is not consistent with the interpretation of what is occurring according to experiments that some of us have conducted in the United States. Perhaps there are other considerations that the Chinese were not willing to discuss. The can, into which the preform is placed, is either vented or sealed, with the appropriate amount of void space above the pitch in order to minimize the pressures that are developed due to the gaseous products that are evolved from the pitch as it is heated. The purpose for these measures is to prevent the can from rupturing and to minimize the pitch-derived gas pressures, which will counteract the autoclave's high pressures outside the can that are being used to force the pitch into the preforms. Apparently, both vented and unvented cans have been tried. Currently, they are using unvented cans where the volume above the pitch must be carefully selected so as not to cause the can to rupture during the pyrolysis stage. The gas pressures are first applied at 250°C and increased to a maximum value at about 400°C. It is held at this value until the matrix has been solidified. They have found that the rate of depressurization is very important in terms of the subsequent performance of the C/Cs. The autoclave wall is cold and the maximum pressure that can be attained is about 15 kpsi. The working space for the sample is 120 mm outside diameter and about 300 mm long.

This R&D effort started more than 6 years ago and the goal is to find the optimum combinations of pressure, temperature, and time conditions to obtain the maximum density of the C/Cs with the least number of impregnations steps. Interestingly and most important, these processing conditions are also being determined with the intent of obtaining a specific type of matrix microstructure that is desired for particular engineering applications of C/C. This means for a high modulus and high strength C/C the matrix should be carbonaceous. Whereas if the C/C is to have more toughness, the matrix should be more graphitic.

The topic of discussion then changed toward applications and the types of preforms and manufacturing techniques. They are making thin (~35 mil), wall long (3 to 4 m) tubes by winding cloth on mandrels much as is being done in the United States. There is interest and plans are just being formulated to develop techniques for making nuts and bolts that are cut out of either 2D or 3D C/Cs. This latter form of C/C is being used in the U.S.S.R. The subject of porosity was also discussed and its importance to the performance characteristics of C/Cs. Prof. Jiang made the point that a certain amount of porosity is necessary to accommodate the differential expansion problems that occur between the fibers and the different types of matrices. They, too, have found that billets can crack during processing if the densities are >1.9 g/cc. But a reduced porosity with the proper size distributions is desired for C/Cs that most resist ablative environments. So for them there is a balance of porosity that must be maintained. Thermal shock characteristics are another aspect that they are trying to enhance and the direction of development appears to be towards increasing the thermal conductivity and work of fracture of the C/Cs.

Quality assurance methods are another area of interest. There was no clear definition, according to them, of which properties to monitor. Currently it appears that x ray, microstructure, porosity, and mechanical properties are being used. Everyone agreed that this system is too costly and time consuming, but an alternative procedure has not been devised as of yet. One possibility that was briefly discussed is the use of pulsed laser heating on different areas and measuring the changes with time of temperature rise and expansion. These values are then compared on a relative basis in order to obtain the quality of the piece of C/C that is being processed. In concept this approach is a good integrator of the microstructure that is being evaluated in each of the areas that is being measured. So the quality of an entire piece can be evaluated by taking a sufficient number of measurements.

Prof. Jiang indicated that in the U.S.S.R. the group size doing R&D at the Institute of Astronautics and Space is >6,000 people, with half of these involved in production. He did not specify the overall size of a similar effort in China, although my impression is that it is in the hundreds if not several thousands of people.

Assessment

The general impression is that this organization has significant background and experience in the areas of fabrication and the processing to fabricate C/Cs that are of a quality that meets their engineering requirements. They appear to be continually developing advanced techniques to improve these materials without the help of advisors from aboard, such as from the U.S.S.R. Aside from the usual language problems, there was a good exchange of technical detail and no apparent withholding of information.

BEIJING RESEARCH INSTITUTE OF MATERIALS AND TECHNOLOGY (MINISTRY OF ASTRONAUTICS AND AERONAUTICS)

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Beijing 100076, China
Tel: 8383228
Date: 25 Feb 1991

Background

The visit was conducted by Prof. Jiang, who worked here for over 20 years, and Mr. Jiliang Wu, who is the vice director of this institute. The other senior engineers and members included Mr. Zi-chun Wang, who is in charge of the carbon R&D effort and who worked as Jiang's assistant when he was here, Prof. Jiaxiang Zhao, Prof. Lian Cheng Hu, the vice general engineer, and

Mr. Zheng Guo. While driving or walking to the different locations within this institute, my impression was that this is a very restricted access area. The security was so tight even Prof. Jiang could not get me entrance into the area until a particular person arrived for work who could grant the permission. Another impression was that this facility is very large and contains many buildings and people, many of whom live on this site. This arrangement is similar to what was observed at the graphite institute in Moscow. Apparently, the research, development, preproduction, and production activities are all conducted at this location. In general, the appearance of the buildings gave the same impression as those at the Wright Development Center in Dayton.

Program Status

The central theme of these discussions was concern with the research and related technology of C/Cs. The general objective at this institute is to develop advanced C/Cs through knowledge of what the processing conditions do to the physical properties for these types of materials. About 700 persons are involved in the R&D and production of C/Cs. The approximate breakdown of this figure was given as 16 professors, 200 senior engineers, and 500 engineers and technicians for R&D work. No further information was conveyed concerning the number of professionals and support persons. I was told that all the analytical and experimental facilities required for this work are available at this site. Their efforts are divided into two general areas:

Division 1 - metallic materials
Division 2 - nonmetallic materials:
- Dept. 1 - Information
- Dept. 2 - Composite materials (all types of matrices)
- Dept. 3 - Design

Clearly, this meeting was being sponsored by Dept. 2. The major thrust of these R&D efforts is to advance the technology and processing capabilities of composite materials, such as C/Cs, for governmental use. In general, the development of the materials that go into these composites is not being performed at this facility. For example, a major effort is being conducted at the Anshan Research Institute of Thermo-Energy in Anshan Liaoning concerning the development of pitch that is used for the impregnation of C/Cs and for the production of fibers. I met and had a discussion with Dr. Jianfeng Wang, who is a senior engineer, at a 117 Committee meeting on 30 November 1990 in Japan. He was on a 6-month leave doing research with Prof. Otani. Prof. Jiang, my host, knows Dr. Wang, as they were in graduate school together in Moscow.

An area that received much attention during the morning discussion was quantitative microstructural analysis and especially possible methods of evaluating the degree of bonding that exists between the fiber and the matrix. Apparently, they are knowledgeable about the open literature on this subject, including my work in this area, for the questions were both general and very specific. They have a keen interest in this whole subject of microstructure because they know from experience the area is complex. Experimental and analytical work is ongoing in how to define defects and how they influence the physical properties of C/Cs.

The laboratory tour involved going to a number of buildings that contained special types of equipment that is of particular relevance to the processing and fabrication of large pieces of both organic and carbon composites. One of the most impressive facilities is their HIP facility for pitch-impregnating preforms that are as large as 15 inches in diameter and over 40 inches long. Prior to being placed in the autoclave, the preforms are rigidized through the infiltration of pyrolytic graphite (PG) into the preforms. Then the preforms are placed in a sealed metal container that contains the pitch. The temperature and the autoclave pressures are increased to make the can and autoclave pressures approximately equal so the can does not rupture. The maximum conditions that can be obtained in the autoclave are 1,750 °C and >23,000 psi. This autoclave was bought in Sweden about 8 years ago; its overall dimensions are about 3 meters in diameter by 10 meters long. Although I asked, it was not clear to me why these extreme conditions were selected. One possibility is that high pressures are known to produce fine-grained microstructures. The autoclave's conditions are controlled manually based on temperatures and pressures that are continually monitored and recorded by the operator. I'm told that this is the largest autoclave of this type in Asia. A second autoclave was for the processing of organic matrix composites. It is about 5 meters in diameter and 14 meters long and can be operated up to 250 °C and at a pressure of 90 psi using computer-controlled programs. This facility is about 5 years old and again it is reported to be the largest one in Asia. The proper thermal cycles for different materials are determined by the "Edisonian" method where test samples, 500 mm in diameter by 100 mm thick, are cured at different heating cycles and then characterized for their properties.

The tour also included a visit to see some of the characterization equipment such as SEMs, TEMs, electron spectroscopy for chemical analysis (ESCA), scanning ion microscopes (SIMs), and other equipment that is normally used in this type of a laboratory. Qualitative determination is the main thrust of their micrographic studies. Optical micrography is used to determine void and fiber content and distributions. SEM is used for evaluating the fracture behavior of these composites, whereas the TEM assists in evaluating the different types of interfaces and the structure of the matrix. I was shown some pictures taken with the TEM where it was evident that about 50% of the matrix was oriented with its ab planes normal to the fiber's surface. Apparently, there is an ongoing research program in this important area. To attain such a microstructure, the samples were processed at high pressures and the surfaces of the fibers were preconditioned. Numerous photographs of the microstructure of the composites were viewed. These were taken with the use of the optical microscope to 2000X and the SEM to magnifications from 50X to 200,000X or higher. The energy dispersive analysis by x ray (EDAX) capabilities can detect mass numbers from 5 to 92. In general, these photos showed the impregnation methods to be of a good quality as the porosity was small in size and uniformly distributed. The weaving seemed to be of a good quality. For example, the spacing of 1K yarns for a 2D cloth was 0.028 inch (0.7 mm). For 3D C/Cs, the spacing can be as low as 1/2 mm (0.025 inch). Other architectures that have been studied are 1D, 4D, and 7D.

A portion of their mechanical testing laboratory was seen. The general impression was that these facilities are capable of performing the usual types of tests. Some of these tests can be conducted from liquid nitrogen to >1,500 °C.

The afternoon discussion involved about 16 persons and was a continuation of the subject matter of the morning and other topics. One of these is their work on oxidation-resistant coatings. Apparently a "shuttle" type processing method is being used for the formation of a SiC coating by the conversion of the SiO_2 from its reaction with the C/C substrate. Researchers are concerned with the fact that the C/C strengths are reduced with the formation of these coatings, so they are trying to devise other methods of improving the resistance to oxidation such as coating the fibers after the preforms are woven and ways of filling the cracked coatings that occur due to the differential thermal mismatch between the coating and the substrate. Similar to the U.S. technique, glass-based fillers are being used to fill these differential thermal expansion cracks. In addition, they are trying to fill the spaces between yarns with silicon carbide particles to enhance the depth resistance of the matrix to oxidation. A loss of the composite's mechanical strength is one of the major problems that must be overcome at this time. The oxidation resistance of these coated samples is determined by two methods. The first is a screening test where the sample is heated to 1,300 °C for 1 hour, and it is acceptable if the weight loss is <1%. Then, the sample is subjected to 30 cycles between RT and 1,250°C and still must lose <1% of its initial weight. There are plans being formulated for conducting more research on higher temperature coatings but no further details were given.

In the course of this discussion, a number of items of interest were mentioned without too much discussion and these are as follows:

- The use of a pyrolytic matrix does increase the toughness of C/Cs. At times this PG matrix is used just to rigidize the preforms, after which they are densified with pitch impregnation.

- There is interest in determining the different types of weave architectures that are best for particular applications.

- Some mechanical property measurements have been made at liquid nitrogen temperatures. But no mechanical property measurements have been made after the samples have been thermal cycled to these low temperatures.

- A large problem is to define a test or a small series of tests that can be performed on C/Cs to insure the reliability of their performance. Furthermore, will the types of tests have to be changed with each different application? At this time there are no such tests nor any standards defined in China that specify the methods that should be used for testing materials. But some efforts have been initiated towards overcoming these deficiencies.

- There is the belief here that China is ahead of the U.S.S.R. in the development of C/Cs.

- The counterpart to this organization in the U.S.S.R. is the Composite Material Science and Production Institute.

- An institute like this also trains students who are on its staff. The people who do the training are designated as professors and they also are affiliated with a university. Presumably students who are finished with courses are doing research for their degree on a topic that is important to the institute.

- When I questioned them about other organizations in China that are doing similar work, the answer was, "This is the leading one." But there are other organizations that are designated to be the focal point for complementary activities for different aspects of the total picture, such as fiber development, which has already been mentioned earlier in this report. There are program coordination meetings between these organizations twice a year. Apparently, the general directions and policies are set by the Commission for Science and Technology.

Assessment

This institute appears to be a focal point in China for the research and development of C/C materials. There are extensive facilities and persons available here, some of whom appear to be well trained. The content of their discussions and the type of questions they asked certainly verify their extensive experience in the area of C/C development.

The question of cooperating with the United States was discussed. Their is interest on their part and I think it would be to our advantage to do so. But it is recommended that the type and degree of cooperation be determined on a case-by-case basis. It is further recommended that we keep in contact with members of this organization as it is expected that significant R&D will be forthcoming in the future.

BEIJING UNIVERSITY OF AERONAUTICS AND ASTRONAUTICS

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Beijing 10085, China
Tel: 2017251 x834 (Prof. Chen)
Date: 26 Feb 1991

Background

The host for this visit was Prof. Chang-qui Chen, who is head of the Department of Materials Science and Engineering and director of the Materials and Failure Prevention Laboratory. The other senior members of this group are Prof. Jiang, who was my general host for my visit to China as was mentioned earlier, and Assoc. Prof. Shu-Zhen Bai of this university, who also is the secretary general of the Technical Committee of Composite Materials of the Chinese Society for Aeronautics and Astronautics (CSAA). Another senior member that I met at lunch was the president of this university, who is also the chairman of the China Universities Society of Intellectual Property, the director of the China Society of Astronautics, and a member of the Standing Committee, Beijing Association of Science and Technology.

This university has about 6,000 students, both undergraduates and graduates, and a staff of 3,000. In addition to this university, there are 10 or 11 other institutes in this local area, so there appears to be a centralization of technical capabilities similar to that which is being done in Japan and Korea. Most of the persons working at this institute live on the site in apartment complexes. The Materials Department has about 170 staff of which 20 to 30 are senior members. The number of students in the department totals 570, of which 70 are graduates working for either their masters or Ph.D. degrees. The general comment was made that there are about 10,000 universities in China.

The main emphasis in this department is the field of metals, which includes materials with high temperature characteristics such as Ti, Ti-Al alloys, and Ti metal matrix and carbon fiber composites. The mechanical properties and fracture behavior research are major thrusts in this department. But they are also considering expanding these efforts towards carbon composites because of their potential utilization for very high temperature applications. One application seems to be use of C/Cs for parts in engines. In the view of the people at this meeting, ceramic-based materials are considered to be the next stage of development of materials for high temperature applications. Beyond the useful temperature range of ceramics, it is agreed that carbonaceous-based materials, including C/Cs, are the only direction that is available. This is why plans are now being formulated to start research in the field of C/Cs at this university using the same approaches that have been successful for metals and ceramics.

Program Status

The only research on C/Cs at this time is on brakes for aircraft. More specifically, the areas of interest are the phenomena that are associated with wear and the thermal incompatibility of oxidation protective layers. As a consequence of these major research directions, there is a significant interest in the fracturing behavior of C/C composites and factors that will influence their mechanical strengths and bonding characteristics. To assist in such studies, there is already experience here concerning the fracture behavior of metal matrix composites (MMC). One approach towards this end has been to observe and record, under high magnification, the progression of microcracking, in situ or in real time, to determine how it is influenced by the microstructure. Apparently, this approach will soon be used for similar types of studies in the area of ceramics at another institute.

In the area of oxidation inhibition, they are investigating the role of vapor coating the individual fibers to form a SiC layer. No further information was forthcoming about this work other than their composites that contained the coated fibers do not have strengths that are comparable to those with the uncoated fibers. Other studies include the creep behavior of metals up to 2,000 °C and enhancing the toughness of ceramics by the addition of various kinds of whiskers, including carbon. For all of this work there are complete laboratory facilities and capabilities to chemically analyze and characterize the physical properties of any of the materials that are being investigated, including a fatigue machine that can stress samples up to 1,000 °C.

During the discussions a lot of interest was evident concerning how to define the microstructure of the fiber to matrix bonds and relate these finds to the physical properties of C/Cs. Their problem seemed to hinge on the variability of bonds along the length of the fibers and how observations in one plane can be representative of the third dimension. Another area of concern was whether thermal cycling of C/Cs resulted in fatigue problems, which will ultimately mean a reduction of strength. They were especially interested for cycles that run from RT to 800 or 1,000 °C. The applications were not identified other than such materials are being considered for "shells." Another area being investigated is fracture mechanics and predicting the failure of materials. Apparently they are trying to determine, with limited success, the influence of defects within organic and metal matrix composites on their failure behavior. These defects are identified nondestructively by x-ray and ultrasonic techniques and destructively by metallographic examination where the samples can be polished.

As a result of this meeting, Prof. Jiang and I had a further discussion about the size and distribution of pores in the microstructure of C/Cs and their influence on the thermal expansion characteristics of C/Cs. He has found that the last two impregnation cycles can have a profound influence on the thermal expansion of certain types of C/Cs. For example, if these two impregnations are only taken to 1,100 °C and the billet has a high density (>1.85 g/cc), the coefficient of thermal expansion value of the C/C can be increased by 75%. Such a result would be very significant for reducing the thermal expansion mismatch between C/C substrates and their ceramic oxidation-resistant layers that are protecting them.

Assessment

This department is just beginning to start research in the area of C/Cs, so not much information is to be expected in the near future. It is difficult to estimate when significant research results will be forthcoming because the facilities are available for conducting this type of research and certainly there are competent materials researchers here. Their selection of research priorities will probably be an important factor in determining their progress in C/Cs. It is recommended that some form of communication be maintained to keep track of this progress. The topic of cooperation between this university and its counterparts in the United States was discussed. There is interest on their part in having some sort of communication that may develop into more specific activities.

CHUNGNAM NATIONAL UNIVERSITY

Daeduk Science Town
Daejon 305-764, Korea
Tel: (042) 821-5600; 822-7914
Fax: (042) 823-2931
Dates: 1-7 Mar 1991

Background

Prof. Bosung Rhee, who is dean of the Engineering School and professor of chemical engineering, was my host.

The Korean Government has been for the past 10 years in the process of creating a science center in this city by moving various research activities from throughout Korea to the city. In this manner the expertise that exists in these organizations is concentrated into one area. Furthermore, they can take advantage of the capabilities at the university that is located here. The most recent activity to move is the Korea Advanced Institute of Science and Technology (KAIST), similar to the Japanese science center at Tsukuba.

The carbon research activities are headed by Rhee and were started in 1970. Rhee received his training in carbonaceous materials at the University of Karlsruhe under the supervision of Prof. Fitzer. Carbon fibers was the initial area of research that was started by Rhee at Chungnam University and it remains the primary thrust of his research even today. The carbon research group consists of three faculty members, including Rhee, and 15 students. The support for the research has varied over the years from the Korean Ministry of Science and Technology, which is interested in starting a national fiber production industry, to the United Nations through their Industrial Development funds, which are being used to develop a national capability for producing pitch-based fibers. Currently, according to Rhee, about 175 tons/yr of PAN and 60 tons/yr of pitch-based fibers are being produced by industrial firms in Korea. Interest in the production of PAN-based fibers started about 1980 and the precursor was obtained from Courtaulds. The initial technology was developed in Rhee's laboratory. In 1985 some steel and chemical company bought the PAN processing technology from Rik Textile Company of the United Kingdom. It is now the process that is being used to produce 115 tons/yr of PAN fibers. The second industrial company, whose name is Taetent Textiles, is the other organization that has been producing PAN fibers since 1987. But these fibers are from a precursor that has been developed in Korea. The tensile strength of these fibers is reported to be between 250 and 700 kpsi with a maximum modulus of 93 Mpsi. The rate of production for all types of fibers is 60 tons/yr. Pitch-based fiber research was also started in Rhee's laboratory in 1985. The R&D on pitch-based fibers is being continued today with some support from the United Nations Industrial Developmental funds since 1987. Currently there is one industrial organization working with him on methods for producing mesophase pitch-based fibers.

According to Rhee, the Korean industry is just beginning be a producer of carbon fibers. Until recently, this country has been a consumer of carbon fibers, which have then been used in composites that have been manufactured in Korea. Eventually the intent is to produce goods that will be exported abroad.

It is estimated by Rhee that as many as 25 professors from various Korean universities are doing R&D that is concerned with the applications of carbon fibers in composites of various types of matrices, i.e., cement, organic, and metal. In addition, there are 10 to 15 professors who are involved in C/Cs. Korean research work on C/Cs started in Rhee's laboratory in 1975. There are about three textile organizations that are now weaving carbon fiber cloth to be used in fabricating 2D preforms and two companies that are prepregging the cloth, which is then used for forming resin or carbon matrix composites. To date, no industrial firm is weaving 3D preforms that contain carbon fibers.

C/C composites have also been of interest since 1973 in Korea and again Rhee and his coworkers did the initial R&D investigations. There is research in C/Cs now being conducted in his laboratory as will be explained in the following section.

To promote an international meeting with the Japanese, a joint seminar on carbon fibers and their applications, hosted by Rhee, was held on 24-27 April 1991. In addition to eight professors from Japan, there were guests from France (Erhburger), Germany (Fitzer), and the United States (Edie). This meeting was supported by the Korean Science and Engineering Foundation (KOSEF) and the Japanese Society for the Promotion of Science (JSPS). This is another example of two governments that are supporting international cooperation.

Program Status

Fiber Development. A unique investigation is being conducted to determine the parameters that control the formation of fibers whose cross sections are atypical to those that are normally produced throughout the world. Consequently, one of the major thrusts of this group is to understand what processing conditions are required for the formation of fibers with a "C" shape or hollow cross sections. Rhee believes that such a cross section provides more surface area for bonding the fiber to its surrounding matrix and that larger strengths per unit area of fiber cross section can be obtained because of the fiber's microstructure and enhanced flexibility. Their experimental approach is to determine the proper treatment for preconditioning the precursor coal tar and selecting the optimum spinning conditions. This means there is a minimum of fiber breakage during the spinning operation. After this step the fibers are stabilized by air oxidation and then carbonized. So far, they have found that the most important parameter is the heat treatment (HT) of the pitch prior to its being spun. Too little HT results in variable viscosity whereas too much HT means excessive brittleness and fiber breakage. But the quinoline insoluble and benzene soluble contents of these mesophase pitches do not appear to be very important. The resulting fibers are then characterized for their degree of shrinkage during the pyrolysis step, surface area, and mechanical properties. At this time the diameters of these laboratory spun fibers are between 10 and 40 microns. The hollow fibers have tensile moduli of 35 Mpsi and a strength of 220 kpsi whereas the fibers with a solid circular cross section have 93 Mpsi and 700 kpsi values, respectively. The outside and inside diameter dimensions of the hollow fibers are about 40 and 7 microns, respectively. It is expected these dimensions will be reduced with further R&D effort. One investigation was made that compared the mechanical properties of carbonized thick- and thin-walled hollow fibers that were made from isotropic and mesophase types of pitch. The thin wall (~15 microns) stabilized more rapidly and had about 20% higher mechanical properties than the >30-micron-thick wall fibers. However, the variability of the cross sections of these fibers makes the interpretation of the data very difficult. The C cross section fibers are variations of the hollow fibers. No strength data were available for this type of fiber nor were there any for composites that contained either types of fibers as the samples were in the process of being fabricated. This research effort is part of a collaborative program with Prof. Edie of Clemson University in the United States, who receives funds from the National Science Foundation according to Rhee. Apparently the orientation of the a-b planes is not uniform within the cross sections of these fibers and therefore is another variation that has to be understood in order to have them orient parallel to the surfaces of the fibers. In most cases the pitches that are being used are prepared by heat treating them prior to their being spun. The goal is to obtain a mesophase content that is more than 98%, which is determined optically at a magnification of 300X. Rhee doesn't feel that the quinoline insoluble (QI) content is an important factor to consider in controlling the spinnability of the pitch precursors.

Another aspect of the research program is to evaluate the influence of different surface preparations like electrolytic oxidation on fibers and their influence on the mechanical properties of unidirectional samples that are prepared in this laboratory. Densities of about 1.78 g/cc are achieved through multiple reimpregnation and carbonization steps. At this time none of these samples are being heat treated to graphitization temperatures.

Activated Carbon Fibers. This investigation was initiated in 1988 by Prof. Ryu, who joined Rhee's group about 8 years ago. The purpose of this study is to determine the mechanisms of adsorption and catalysis that occur in the fibers that contain different types of pores.

They have been produced by different chemical and thermal treatments. Apparently, the most efficient performance of these fibers is with submicron size pores that are uniformly distributed in size, as small as 1 to 5 Å, over the surfaces of the fibers. The general procedure for obtaining these pores is to oxidize the fibers at elevated temperatures in a moist water atmosphere. This evenly sized pore structure within and on the fibers is also being used as a support system for catalysts. Another advantage of using carbon fibers is that they can be woven into a cloth form that can be laid up with a predetermined architecture in order to obtain a given flow pattern of fluids or gases that are passing over the fibers.

In general, the laboratory capabilities in this group are adequate to perform the necessary evaluations for determining the chemical nature of the precursors and the density and surface areas of the fibers as well as their microstructures. In addition, there is equipment for the spinning, stabilization, and heat treatment of the laboratory produced fibers to graphitization temperatures. In general, the physical properties of the fibers were determined in other departments of the university.

Assessment

Prof. Rhee's group is performing some interesting and innovative development work. He is interested in doing collaborative research with universities in the United States. Much of his activities are collaborative efforts with foreign organizations. An area that is of interest is noncircular cross section fibers to see if they have significant advantages as Rhee believes. It is recommended we wait until more information is obtained before proceeding further. One of the best sources of information will be Prof. Edie of Clemson University.

KOREA ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY (KAIST)

P.O. Box 150, Chongyang-ri
Seoul, Korea
Tel: 966-1931-7, 967-6811-8
Fax: 962-8835
Dates: 3-4 Mar 1991

Background

Prof. Jai Young Lee, who is dean of research at KAIST and a professor in the Materials Science Department, was my host. Unfortunately, his laboratories were in the process of being moved to the Daeduk Science Town and therefore I was not able to see his facilities. So, our meetings were held at Chungnam National University in Prof. Rhee's office or in Seoul.

There are approximately 25 professionals in the KAIST Materials Science Department and the carbon group is composed of a postdoctoral fellow, about 2 graduate students, and 15 undergraduate students. Lee has been directing this effort for about 8 years. There are laboratory capabilities for performing chemical analysis, thermal-mechanical testing, and evaluating the microstructures of the samples that are prepared in these laboratories. At this time, no creep or fatigue tests are being conducted here on C/Cs, although it is expected these property characteristics will be investigated in the future. Any capabilities that are not available at KAIST can be readily obtained at the university. Support for the research at KAIST is from multiple sources such as the Korean Government through an organization that is comparable to our National Science foundation, other institutes, private foundations, and a small number of industries.

Program Status

The primary thrust of Lee's C/C research is to understand the behavior of these materials based on their composition and microstructural characteristics. The samples that are being studied are formed from prepregged yarns or cloths that are laid up and pyrolyzed, after which they are densified by CVD methods. The resulting densities can exceed more than 2 g/cc, which is higher than can be obtained by pitch impregnation according to Lee. The sample sizes that are tested are approximately 2 mm by 2 mm by 2 cm long. One of the current investigations is to determine the influence of different forms of cracks in the matrix on the work of fracture. The samples used in this study are composed of Torayca #6151B cloth that contains PAN-based fibers. The cloth is laid up to form a 2D structure, which is densified by an isothermal CVD technique at furnace conditions of 1,000 °C using 1 atm of propane gas at a concentration of 5% to 30% in an inert carrier gas. In general, the deposition conditions were selected to form a smooth laminar type of microstructure in the matrix that surrounds the fibers. Using different cooling rates of the furnace after deposition had been completed, it was possible to generate various types of cracks in the matrix. Thus, by slowly cooling the furnace, many long and wide circumferential cracks were formed around the individual fibers. However, with rapid cooling, fewer, shorter, and narrower cracks were generated. The influence of these two types of cracks on the fracture behavior is the objective of this investigation. Tensile tests are conducted at room temperature on notched and unnotched samples. It appears that the load extension curves for these two types of samples show three distinct regions prior to their failure if the strain rate is kept constant throughout the test. This means that during the initial stages of loading there is an increase of stress with strain. The second region is characterized by very little increase of stress although there is a significant amount of strain taking place. The third region again shows stress increasing with strain but with a slope that is lower than that which occurred in the first region. Finally, failure takes place in an abrupt manner. Examination of the fractured surfaces shows fiber pullout and a terraced-like matrix near the fibers when there were numerous and large cracks in the matrix. But, a brittle type of fracture occurred in the samples that contained fewer and smaller cracks in the matrix. In addition, lower values of the work to fracture were found to occur for these samples that were cooled slowly. Therefore, it appears there is a difference in the fracture behavior that can be attributed to the microcracks in the matrix. This difference is attributed to diversion of any cracks that are propagating through the sample by the matrix cracks while the sample is being stressed. The plateau of stress-strain curves in region 2 is considered to be evidence that diversion of cracks is occurring, which means the work of fracture is increasing. Other studies are being conducted to determine the difference of the work of fracture if the matrix microstructure is smooth or rough laminar. The initial evidence indicates that it takes more work for the latter type of microstructure. Lee and I agree that the exact phenomenology that is occurring at the grain boundaries within the matrix is still not understood and that more research is needed to resolve these questions. So far none of the CVI densified materials have been heat treated above their deposition temperatures of around 1,200 °C. Such studies will take place in the future as it is recognized that higher heat treatment temperatures may have an effect on the mechanical properties.

Other research areas that are being addressed at KAIST include the formation of diamond layers by gas vapor techniques and their chemical interactions with different kinds of substrates. Also, they are trying to understand the causes of and develop methods for improving the oxidation resistance of C/Cs. Another area of interest is to determine what role the vapor-deposited matrix microstructure plays in the frictional properties of C/Cs that can be used for brakes for aircraft. At this time, Lee believes his preliminary data show that microstructure of the matrix plays only a minor role in determining the performance of these brake materials. This view is contrary to that of other investigators throughout the United States, Japan, and Europe. Clearly, more research needs to be done in the area of brakes. It is of particular interest to Korean industry because aircraft brakes is one of the few areas that can be readily identified as a money maker. Apparently, Korea is responding to this potential market in a similar manner to that which is occurring in Japan.

Assessment

I was favorably impressed with the attitude and approach of Prof. Lee towards obtaining a better understanding of the mechanical and fracture behavior of C/C materials through innovative research programs. He has a good appreciation of the importance of the fiber matrix interactions on the thermal-mechanical behavior of C/Cs. The possibility of some sort of communicative or cooperative research interactions with U.S. universities or other organizations is a real one in his opinion. I certainly feel that information from his research will be of significant interest to us. Lee is quite familiar with the U.S. system of research as he received his Ph.D. from Stanford. It is recommended that continued communication be maintained with Prof. Lee with the view that some sort of collaborative research efforts might be initiated with him in the future.

AGENCY FOR DEFENSE ANALYSIS

P.O. Box 35
Daejon, Korea
Date: 5 Mar 1991

Background

A discussion was held with Dr. Hyeon-Wu Sonn, who is head of the C/C activities that are being conducted at this institute. Time did not permit a visit to his laboratory. Furthermore, this activity in just starting, so a discussion was satisfactory at this time. The group is composed of three people with Ph.D. degrees and eight people with masters degrees. The main purpose of the effort is to develop advanced C/Cs for long range missiles and planes that contain hot structures and high temperature components in their propulsion systems.

Program Status

The program plans are now being formulated so there are no laboratory results or published papers at this time. Their emphasis will be toward understanding the behavior of C/Cs with the initial effort on the science that is concerned with pitch carbon fibers and unidirectional samples that have been densified by CVD methods. The influence of additives was mentioned as one area of interest. I am guessing that oxidation resistance studies will also be undertaken, although no direct statements were made to me about this type of investigation.

Assessment

It is too early to form any opinions about this program. Therefore, it is suggested that this activity be kept in mind for a review of its status some time in the future.

RESEARCH SCHOOL OF EARTH SCIENCES

Australian National University
P.O. Box 4
Canberra, Australia
Tel: (06) 249-2610
Fax: (06) 249-0738
Dates: 8-15 Mar 1991

Background

My host for this visit was Prof. Geoff H. Taylor, who is the leader of the carbon research group at this university. A modest research effort is being conducted here as the group consists of approximately four researchers and an equal number of support staff. However, there are a number of research staff and laboratory facilities available in the School of Earth Sciences, as its purpose is to function in a manner that is comparable to the Institute for Advanced Studies at Princeton, NJ. Consequently, through collaborative efforts with other investigators, the chemical nature of the different pitches and fibers can be determined for the different stages of processing as well as their mechanical properties and crystalline structure. Eventually, it is intended that this group's efforts will be to study the detailed microstructure within C/Cs and relate it to their mechanical properties.

The purpose of coming here is because of the excellent fundamental research that is being conducted by this group. The scope of this group's research has been purposefully keep narrow so the group may focus on the minute details that need to be understood and to define the "structure" of carbon fibers. Through this knowledge it is expected that correlations will be formulated between the processing conditions that result in a particular type of fiber structure. Then, it should be possible to select the kind of manufacturing process that will reliably produce fibers with specific properties with which to meet particular engineering requirements. Taylor, the leader of this group, which was formed more than 4 years ago, is the codiscoverer of the "mesophase" state of pitch, which is one of the major building blocks in the development of microstructure for fibers, matrices in C/Cs, and grains in polycrystalline graphites.

Program Status

The main thrust of this group is to determine the structure of different types of commercially produced fibers by defining their microconstituents on a scale that is as fine as the spacing between atomics to as coarse as grain sizes that are measured in millimeters. These studies are performed with the assistance of a whole spectrum of laboratory capabilities from TEM to optical microscopy, definition of the crystalline structure by x ray and electron diffraction techniques, Brunauer-Emmett-Teller (BET) surface area determination, mercury porosimetry, and the identification of the chemical constituents of the organic precursors before and during the different stages of pyrolysis. The combination of excellent laboratory techniques and taking the time to carefully evaluate each type of fiber is providing knowledge that the industrial producers are not able to gain from an economic viewpoint according to Taylor.

One of the most recent investigations has been the determination of the domain structure in some high-modulus, mesophase pitch-based carbon fibers. Carbonic fibers contain extensive sheet structures that are complexly folded in a direction that is generally parallel to the fiber's axis. As these fibers are heat treated to a graphitic state, these sheets take on different forms, which ultimately result in the determination of the fiber's physical properties. A detailed description of these sheets is therefore essential and this has been accomplished by ion milling samples that have first been mechanically thinned to a thickness of about 30 microns. Then a high velocity ion beam of argon is directed at an incident angle of 45° on the sample's surface. Both longitudinal and transverse sections of these fibers are examined to define the domain structure that exists within them. Domains exist in all fibers and are defined by the texture and orientation of stacked graphene sheets. Domains extend in length up to 100 to 150 microns parallel to the filament axis but are much smaller in the transverse direction to that axis with dimensions between about 0.2 to 3 microns. High and low density domains exist in all fibers. The high density domain is composed of densely stacked graphene layers. These regions are surrounded by low density or microporous domains that are the result of thin walls of curved graphene sheets that enclose a high proportion of voids. There is no preferred order in this type of region. The state of ordering of graphene layers, and therefore the domain structure, varies with fiber type. It is believed that the shape of these domains is dependent on the pitch precursor and processing conditions. As a result of these different domains, the fiber's properties such as strength, stiffness, strain, and work to fracture will be affected [J.D. Fitz Gerald, *International Symposium on Carbon*, Tsukuba, Japan, p. 308 (1990)]. It is interesting that this group does not agree that their domains are equivalent to Dr. Oberlain's (CNRS, Pau, France) definition of the basic structural unit (BSU). The presence of microporous domains in any significant amount affects both fiber strength and modulus adversely. Pitches without isotropic material may have comparatively coarse mesophase domains. Complex flow during spinning will distort this structure which, in turn, will change the work of fracture of the fiber by inhibiting the propagation of cracking. It is concluded from this research that the size and distribution of both dense and microporous domains are among the most important factors influencing fiber strength and its other physical properties.

The identification of variable densities in fibers is considered significant with respect to the lamellar structure that is observed in matrices of C/Cs. When they are polished and ion etched, it has been shown that the density of the lamellar structure increases as the matrix becomes more graphitic [R. Meyer et al., *Extended Abstracts*, American Carbon Society (1981)]. Until now, the regions between these lamella have been considered to be of a lower density solely on the basis of the etching characteristics by ions, which produce grooves that are observed at high magnifications with the SEM. But there has not been any clear evidence whether this interpretation is correct until now, where variable densities have been identified by Taylor et al. in regions that are much smaller than those that exist in the matrix. Thus, it seems most likely that the lamella are high density regions that are in the graphitic state, whereas the grooves between the lamella are of a lower density and more susceptible to being etched by the impinging high velocity ions.

The Australian and French groups appear to be the largest efforts that are devoting a major portion of their research time toward obtaining a better understanding of the structure of fibers. Other, but smaller, efforts are being conducted by Prof. Endo (Japan) and Prof. Johnson (United Kingdom). The research work of both of these investigators is described in other sections of this report.

Other areas of research that are underway or being considered at this institute in the future are:

- The effects of quinoline on the development of mesophase
- The use of heteroatoms to form new carbonaceous materials
- Controlling the rheology of pitch to improve its spinning properties
- The use of ultrasonic interferometry as a means of evaluating defects in C/Cs

Assessment

The research that is being conducted at this university is excellent. It is expected that it will be continued for many years to come as the group is relatively young with the exception of Prof. Taylor. But, he expects to continue this work for at least another 3 to 4 years and to pass on to the rest of the team his knowledge and enthusiasm for this research. When asked about collaborating with organizations and universities in the United States, Taylor felt that there were a number of possible areas of common interest where such activities would be beneficial. It is recommended we do so.

COMMONWEALTH SCIENCE AND INDUSTRIAL RESEARCH ORGANIZATION (CSIRO)

Division of Coal and Energy Technology
51 Delhi Road
North Ryde, NSW, Australia
Tel: (02) 416-8211
Date: 14 Mar 1991

Background

Dr. Alan Buckley was my host for this visit. He is the head of a group that is composed of three staff and three support persons whose research activities are concerned with the development of coal tar pitch for fibers and for binders that are used in electrodes for the aluminum industry. A large Australian industrial organization is now running a fiber producing pilot plant based on the recommended process conditions that have been developed by this group. The purpose of this research is to determine if domestic fibers can be economically produced. Currently, the intent is to use the fibers in plastic matrix composites. As part of the group's responsibilities, techniques have been developed for improving their capabilities for characterizing different types of pitch by nuclear magnetic resonance (NMR) measurements. This research work was initiated more than 15 years ago.

Prof. Taylor was in this organization when he discovered the mesophase state within pitch that had been derived from coal.

Program Status

Special equipment was developed for performing the NMR measurements. Apparently, this equipment has been performed so successfully that CSIRO is now marketing and selling it.

Some of the characterization information of the different types of pitch includes:

- Variations of NMR signal as a function of temperature for different types of pitch.
- The thermotropic properties of the different types of pitch as the temperature is changed through the range of 300 to 600 °C.
- The hydrogen and quinoline content of the various types of pitch. In fact, Buckley considers the precision of these measurements to be within 2%, which he believes to be better than the Japanese are obtaining with the use of carbon 13. Therefore, it is possible to monitor the transformation of the pitch during pyrolysis.

Fibers are being developed that are derived from Australian coal and their properties are being compared to fibers whose precursor is A240 from Allied Chemical. Generally, all of these fibers have diameters of 8 to 12 microns. They have found that the texture and shape of the fibers are dependent on the chemical content and rheology of the precursors as well as the shapes of the different spinning orifices. The different types of fibers are compared to one another for tensile strengths after being heat treated at 600 to 800 °C. Their moduli and strengths are in the mid-range of those found for pitch-based fibers and their strain values are about 1.5%.

NATIONAL PHYSICAL LABORATORY

K.S. Krishnan Road
New Delhi 110012, India
Tel: 586086
Fax: 91-11-575-2678
Dates: 15-22 Mar 1991

Background

My host was Dr. O.P. Bahl, who is the assistant director of the National Physical Laboratory (NPL) and is in charge of the Carbon Development Program, which is in the Materials Division. NPL is organized into three divisions: Standards for India, Materials R&D, and Material Characterization. The carbon effort started at NPL more than 30 years ago and was concerned with the development of processes for the production of electrodes for batteries and for steel production. In addition, the development of new forms of carbon was added in 1972 as a major thrust area. Currently, this includes the development of carbon fibers, C/Cs, intercalation of graphites, glassy carbon, densification methods, and the characterization of different pitch systems. Research, development, and prototype studies are used to accomplish the primary goal of allowing India to be self-sufficient. The approach is to develop the processing methods at NPL and assist industry in establishing production capabilities on an economical basis.

Bahl's R&D group consists of 8 scientists, 4 research assistants (students), 1 laboratory assistant, and 12 technicians, plus office support. Frequently, this group must carry their developments through the prototype stage and make kilogram quantities of the material that they have developed in order to convince the industrial management that the process is practical. Another major customer for the efforts of this group is space and defense agencies of the Indian Government.

Development projects undertaken at NPL in the carbon group are then turned over to Indian industry for production and utilization on a national scale. One of these projects was for the production of highly compressible (400%) sheets made of natural flake graphite for use as gasket material from room to high temperatures. This material is processed by using rhenium as the intercalation medium, which greatly expands the flakes of natural graphite. This project was turned over to industry in 1990 after 2 years of development.

Other carbon activities that are ongoing in India include:

- Indian Institute of Technology (IIT), New Delhi (the role of interfaces in carbon fibers, acoustic emission and fracturing behavior, thermal characteristics of carbonaceous systems)
- IIT, Bangalore (nondestructive evaluation, fatigue, impact)
- IIT, Powai (fracture toughness)
- IIT, Kanpur (fracture behavior of notched samples, toughness, cryogenic properties)
- Aeronautical Development Agency (carbon fibers in organic matrix composites)
- Defense Research and Development Laboratory (weaving 3D, 7D, 11D; aircraft brakes; C/C nose tips for AGNI system)
- Indira Gandhi Center for Atomic Research (influence of defects on the properties of C/Cs, thermal imagining for the detection of defects)

The primary technology thrusts in India are defined by the Council of Science and Industrial Research.

Program Status

1. The development of high strain PAN-based fibers:

- Modification of plasticizer for use with the PAN precursor (Courtaulds) and adjusting the stabilization portion of the processing conditions between 270 and 340 °C
  - Increased the strain capacity from 1.3% to >2%
  - Modulus 33,000,000 psi (225 GPa)
  - Strength 610,000 psi (4.2 GPa)
- Prototype plant for the development of fibers; 200 g per day which was started in 1986 and finished in 1987:
  - Process gives textile grade fibers for industrial consumption
  - Methods developed for sizing, oxidizing, and incorporating functional groups on the surfaces of the fibers for special bonding applications

2. The densification of C/Cs to 1.9 g/cc without the HIP method:

- Six pyrolysis cycles with two graphitization cycles to 3,000 °C

- Phenolic rigidization
- Pitch impregnation at 300 psi, wrap in aluminum, and heat very slowly (<10 °C/h between 300 and 550 °C)

- Yarn spacing 1.5 mm
- Billet size 400 by 400 by 200 mm
- Characterization and modification of coal tar pitches for C/Cs

3. Development of high density and strength isotropic graphites
4. Glassy carbon development that is now being manufactured by the company "Graphite India"

Another project that is currently being undertaken is to understand the intercalation kinetics of fluorine in different carbon systems to develop high energy electrodes for use in batteries. One of the candidate materials for this project is the use of carbon fibers in the electrodes. The Electrochemical Institute of India will manufacture batteries after they have been developed at NPL.

They are just starting to do research in oxidation protection. The studies are concerned with the differential thermal expansion effects between the silicon-based coatings and the C/C substrate. They are considering putting a thin transition layer to accommodate more effectively the expansion problem. They are also considering the use of the sol gel process as an economical method of depositing coatings.

NPL's collaboration activities are as follows:

- Bahl did research in 1984 with Prof. Donnet of France on the plasma etching of fiber surfaces.
- The Indo-French Center for the Promotion of Advanced Research was established.
- One of the staff members was sent to Dr. Marchant's laboratory in Bordeaux, France, to study intercalation phenomena.
- There is close collaboration with Prof. Fitzer of Germany, Dr. LeHay of France, and Prof. Inagoki of Japan.
- Bahl is going to Rumania for 4 weeks to help them start a carbon fiber program.
- The director of NPL expressed a strong desire to have collaborative programs with the United States. The current efforts through the National Science Foundation have taken more than 3 years. He is interested in shortening this time by going through the Office of Naval Research. One possibility is that NPL could make samples that would be sent to the United States for characterization and study of the phenomenology influencing the structure. He desires to send his people to the University of California at Santa Barbara.

Assessment

This organization has shown itself to be resourceful and imaginative in selecting and accomplishing its research objectives. These objectives have covered the most important aspects of the technologies that are necessary for the processing of C/Cs. Considering their progress over the last 10 years, it is recommended that communications be continued with the Carbon Group to keep track of their progress now and in the future.

GENERAL ASSESSMENT AND SUMMARY

Why Consider C/Cs as the Material of the Future?

C/Cs are currently used for specialized applications where high strengths and stiffness properties are desired at elevated temperatures. Examples of such applications include dies and radiation shields for industry, gas diverter fins for aircraft, nose cone and leading edge protection surfaces for the shuttle, and nose tips and exit cones for military purposes.

There are other applications for C/Cs now beginning to emerge such as for artificial limbs and implants in humans, where high specific strength and inertness of carbon in the human body are desirable; as substrates for semiconductors, where the heat that is generated within the chips is rapidly conducted away by the high conductivity C/C; for antenna dishes, where the excellent electrical conductivity and thermal dimensional stability properties are used; and for radiator panels for space systems, where the high thermal conductivity of C/Cs provides an excellent means for thermal management. Furthermore, this material's excellent thermal shock resistance property, very high sublimation temperature, and chemical purity make it a prime candidate for diverter plates in fusion reactors.

In the future, it is expected C/Cs will be used for:

- Turbines for aircraft engines
- Hot structures for space craft and aircraft
- Structural members and solar energy panels for space systems
- Undefined applications because the optimum properties of C/Cs have not yet been defined or obtained

There is a concerted effort throughout the world to find other applications for C/Cs. One of the two major obstacles that is preventing the full utilization of C/Cs is the lack of a method for protecting it from oxidizing in air at elevated temperatures. The second obstacle is that there is limited fundamental knowledge on how to develop the full capabilities of C/Cs for meeting special engineering requirements where specific properties are required. But such improvements frequently mean a further refinement and optimization of processing conditions through a better understanding of how they must be adjusted to obtain the desired physical properties on an economical basis. This understanding is derived from information that can only be acquired by conducting additional research. Significant investments must be made in time, talent, and equipment, all of which are in short supply. Thus, it behooves U.S. investigators to understand what research activities are being conducted abroad so as not to duplicate the European or Asian efforts and to use this information to complement the overall research efforts in the Office of Naval Research (ONR), the Department of Defense (DOD), and the U.S. scientific community.

Research Activities in Asia

Fiber Development for Use in Preforms. Generally, all the organizations that were visited used fibers in their composites that were primarily obtained from Japan or the United States. Several industrial-sponsored fiber production facilities were visited in Japan because it is believed that their research and development activities are an important part of the available research data that also come from the universities and government laboratories.

Numerous research and related technology activities in the foreign countries are concerned with the development of carbonaceous and graphitic fibers from pitch-based precursors and to a lesser extent fibers that come from PAN. The exact reasons for this emphasis are not specifically known. One possibility is that sufficient information is known about the PAN system and how to improve the quality of the fibers. Another possible factor that may limit general research efforts on PAN is this fiber is being successfully used throughout the world, so a majority of the research is sponsored by the producers. Naturally, any of their research findings are being withheld from the public; thus, other researchers are reluctant to enter this area because the proposed research may have already been done. Consequently, only a limited amount of additional research is being funded either by industry or the government for making further improvements to the physical properties of the fiber or by universities for investigating new concepts. In contrast, the pitch system is not as widely used in the world market because it is more expensive to produce compared to PAN-based fibers. Therefore, a real incentive exists for conducting research to understand the fundamental reasons for improving the processing procedures and lowering costs or to upgrade the properties of the fiber so that it can become more cost effective. At this time, the information that is derived from such research remains largely in the public domain because no clear breakthrough is imminent that might give one industrial producer an advantage over the others. In fact, a number of industrial firms in Europe and Asia are giving small grants to universities for them to conduct exploratory research with the hope that new approaches and solutions can be found for the problems that are now identified.

The purpose of the research for different pitch systems is to understand the mechanisms that cause the formation of the various types of microstructures and physical properties that are in the carbonaceous and graphitic fibers. For example, the high modulus and strength values are due to the well aligned layer planes of graphite. These may be planar or crenelated and have radial, concentric, or other orientations as viewed in the transverse sections of the fibers. Their different microtextures depend on the source of the fiber precursor, which is usually a coal or petroleum pitch, and the processing conditions. The sequence of formation of these microtextures is complex due to the large number of different chemical compositions and how these interact with each other as the heat treatment proceeds. But understanding this phenomenon is important if specific types of microstructures are to be produced in the fibers. So numerous investigations are underway for the purpose of determining the compositions of the different pitches and how they are affected by different pyrolysis and extrusion conditions (Koa Oil, Japan). Parameters that determine the ultimate microstructure of the fibers include the molecular weight, rheology, and viscosity characteristics of these pitches, which influence the flow characteristics of the pitch as it passes through the orifices during the spinning operation. Extensive studies are also being undertaken to understand the nature of the microtextures that are developed during the spinning operation. By carefully identifying the types and distributions of the defects that are produced during the spinning, the processing conditions can be altered to minimize the defects to the point that the specific moduli and strengths can exceed that of PAN fibers, which is a highly unusual situation (Shinshu Univ., Japan). Upon heating the fibers to graphitization temperatures, the anisotropic phase will be highly oriented whereas the isotropic phase will show a poor degree of orientation. The different combinations of these phases within fibers result in variations of the fiber microstructure, which is important in determining its mechanical properties (Nippon Oil, Japan). Graphite fibers, from either acrylic and rayon precursors, can have mechanical properties of 600 kpsi strength and modulus and strains of >90 Mpsi and >2%, respectively (Toho Rayon Co., Japan). With other precursors, such as pitch, some of these properties can be altered to obtain even larger values. But fibers become more expensive as their properties increase in value. Expense is the main reason that PAN fibers are used more than pitch fibers. Their cost must be reduced by 50% to 100% before they will be competitive with PAN fibers. Studies are also being conducted to find alternative and cheaper precursors for PAN-based fibers (Feng Chia Univ., Taiwan; National Physical Laboratory, India). Some experimental types of fibers are being made with hollow centers, star shapes, etc. in the laboratory to determine if the larger surface area fibers will bond better to the matrix or perhaps be stronger. At this time the processing conditions are being determined to obtain uniform cross sections so no data are available (Chungnam National Univ., Korea).

The general assessment of the status of the R&D on fibers is that there are numerous organizations that are making significant and sometimes unique contributions toward a better understanding of the complex phenomena that take place during the formation and processing of these fibers. Without question, Japan is ahead of the world in developing and producing carbonaceous fibers and will probably maintain this position in the future because of the large technical and financial investments that are being made in this area. Other countries, like Taiwan, Korea, and India, are working towards producing their own fibers for internal consumption and possibly for export.

Weaving of Preforms. The preforms that were seen during the site visits in Asia usually contained yarns that are woven into 2D or 3D orientations. The 2D cloth materials are usually impregnated with a polymer and processed into preforms by conventional procedures, either as layups by layers of cloth or tape winding. In the case of 3D preforms, a unique method has been developed, over the past 10 years, of weaving by an interlocking stitch different shapes, i.e., cubes, rectangles, tubes, cylinders, Ls, or Ts (Research Institute for Polymers and Textiles, Japan). The yarn spacing can be varied from 0.7 mm (0.028 inch) to 3.2 mm (0.128 inch) and the preforms can be woven with high modulus carbon as well as with silica yarns. This method has now been licensed to a Japanese industrial firm that has scaled up and refined the method. This company wants to continue to reduce the cost of weaving by another 25% to 50% (Shikibo, Ltd., Japan). This method of weaving is different because the z orientation yarns are endless as they exit from the preform, loop back, and reenter it. The refinements to the method of weaving allow yarns to be oriented at 0°, 45°, and 90° and to be added or subtracted from the weaving pattern. These capabilities permit many different shapes to be woven such as a turbine wheel, where the curved blades are an integral part of the hub. The finest weave I was shown was a 12-inch cube of 3D where the yarns were spaced 0.5 mm apart (Chung-Shan Institute of Science and Technology, Taiwan). This is a refined weave that is comparable or slightly better than any preforms made in the United States or Europe.

The general assessment about weaving is that in Japan, and probably elsewhere like Taiwan and China, organizations exist with capabilities of weaving any configurations that are required by the design. There was no opportunity to determine what types of research are being conducted in these organizations for designing improved weaves through computer analysis.

Methods for Densifying Preforms. The next step in the fabrication procedure for making C/Cs is to densify the woven preforms by impregnation methods that use either liquids or gases to fill the voids that exist between the fibers and yarns. Impregnation is followed by heat treatment to form a carbonaceous matrix around each fiber and in-between the yarns. Usually the impregnation and heat treatment cycles must be repeated a number of times to attain the desired densities of the C/Cs. The physical property of each preform is determined by the fiber type, the architecture of the yarns, and the interaction of the fiber with the matrix. This latter parameter, the matrix, is controlled by the microstructure which, in turn, is a function of the processing conditions such as whether the preforms are permeated with liquid or gases (Toho Rayon Co.). It is important to understand what mechanisms are occurring during the heat treatment step that control the formation of the necessary microstructures in order to acquire the desired properties of the C/Cs and also to fully utilize the mechanical properties of the fibers (Nippon Oil Co.). Today, even after more than 25 years of making C/Cs, this utilization factor is usually less than 65% of the strength the C/C should have based on the strengths and volumes of fibers that are contained in the C/C. Furthermore, this value is far less than the >90% that exists for the polymeric matrix types of carbon fiber containing composites. This difference of utilization factors means there is a good possibility for improving the properties of C/Cs provided the proper yarn architectures and types of matrix microstructures can be identified and produced. Therefore, numerous research activities are being undertaken to achieve better performance of C/Cs (Nippon Steel, Japan; Beijing Research Institute of Materials, China).

The liquid impregnation method is one of the two major procedures for the densification of C/Cs. The liquids used are normally derived from organic precursors like a phenolic or from pitch that is derived from coal or oil. In general, pitch is preferred because a larger variety of microstructures can be derived from it. The conversion of pitch to carbon takes place by a process of pyrolysis where there is evaporation of low molecular weight species as the temperature is progressively raised. At higher temperatures, on the order of 350 to 425 °C, cracking reactions occur followed by evaporation of volatile fragments that mainly result from the thermal scission of aliphatic side-chains to polycondensed aromatic ring structures. The polynuclear aromatic radicals produced are quite reactive and combine to form planar aromatic ring structures of even higher molecular weight and aspect ratio. These will have an influence on the viscosity and rheology of the pitch which, in turn, will determine how well the pitch enters and impregnates the woven preforms. As pyrolysis is continued, an alignment of these planar ring molecular structures will occur and the liquid or mesophase state of the pitch system will develop. It is at this stage of the transformation of pitch to carbon that the ultimate microstructure of the matrix is determined (Shaanxi Nonmetallic Material and Technology Institute, China). It is for this reason that a great deal of research effort is being directed toward understanding the nature of these pitch systems and the influence on the mechanical properties of C/Cs (Toyohashi Institute of Technology, Japan). Numerous research investigations are concerned with the chemical composition of these mesophase systems and how chemical additives influence the polymerization, carbonization, and graphitization steps and control the grain size and orientation of the matrix microstructure (Hokkaido Univ., Japan; Univ. of Kyushu, Japan; National Physical Laboratory; GIRI Kyushu, Japan). Microstructure, as it is used in this report, means the inclusion of the pores and cracks that exist in C/Cs. Research has shown that controlling the size and distribution of the pores can have a profound influence on the mechanical properties of C/Cs. The concentration of pores can be altered by properly heat treating C/Cs. This capability is useful for it can be used to increase the toughness values of the C/Cs (Toyohashi Institute of Technology). Cracks can be distributed either within the matrices or at the interfaces between the matrix and the surfaces of the fibers or yarns. A significant amount of research is being undertaken to understand the phenomenology of bonding between fibers and matrices as it is important to know how to properly adjust the degree of bonding to fully utilize the strengths of the fibers (Tokyo Institute of Technology, Japan).

The densification of preforms to a density of 1.9 g/cc by liquid impregnation is usually considered to be accomplished by good processing methods and the use of a high pressure autoclave. These kinds of billets were seen in Japan (Nippon Steel), Taiwan (Chung-Shan Institute of Science and Technology), and China (Beijing Research Institute of Materials and Technology). In the latter case, this institute has various size autoclaves for processing preforms. The largest is 18 inches in diameter and >36 inches long and is comparable to the maximum size that is processed in the United States. However, in India, preforms are being processed to nearly 1.9 g/cc density with six or seven impregnation cycles without the use of a high pressure autoclave! To my knowledge, this is an achievement that has not been done before and represents a real breakthrough because the cost of processing C/Cs will be reduced by the elimination of a very expensive autoclave. Equally important, there is no size restriction on the sizes of the preforms that can be processed due to the size of the autoclave (National Physical Laboratory).

The second major procedure for the impregnation of C/Cs is to deposit carbon by the chemical vapor deposition (CVD) method onto the walls of pores of the preforms. This method is the best for its ability to fill pores that are too small for liquid pitches to enter. Consequently, C/Cs that are densified in this manner have slightly higher mechanical strengths than those processed by liquid pitch. However, one of the major difficulties in using the CVD method is that the deposited carbon is not deposited uniformly through the preform if it is too thick. Therefore, special attention needs to be given to the processing conditions by understanding the phenomenology of gas diffusion and carbon/graphite deposition on the various types of pore distributions that exist in preforms (Nippon Steel). The time to fully densify large preforms can be hundreds of hours, which is very costly unless large quantities of materials are being processed at the same time, such as brake disks. Not many fabricators are using the CVD method because of the limitations of density gradients and long processing times unless large quantities or sizes of preforms are used.

The general assessment of impregnation processing technology is that significant capabilities exist in Asia and India for the densification of all types and sizes of C/Cs. Furthermore, these capabilities are being guided by research that is concerned with the nature of the liquid or gaseous precursors, the phenomenology that controls the type and distribution of the matrix microstructure, the use of optimum processing conditions, and how the matrix interacts with the fibers/yarns that it surrounds.

Characterization of C/Cs and Optimization of Properties. The physical properties of C/Cs are determined by the type and the architecture of its fibers and how these are bonded together by the various kinds of matrices that exist in each type of preform. To be able to select the optimum combinations of processing conditions, characterization methods must be available to properly evaluate the performance of the constituent parts of the C/Cs as they are being subjected to thermal-mechanical stresses. The usual practice of characterizing C/Cs is to measure their mechanical properties and correlate any variations of these with changes of the processing conditions. Sometimes, the microstructure of test samples will be examined by optical or SEM methods after the samples have been fractured. Now more detailed fractographic experiments and theoretical analysis are being conducted to understand and model the fracturing behavior of these C/C materials (Toyohashi Institute of Technology; Tokyo Institute of Technology).

Combinations of methods are being used for conducting evaluations of the microstructure of fibers at the molecular size of magnification (Australian National Univ.). This is important information if the physical properties of the fibers are to be improved by the elimination of defects in their microstructure. The various experimental methods that are used include SEMs, TEMs, optical microscope, x ray, Raman spectroscopy, and electrical and thermal diffusion characteristics. Information from these various sources can be added by computer-aided analysis, resulting in an image of the sizes and distributions of the defects in a fiber. Variations of these defect distributions are compared to the processing conditions in order to select the optimum conditions for minimizing the defect problem (Shinshu Univ.).

The benefit of C/Cs is its ability to have high strengths at temperatures over 2,000 °C. But such characterization measurements are difficult to make, so only a few organizations are conducting such research (Tokyo Institute of Technology).

The optimum properties of C/Cs can be obtained more quickly and economically by understanding the microstructural factors that control the fracturing behavior. This is best achieved by using a combination of experimental data and theoretical analysis to select an optimum type matrix microstructure. But at this time only a small amount of research is being conducted for this purpose as has been indicated from the above information.

Capabilities found in the organizations visited for conducting nondestructive evaluations (NDE) of C/Cs consist of the usual x ray and ultrasonic procedures that are used in most U.S. production organizations. No information was obtained concerning advanced technology such as computer-aided tomography, thermal mapping, or other advanced techniques. This is a surprising situation especially for large and advanced organizations in Japan. Perhaps these organizations do not believe these advanced techniques are cost effective.

The general assessment of this last step in the fabrication of C/Cs is that there are important research programs being undertaken to determine the contributions of the constituents of C/Cs to their physical properties. Consequently, there is a capability for selecting optimum processing procedures for obtaining the desired engineering properties. It appears that the NDE capabilities in these countries are of a good quality to meet the needs for production purposes. But more advanced NDE technology and related research do not appear to exist.

Protection of C/Cs Against Oxidation. Protecting C/Cs against oxidation at elevated temperatures is a major factor in maintaining their mechanical properties. Although research about oxidation and its suppression is not a prime objective of this study, such information is included in this report because of its importance to the future applicability of C/Cs. At least half of the 32 organizations that were visited are concerned with the phenomenology of or developing methods for inhibiting oxidation effects on C/Cs.

Silicon carbide (SiC) is the material normally used to coat C/Cs to protect them from oxidation and it has been used for almost 20 years on the shuttle. One of the major problems with this system of protection is the differential thermal expansion effects between SiC and C/Cs that cause cracks to develop in the coating as it is thermally cycled, thereby reducing its ability to protect the C/Cs. Therefore, current research and developmental efforts are attempting to overcome the cracking problem by applying more than one layer of coating to the C/Cs (GIRI Kyushu). Another approach is to form layers on the substrate that have various thermal expansion coefficients (Kobe Steel, Japan).

The general assessment is that there is a lot of research and development effort being directed to finding a method for protecting C/Cs against the effects of oxidation. This opinion is based on a limited amount of information and therefore additional information should be obtain to be sure this assessment is representative.

Factors That Enhance Asian Research Activities

Collectively in Asia, the capabilities now exist through proper research efforts for acquiring the necessary information to develop advanced C/Cs. In the future it is expected these collective capabilities will have a very significant influence on the utilization and production of C/Cs in the United States and throughout the world. This expectation is made on the basis that in time these Asian countries, especially Japan, will be able to concentrate and coordinate their research and development efforts more effectively either on a national or international basis. In addition to Japan, a number of countries, such as Taiwan or India, would like to export their materials. The major question is how well can the capabilities of these countries can be integrated into effective research and development programs? A certain amount of duplication of effort naturally occurs between the different countries, but this is partially mitigated because there is usually a difference of interest and expertise even in the same research areas.

Other nontechnical factors are being used to enhance the collective research capabilities of these countries, including:

- Communication links that are well established and are frequently used between investigators, organizations, and societies on national and international levels. For example, there are strong communication links within Japan and between the French and the Japanese in the carbon and ceramic areas.

- National coordination of research efforts to insure that they are complementary to attain the general objectives of the program. This is best illustrated by the reviews and planning sessions that are held in Japan, under the sponsorship of MITI, between industry and government laboratories. In addition, there are the monthly meetings of the New Carbon Forum or the 117 Committee that are sponsored by the Japanese Society for the Promotion of Science.

- Collaboration between different researchers and organizations on a national or international basis. There is a large source of information available to the United States because all of the 32 organizations, including China, that were visited want to collaborate with us. The level of collaborative participation is dependent on the needs of the researchers and therefore is determined on a case-by-case basis. This may be as simple as the exchange of data or as complicated as having visiting professors or graduate students. Sometimes these links for collaboration are established years earlier because many researchers in Asia did their graduate work at a foreign university.

- Collection of research information is a most important factor, especially with the wealth of C/C data that exists throughout the world. Methods for collecting information vary. One of the more efficient ways is to invite a foreign expert to stay for several weeks in your country with all expenses paid for by the host country. In recent years many countries have increased their support of foreign travel because it has been found to be a very cost effective method of obtaining research information.

The general assessment of this area is that these Asian countries are more effectively using the nontechnical factors (communication, coordination, collaboration, and collection) to augment and enhance their research capabilities than the United States.

Impact of Asian Efforts on U.S. Technology and Leadership

Near term (<5 years)

- The "relative" effectiveness of U.S. research efforts on C/Cs and related technology will diminish because of the increased efforts in Asia. Unfortunately, this problem is being compounded because the industrial and governmental sponsorship of U.S. research has been declining for the past 10 years. Unless there is a reversal of this trend "soon," a critical point will be reached where there is not enough research being performed in the United States to have a significant influence on the future development of advanced C/Cs. A current example of this situation is the National Aerospace Plane (NASP) program. It was forced, by time constraints, to use C/C materials that were developed many years ago based on research information that was obtained long before that. The total elapsed time may be as much as 15 to 20 years.

- The reduction of ONR and DOD funds for C/C research will have the additional effect of cutting back on the training of graduate students at universities in the field of carbon.

- The U.S. ability to be a leader of carbon research will decrease, so it cannot be the first to identify new opportunities or alternative approaches for developing advanced C/Cs and related technology. A prime example of this type of situation is a shift of the leadership in the area of carbon fibers to Japan during the last 5 years.

- The potential loss of U.S. leadership in the development of advanced C/Cs will also limit its capability to design and fabricate new and high technology equipment or systems for domestic and governmental purposes or for world consumption.

Long term (<10 years)

- It is expected the collective research efforts in Japan and the other Asian countries will improve and surpass in time the research activities in the United Stateds if the present financial support trend continues.

- Continuous cutbacks, for the reasons cited above, of research funds from ONR and DOD will mean fewer researchers at the universities will be interested in investing their careers or facilities in an area that appears to have no future growth. Consequently, fewer graduate students will be trained and our primary source of young researchers will eventually disappear. Then, the United States will have fewer qualified leaders in carbon research for identifying new developmental opportunities.

- The loss of technological advantages by the United States will diminish its domestic and world sales of C/Cs. This situation will result in a further loss of research funds, which are needed to remain competitive with the rest of the world. The United States stands a good chance of becoming dependent on foreign sources for its supply of advanced C/Cs. This is a serious problem because it limits the procurement of equipment essential for national defense purposes to foreign countries.

- The limitation of the U.S. capacity to develop and apply new types of C/Cs will greatly inhibit its ability to formulate high technology and long range plans for the use of C/Cs in future space systems, high performance and lightweight turbines, space planes for reentry, and other applications that have already been mentioned.

Recommendations for ONR and DOD to Capitalize on the Foreign Research Efforts

- Identify the areas of research that should be undertaken to meet ONR's long term goals for C/Cs. In defining the scope and objectives of these areas, consideration should be given to the present programs that are being supported by ONR as well as the pertinent ones in other DOD organizations.

- Determine what research information is needed to complete ONR's long term goals, and if the missing information cannot be addressed by support from ONR, other DOD agencies should initiate new programs. If this is not possible, can the desired information be obtained from research that is being conducted abroad?

- Find and establish methods of increasing the rate that foreign research information is acquired, evaluated and disseminated to the interested researchers. Organizations in Asia are using various means for acquiring the information including attending society meetings, inviting visiting scientists from foreign countries, accepting invitations to foreign countries, and establishing collaborative research programs on a national as well as an individual level where visiting scientists are exchanged for a period of weeks or months. It was found in discussions during this survey that the exchange of information with the United States could be greatly improved if U.S. research activities could be discussed without so many national security restrictions, especially when it is clear that both U.S. and foreign investigators are conducting the same type of research. This means better clarification of what specific information cannot be exchanged and not binding the U.S. researcher's hands with restrictions that use sweeping generalizations.

- Ascertain if collaborative efforts can be undertaken with the desired foreign researcher on a basis that would best serve both ONR and the research effort in Asia.

- Increase the coordination between the different U.S. research programs on a national and international basis. Enhancing communications in the United States is a vital component in achieving better coordination and improving the effective use of the funds.

Summary

- Foreign research activities encompass all the important areas for developing advanced C/Cs.

- U.S. research is not as broad in scope or in the degree of effort in numerous areas of research as that being undertaken abroad.

- Some of the foreign research activities are highly coordinated through enhanced communication procedures and collaboration activities with other European and Asian countries.

- U.S. research activities and the selection of alternative approaches can be improved by better coordination of our overall program directions, communication procedures, and timely evaluations of the specific objectives of current programs for their ability to meet ONR's long term goals.

- Practically all foreign organizations want to collaborate with the United States as they are already doing with other foreign countries.

- There is significant foreign information and laboratory capabilities available to the United States to enhance its research efforts. Methods should be actively considered for taking advantage of this situation.

- Time is running out for the United States to take corrective action through more support of research activities if it wants to maintain a leadership role in the developmental, technological, and engineering applications of C/Cs.

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FIRST WORKSHOP ON THE YELLOW SEA EXPERIMENT (YESEX-1)

The Yellow Sea is an extension of the Western Pacific Ocean bordered by China, Korea, and Japan. It is open to the south via the East China Shelf Sea, which is screened from the open Pacific by the Ryukyu Island Arc. The Korea Ocean Research and Development Institute (KORDI) has proposed the Yellow Sea become an international full-size test laboratory as an outgrowth of the Korean program of real-time coastal monitoring and prediction initiated in 1991. To test the feasibility of this concept and to bring together workers and knowledge about the Yellow Sea, KORDI sponsored an international workshop, YESEX-1, at Seoul National University on 10-11 April 1992. The technical sessions included Marine Environment of the Yellow Sea, Research for Coastal Development, Coastal Prediction Models, Coastal Environmental Studies, and Technologies for Coastal Monitoring Systems. Brief summaries of the papers given at this workshop are presented.

by Pat Wilde

INTRODUCTION

With the emergence of South Korea as a modern industrial state, it became obvious that due to its long coast line compared to its surface area, many types of maritime activities are conducive to economic development. To foster coastal development and at the same time to prevent environmental degradation of the coastal zone, Korea has established an Integrated Coastal Monitoring Network. Korea has two different coastal zones. The east coast is bounded by the relatively deep East Sea (Sea of Japan), which is opened to the north to the Sea of Ohkotsk and to the south via the Tsushima Straits to the East China Sea. The west coast is bounded by the shallow Yellow Shelf Sea, which is only open to the south where it merges into the East China Sea. These two coastal zones are significantly environmentally and oceanographically different to pose separate problems with respect to monitoring and modeling strategies. Also, natural phenomena related to these areas are functions of processes that are multinational in origin, so they could not be studied properly with cooperation of the nations with common oceanic borders. Accordingly, the Korea Ocean Research and Development Institute (KORDI), which is the primary governmental ocean research agency, has proposed an international program of study using the Yellow Sea as a full-size test facility. Besides the obvious benefits with respect to planning and development of the neighboring coastal states, the Yellow Sea is a relatively unique natural laboratory for the development and testing of both equipment and various numerical models. The attractiveness of the Yellow Sea as a natural laboratory stems from its shallow depth (44 meters mean), uniform fine-grained sediment cover, extreme tidal range (up to 9 meters), persistent monsoonal wind direction for most of the year, one major sediment source (Hwang-Ho River of China), and quasi-flume like shape. The First Workshop on the Yellow Sea Experiment (YESEX-1), which was held at Seoul National University (SNU) on 10-11 April 1992, was the initial effort to attract an international audience while summarizing prior investigations.

PROGRAM

Opening and Keynote Session

The introductory session, chaired by Prof. Choung Mook Lee of the Pohang Institute of Technology, set the tone of the meeting, emphasizing the importance of regional studies of this nature to both the global and local environmental scenes. The president of KORDI, Prof. Byoung-Young Park, noted that monitoring systems for warning and thus prevention or mitigation of marine and coastal disasters were a major United Nations effort.

Dr. Dong-Young Lee of KORDI and the principal organizer of the workshop outlined the "Development of the Integrated Coastal Monitoring Network and the Yellow Sea Experiment." He showed that a combination of various techniques was required, not only in-place and at-a-station instrumentation but also wide area real-time measurements such as wave properties from radar. The starting point would be 175 fixed stations already monitored by the Korean Fisheries Agency to obtain some historical record and data continuity. Such stations could be upgraded with additional instrument packages. He proposed to augment the instrumentation at some 350 light buoys already maintained for navigational reasons and to take advantage of ships of opportunity, especially ferry boats on fixed and sequential runs to relatively cheaply expand both the database and the time series. Additional new stations such as specially constructed instrumented towers and at-sea weather buoys, similar to the U.S. "monster buoy" program, were proposed as evolving options as the monitoring program grew. Dr. Lee stressed the salient features of the Yellow Sea that make it attractive as a research area: shallow depth, tide dominance rather than wave dominance, uniformly fine sediment cover, and relatively persistent winds during the winter monsoon. He mentioned that he has contacted marine groups in China at Tshingho, Shanghai, and Nanjing, all with positive responses in regards to potential Chinese cooperation in the YESEX project.

Dr. P. Kihlo Park of the U.S. National Oceanic and Atmospheric Agency (NOAA) put YESEX in the context of various international programs such as the United Nations International Decade for Natural Disaster Prevention and Oceanographic general surveys. Much information, he noted, may be obtained from the satellite databases, which offer estimations of many oceanographic parameters on the synoptic scale simply not available from individual station data. He showed some ocean color satellite pictures for different times of the year for the Yellow Sea and the Sea of Japan. The pictures displayed some anomalous features, particularly if the color was used as an indication of productivity, such as high winter productivity (see later talk by Dr. Yoo on color remote sensing).

Marine Environment of the Yellow Sea

Prof. Young-Ho Seung of Inha University of Korea opened the technical portion of the workshop with a talk on the physical oceanography of the Yellow Sea. He discussed the strong tidal influence on the total picture, noting regions of mixed, semi-diurnal, and diurnal tides. The general oceanographic picture is clouded by lack of systematic and long time series records. The best available series is from the Korean Fisheries research dating from 1961. Records from the Chinese side of the Yellow Sea are irregular. Since 1986, there has been formal cooperation among China, South Korea, and the United States. The basic winter circulation pattern is towards the open sea with a dominant northwest monsoonal wind. This produces a south-to-north slope as surface water is being blown out of the Yellow Sea. Maximum fresh water input from the Hwang-Ho River in China is in the summer. The general circulation pattern in the summer is not clear. There is controversy over the existence of a summer warm water current as an offshoot of the Kuroshio, which would penetrate the central Yellow Sea in the absence of the persistent winter monsoonal wind. In the late summer and fall, many typhoons blow in, adding to the mixing of the shallow sea. The exchange rate of heat and salt in and out of the Yellow Sea is not well understood as a result of the complicated circulation picture and the lack of real observations on a broad scale. Due to the strong tides, up to 9 meters, the coastal waters are well mixed and stratification is seen only in the central portions of the Yellow Sea. It is clear that the international efforts proposed in the Yellow Sea Experiment will clarify many of the unsolved oceanographic questions.

Drs. Dong-Beom Yang and See Whan Kang of KORDI gave an overview on the marine pollution of the Yellow Sea. The problems they identified include red tides and associated anoxia especially on the south coast and oil pollution with about 200 oil accidents per year in Korea. Some mean values of chemical parameters are:

Chemical oxygen demand (COD)	
West Coast	2.1 ppm
East Coast	2.9 ppm
Dissolved inorganic nitrogen	
West Coast	409 mg/L
East Coast	800 mg/L
Phosphorus	
West Coast	13
East Coast	33

Heavy metal concentrations are low and the copper measured in Project Musselwatch is considered safe. Cold bottom waters are poor in nutrients, while high salinity waters tend to be richer in nutrients. Korea will be involved in a United Nations program in measuring coastal nutrients in 1997.

The first technical session was ended by a summary talk by Prof. Yong Ahn Park of SNU on the sedimentation patterns at the eastern part of the Yellow Sea. The Yellow Sea coast line of Korea is unique as it is uniformly fine grained with little or no sand-sized material. This is generally not found in regions of such high tides. On the Korean side, Holocene mud lies right on the bed rock. Sediment transport varies with the season, with along-shore movement in the winter, probably related to the northwest monsoonal winds and offshore transport in the summer. Most of the material in the Yellow Sea originally came from deposition from the Hwang-Ho River in China. The clay material from China is high in smectite (montmorillonite-swelling clay), whereas clay from the Korean Peninsula is high in chlorite (metamorphic rock) and kaolin (granite source). Near Korea there is not much evidence of a significant Chinese source of sediment. Since 1855, the Hwang-Ho has emptied into the Bohai Sea, an arm of the Yellow Sea north of the Shandong Peninsula. There, most of the sediment is trapped before reaching the eastern and central parts of the Yellow Sea.

Research for Coastal Development

This session concentrated on more ocean engineering related activities and included a report on Russian activities in wave monitoring, outside of the Yellow Sea, which have an implication on the type of modelling and measurement programs that might be proposed for the Yellow Sea Experiment. Drs. Sand Hyun Park and Chang Kyoo Park of the Hydraulic Laboratory of the Korean Rural Development Corporation reported on the hydraulic model test on the Seamankeum tidal land reclamation project. This would be a typical example of how field information from the YESEX project would be used in the development of Korean coastal regions in this area of high tidal flow. The project is to reclaim just over 40,000 hectares of tidal lands with a 29-km-long sea dike. Two types of models will be used: (1) analog hydraulic scale models to be built in a 100- by 100-meter shed and (2) two-dimensional numerical models. The proposed model has the following scales:

Horizontal	1:500
Vertical	1:80
Velocity	1:8.9
Time	1:55.9
Discharge	1:357,770
Roughness	1:2.5

Another applied paper was given by Prof. Isao Irie, of the Civil Engineering Department of Kyushu University, Japan. Irie talked on the recent development of port and harbor engineering in Japan. The discussion was on various innovative designs for multipurpose shore protection structures in Japan. The concept is for both expanded civilian use as well as conventional port protection in the coastal zone. Such designs also include artificial headlands; artificial multipurpose offshore islands; fish attractants; and combined sport fishing, sightseeing, and recreation facilities on breakwaters.

Dr. Alexander B. Rabinovich of the Institute of Marine Geology and Geophysics, of the Russian Academy of Sciences, Yuzhno-Sakhalinsk, discussed the investigation of long waves on the shelf of the South Kuril Islands and the Skurshex Experiment. The experiments were part of a study hoping to improve marine disaster prevention especially for tsunami on the open Pacific islands of Russia. The Skurshex Experiment is on Shitotan Island, which is one of the disputed islands seized from Japan by the Soviet Union at the end of World War II. Here research on seiches is being done with bottom-sitting pressure sensors placed in 1986. The concern is that resonant amplification of tsunami waves in the bays may be disastrous if it occurs in conjunction with seiching produced by other phenomena such as wind waves and longshore edge waves. These studies also are supplemented by the investigations of long waves, surf beats, and infragravity waves done off Kamchatka in 1987-88. Interpretation of the data uses sophisticated methods of conformable mapping of eigen oscillation values. Although the survey area was not in the Yellow Sea, the instrumentation, placement strategies, and analysis techniques could be used as prototypes for the Yellow Sea Experiment wave monitoring component.

Coastal Prediction Models

Dr. Sok Kuh Kang of KORDI, on behalf of his colleagues Dr. Ki Dai Lee Yum (KORDI), Prof. Sang Ryong Lee (Pusan National University), and Prof. Jong-Yul Chung (SNU), described the tidal computation of the seas adjacent to Korea. Their two-dimensional model uses a polar coordinate system with 11 cells. The M-tide model shows 1930 co-tidal lines and three amphidromes in the Yellow Sea. The diurnal tide has two amphidromic points. They would like to go to 100,000 grid points in future models. Thus far the question of the intrusion of the Kuroshio Current in the summer cannot be resolved. Actual field measurements are scarce and the need for an integrated tidal station network was emphasized. They do have a 2-km gridded model of the area near Pusan, which should resolve eddies not seen in the original model.

"Development of a Mixed Spectral-Finite Difference Model for Computation of Wind Induced Currents in the West Coast of Korea" was given by Dr. Jae Kwi So of KORDI with coauthors Kwang Soo Lee (KORDI), Kyung Tae Jung (KORDI), and Prof. Woo Jin Jung of Inha University. The model is a three-dimensional Davies type also in polar coordinates. Eddy viscosity is used in an attempt to do real-time modelling. In the present eigenfunction model the eddy viscosity is fixed in the vertical. For the winter monsoon case the wind stress is set at 1.6 N-m^2 from the northwest. For a low eddy viscosity of 0.0125 m^2/s, the wind energy is trapped at the surface and current reversals occur at depth. For a "high" eddy viscosity of 0.1 m^2/s, much more mixing occurs and the velocity profile is more uniform. The next steps are to: (1) vary the eddy viscosity with depth, (2) compare with field measurements, (3) use the mixed Davies United Kingdom base set, and (4) expand the scale of the model to the whole Yellow Sea. Prof. Chong Mook Lee of the Pohang Institute of Technology suggested in the question period that a moving pressure field might be added to augment the shear stress used. There also was a discussion of how to match the boundary conditions from the two-dimensional "big" model to the three-dimensional nearshore models of finer scales.

The next presentation was by Prof. Im Sang Oh of SNU for his colleagues Prof. Jin Kyung Lee (SNU) and Dr. Ki Chun Jeon (KORDI) on storm surge and wave hindcasting models and comparisons with field data at the Yellow Sea. This was a pilot study for YESEX done at the end of December 1991 off the west coast of Korea using wave height and tidal current information from several on and offshore stations. The hindcast models used were a finite difference two-dimensional storm surge and a decoupled shallow water wave type. The results show general agreement in phase and magnitude of computed sea level, but "some discrepancies" were found between calculated and observed waves. Swell was not considered in these models as only local atmospheric terms could be used.

The project organizer, Dr. Dong-Young Lee, and Dr. Ki Chum Jeon, both of KORDI, described plans for the development of a real-time coastal prediction system The goal is a real-time user input system, probably PC computer based, where a series of oceanographic/ocean engineering questions can be answered. Ideally the user gives the time/s of observation, location, and parameter/s requested and receives the answer through a computer search of the appropriate model or tables stored in the database memory.

Mr. Kyung Ok Ko of the Maritime Police and Dr. Sin Young Kang of the Korea Maritime University presented, in Korean, "Statistics of Marine Accidents in Korea and the Development of a Drift Prediction Model in Search and Rescue." Due to the increase in maritime accidents and as a result of international agreements concluded by the International Maritime Organization, Korea has revised its own search and rescue procedures. KORDI and the Maritime Police are working jointly on the use of drift prediction models in search and rescue and are identifying areas of risk through the compilation of marine accident statistics.

Coastal Environmental Studies

This session began with a general discussion of the sediment siltation process in coastal waters by Prof. Tetsuya Kusuda of Kyushu University, Japan. Tetsuya commented that four major areas of the world's oceans have extensive areas of cohesive mud bottoms: the Baltic-North Sea area of Europe, the Gulf of Mexico, Southeast Asia, and the Yellow Sea. His major concern would be transport underwater action, as the Yellow Sea has a shallow mean depth of only 44 meters. Sixty percent of sediment transport in such areas is in the transitory upper layer of the bottom where material is settling into the bottom. Below the mobile fluid Lutocline, where there is a rapid change in concentration of sediment, is a "stationary" layer overlying cohesive mud To produce mud erosion due to "to and fro" shear stress produced by wave action, the wave period has to be greater than 1.2 seconds. Otherwise the cohesive particles, which are ideally arranged like sheets of paper, cannot be lifted and eventually transported. The question of the relative importance of unidirectional flow (i.e., currents) as opposed to wave action with respect to erosion was discussed. The shear stress required for erosion is lower for wave action than for unidirectional flow.

Dr. Sinjae Yoo of KORDI reviewed efforts to interpret ocean color remote sensing of the Yellow Sea. The atmospheric interference, the in-water algorithm, and the calibration of productivity estimates via chlorophyll-A in-situ measurements were investigated. The atmospheric problem is due to the high proportion of dust from the Asian mainland and particularly from the Gobi Desert. Use of the National Aeronautics and Space Administration (NASA) standard clear water radiance method algorithm leads to misinterpretation of the satellite color pictures. Relative error estimates for productivity are from 200% to 960% in the Yellow Sea area, whereas the previous error estimations based on the commonly used algorithm were only 40%. This emphasizes the importance of site specific algorithm evaluation and the danger of reliance on some "universal" formula for satellite interpretation, particularly for parameters such as color/productivity that have a high atmospheric and water column variability.

Prof. Hang Soon Choi of SNU gave an overview on marine oil spill accidents and development of a short-term prediction model for oil spill spreading for his coauthors, Mr. Chang-Sup Lee of the Maritime Police, Prof. Choung Mook Lee of the Pohang Institute of Technology, and Prof. Kwang Joon Bai of SNU. This paper supplements the talk on drift prediction model use in search and rescue discussed earlier. The validity of calculating surface currents from a depth integrated model based on Ekman theory was questioned.

"Modelling of Coastal Currents and Pollutant Transport in the Western Coastal Water of the Yellow Sea" was presented by Profs. Young Jae Ro, Ik Hwan You, and Ki Won Song, all of Chungnam National University. The oil spill model is under development. The tentative specifications are:

Area	35 to 37° N. and 125 to 126.5° E.
X,Y grid spacing	3′
Time interval	720 s
Tidal components	12

The planned model is vertically averaged two-dimensional transient, using shallow water wave equations forced by water elevation at open boundaries. It is hoped that the model can be run on mini-computers such as a 386 or 486 PC.

Technologies for Coastal Monitoring System

Dr. Kwang Soon Park, for his coauthor Dr. Dong-Young Lee, both of KORDI, discussed real-time wave monitoring system of the Korea Maritime and Port Administration. The system, initiated in 1987, has eight basic stations in Korean waters, two of them in the Yellow Sea. The primary stations have a wave riding buoy, a directional wave gauge, and a pressure gauge. Data from the sensors are cabled to the beach, whereas data from the wave rider buoy are transmitted via radio.

New measurement techniques besides conventional at-a-station observations were reported by Drs. Soo-Yong Kim, Ki Bong Kim, and San Baek Han of the Korea Advanced Institute of Science and Technology (KAIST) in their talk titled "Present Status and Future Prospect of Ocean Current and Sea State Measurement by HF Radar." This was mainly on developments in other countries and the potential application to Korean waters.

"Measurement and Analysis of the Detail Directional Spectrum" was presented by Dr. Byung Cheol Oh and his coauthors, Drs. Jae Seol Shim and Kyung Soo Bakh of KORDI. This was a mathematical treatment of the data from a field study of wave spectra from the east coast of Korea, not from the Yellow Sea, but it was indicative of the approach considered for YESEX. Two type of wave gauges were used: (1) a Datawell directional wave rider buoy measuring heave, sway, and surge deployed in 38 meters of water and (2) a sensor (Pacer Systems) measuring subsurface pressure and two components of horizontal velocity, deployed in 11 meters of water. The Maximum Entropy Method was used to obtain the directional wave spectra. The spectral width in shallow water was narrower than in deeper water.

Dr. Hong-Rhyong Yoo of KORDI presented a slide show illustrating remote sensing techniques for studies on the Korean coastal environment. He emphasized the advantage in coverage using satellite data from NOAA, Lansat, etc. for pollution studies and general circulation and investigations of sedimentary processes in coastal waters. Studies are underway on the application of radar remote sensing (see above) and airborne ocean monitoring sensors to see how they might be integrated into the existing Korean coastal monitoring system.

The final talk of the session and of the program was by Prof. Yoon-Hae Ye of Kyunghee University discussing new technologies of ocean data measurement using optical fibers. He suggested that conventional measurement sensors for parameters such as temperature, pressure, turbidity level, etc. may be replaced by compact and reliable optical fiber sensors. Also, new parameters previously impossible or difficult to measure in the marine environment, such as chemical concentration, now might be monitored in real time using new optical fiber techniques.

Closing Discussion

Dr. Dong-Young Lee, the organizer of the workshop, after thanking the participants, closed the meeting by calling for innovative thinking and international cooperation in bringing together instruments, models, and analytical techniques to attack the problem of understanding such a system as the Yellow Sea. With such a good beginning he believed that a YESEX-2 workshop would be even more successful.

Papers presented by title only, but not given, are listed in the Appendix. These papers will be included in the workshop proceedings.

SUMMARY

The first Workshop on the Yellow Sea Experiment was a showcase for Korean scientists, engineers, and government agencies concerned with oceanic problems to demonstrate their approaches and activities. Unfortunately, the scheduled participation of Chinese scientists was prevented by the long lead time for them to obtain exit visas. Otherwise, except for North Korea, all the nations bordering on the Yellow Sea would have made meaningful contributions. The Yellow Sea Experiment is still in the formative stages, but the Korean approach of

expansion of existing monitoring programs and extension using relatively low cost ships, buoys, etc. of opportunity seems a proper evolutionary phase. As with other Korean scientific endeavors, the politically astute, intimate involvement of the government, academic, and private sector groups in all facets of the planning leads both to concrete results and general long-term programmatic stability, which are critical to the success of a project as vast and as complex as the Yellow Sea Experiment. The emphasis on the uniqueness of the Yellow Sea as a full-scale test facility to examine various oceanographic problems and models should attract workers from the international community not specifically interested in the geographic location of the Yellow Sea. The fact that such a multinational project is being contemplated seriously in an area associated with bitter local enmities and with large standing armies technically at war certainly is an indication of the value of marine research as a benefit to all nations.

Pat Wilde joined the staff of the Office of Naval Research Asian Office (ONRASIA) in July 1991 as a liaison scientist specializing in ocean sciences. He received his Ph.D. in geology from Harvard University in 1965. Since 1964, he has been affiliated with the University of California, Berkeley in a variety of positions and departments, including Chairman of Ocean Engineering from 1968 to 1975 and Head of the Marine Sciences Group at the Lawrence Berkeley Laboratory (1977-1982) and on the Berkeley campus (1982-1989). He joined ONRASIA after being the Humboldt Prize Winner in Residence at the Technical University of Berlin. Dr. Wilde's speciality is in paleo-oceanography and marine geochemistry, particularly in the Paleozoic and Anoxic environments. He maintains an interest in modern oceanography through his work on deep-sea fans, coastal and deep-sea sediment transport, and publication of oceanographic data sheets showing the bathymetry with attendant features off the West Coast of the United States, Hawaii, and Puerto Rico.

Appendix

PAPERS NOT PRESENTED

"Brief Introduction to Coastal Engineering in China," Asian Yak, Hah University, China.

"Research Activities for Marine Disaster Prevention at the Yellow Sea in China," Dunxin Hu and Fagao Zhang, Institute of Oceanology, Academia Sinica, China.

"NOAA Yellow Sea Project and Large Marine Ecosystem Program," Thomas L. Laughlin, National Oceanic and Atmospheric Administration, U.S.

"Studies of the Yellow Sea Using Remote Sensing Technology," Jiamin Hu, Institute of Estuarine and Coastal Research, China.

SUPERCONDUCTING MAGNETOHYDRODYNAMIC SHIP PROPULSION - A WORLDWIDE RESEARCH EFFORT

This article summarizes observations and opinions of many of the participants of MHDS'91, the International Symposium on Superconducting Magnetohydrodynamic Ship Propulsion, held in Kobe, Japan, 28-31 October 1991. As the most significant development within the topic area is the near-completion of the magnetohydrodynamic (MHD) experimental ship YAMATO-1, with the sponsorship of the Japan Ship and Ocean Foundation, a large portion of this article is devoted to a description of YAMATO-1. International activities in superconducting MHD propulsion are also updated. The author also provides his personal assessment of the state-of-the-art of the technology.

by Thomas F. Lin

INTRODUCTION

Since 1985, the Ship and Ocean Foundation of Japan has sponsored an extensive research and development project in superconducting magnetohydrodynamic (MHD) ship propulsion, resulting in the design and construction of the experimental prototype ship, YAMATO-1. Considering the ocean trading economic structure of Japan, this research and development initiative appears to be prudent. The MHDS'91 conference held in Kobe, Japan, at the end of October 1991, marked the completion of YAMATO-1's drydock construction. The Japanese hosts and international attendants not only joined together for in-depth discussions and exchanges on superconducting MHD propulsion, but they also visited YAMATO-1 at Mitsubishi Heavy Industry's Kobe shipyard. It was a unique occasion in one sense. That is, as the experimental ship was still on the drydock, visitors were able to closely examine the two MHD thrusters beneath the ship on both sides. When the ship goes on sea trials in the spring of 1992, a close-up look of the thrusters will be impossible. International participants were from China, France, Germany, Italy, Korea, Taiwan, the United Kingdom, the United States, the former U.S.S.R., and Yugoslavia. Japan by far contributed the most papers and was followed by the United States. Organizations representing the United States were Argonne National Laboratory, the David Taylor Research Center, the Massachusetts Institute of Technology (MIT), the Naval Underwater Systems Center, Newport News Ship Building, the Office of Naval Research Asian Office, Pennsylvania State University, Physical Science Inc., and Textron Defense Systems.

MHDS'91 MEETING

The 4-day meeting focused on the following five topic areas related to superconducting MHD ship propulsion technologies.

Specifics of YAMATO-1

The YAMATO-1 experimental ship, shown in Figure 1, was built to meet the marine architectural specifications as listed in the inset. The two MHD thrusters beneath the ship on both sides are the most visible features of the ship. They replace the conventional propellers for propulsion. The two thrusters were separately built by Mitsubishi and Toshiba Heavy Industries. Six parallel MHD channels arranged in a circular pattern were shrouded in the thruster unit, as shown in Figure 2. Each MHD channel has its own superconducting dipole magnet, electrode pair, and seawater passage. Since each thruster has only one seawater inlet and one outlet, flow division to and combination from the six MHD channels are configured internally. Each thruster produces 8,000 N of Lorentz force at a combined 4-T magnetic field and 4,000-A total electrode current. The six magnets in the thruster share the same cryogenics dewar and cryostat. The effective length of the active Lorentz force region is 3 meters. Each dipole magnet was wound with double layers of 1.82- by 10.86-mm NbTi superconducting cables.

The operation of YAMATO-1 will begin with the energization of the superconducting magnets on the dock. Once energized, the superconducting coils are maintained persistently and no more current charging by the power supply is required. Nevertheless, electricity remains necessary for the electrodes to pass current through the seawater. Two diesel generator units are placed onboard to provide the needed electricity for the source panels of electrodes. The speed of the ship is controlled by regulating the electrode current, while the maneuverability of the ship is controlled by distributing differential currents to the individual thrusters or by controlling the conventional rudder at the back of the ship. The control panel in the maneuvering room provides all these functions. Since diesel engines are used for electric power generation, which includes the power for liquid helium refrigeration, ventilation and silencing of the exhaust gas from the diesel engines are important considerations for safety and comfort.

YAMATO-1 is designed to have a cruising speed of about 8 knots and can accommodate 10 persons. Its overall energy conversion efficiency is about 4%. Power losses are generally due to the load factor (or counter electromagnetic force), hydrodynamic friction in the MHD channels, Joule heating while current is passed through seawater, and the skin drags of the ship. Although 4% overall efficiency appears to be low, this value has long been expected for an experimental ship of this size. The Japanese are already considering the MHD ship of the next phase, YAMATO-2. Proposing to use superconducting magnets of more than 8 T, YAMATO-2 would be much more energy efficient.

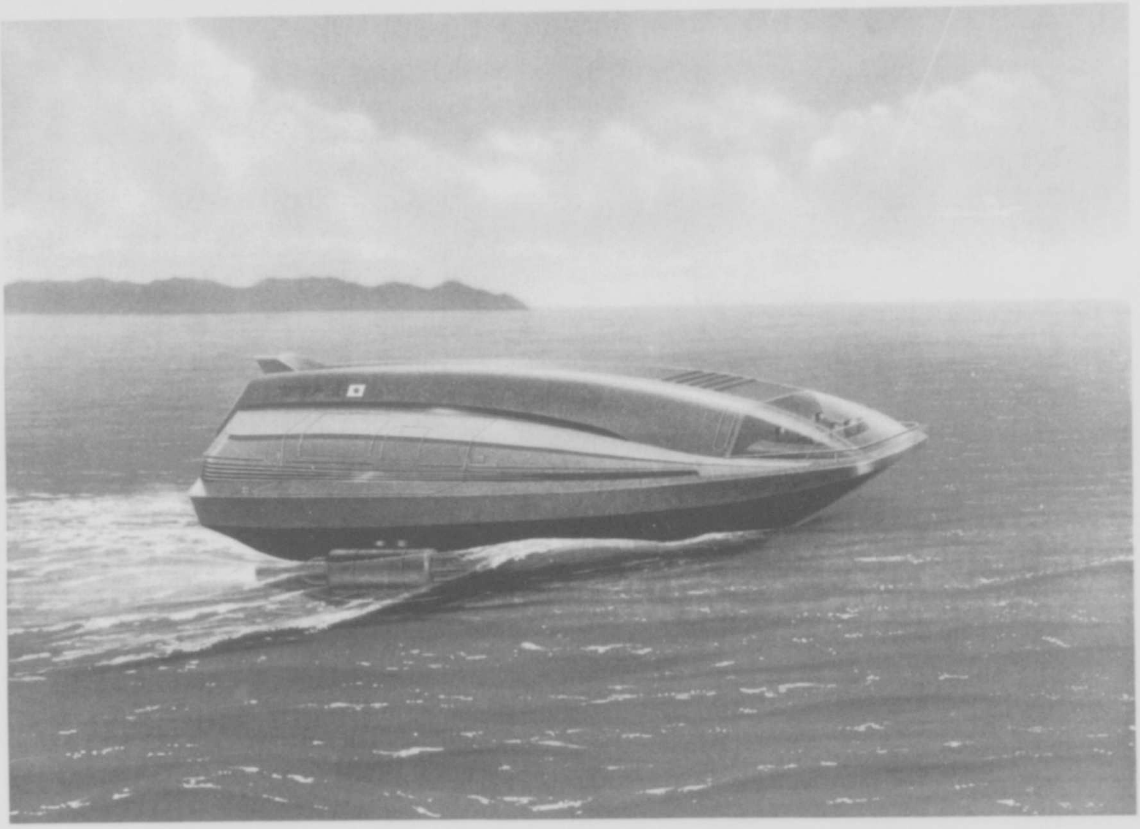
Propulsion

YAMATO-1 produces 8,000 N of Lorentz force at each thruster. As the efficiency of converting the Lorentz force into thrust is estimated to be 50%, the propelling thrust of each thruster is about 4,000 N. Hence, each of the six MHD channels in a thruster contributes 667 N. The inside diameter of the seawater duct of each MHD channel is 0.24 meter, and the inside diameter of the superconducting coil is 0.36 meter. The gross ship tonnage is 280 tons, while each thruster weighs 18 tons. The electrode currents are produced by two 2,000-kW MTU Bentz diesel engines and two 2,105-kVA ac generators. The ac current must be rectified and filtered into dc current. Many of these performance characteristics have been confirmed in the dock. However, the sea trials of YAMATO-1 in the spring of 1992 will verify all the performance characteristics while at sea cruising.

Several noticeable research and development efforts in superconducting MHD ship propulsion were presented by various organizations in the United States. They were all laboratory-scale studies, and few plans for experimental ship or sea trials were made. An experimental investigation of a large scale MHD thruster is currently underway at Argonne National Laboratory (ANL). A 6-T dipole magnet with a 1-meter bore diameter is being used for electromagnetic pumping of seawater in a closed system. Although no experimental results were given at MHDS'91, theoretical studies addressing loss mechanisms such as load factor, channel aspect ratio, and end effect were presented. It is reported that in November 1991, ANL had run their seawater MHD loop achieving flows of several meters per second and load factors on the order of 4. However, this information must be confirmed in future scientific reports. The Naval Underwater Systems Center (NUSC) has been working on the Superconducting Electromagnetic Thruster (SCEMT) project for several years. They reported that, in their 3.3-T system, pressure increases in the MHD channel with electrode voltage and magnetic field. They also provided a comparison between the theoretical prediction and experimental result. The overall efficiency was generally less than 4%. Two U.S. industrial firms, Newport News Ship Building and Textron Defense Systems, presented their conceptual designs of MHD-propelled submarines and the associated naval stealth characteristics. Since 1987, Textron has been developing an MHD propulsion system for generic attack class submarines. They presented their optimization study, performance assessment, and the propulsion system/submarine integration study. Their conceptual design study has shown that the conventional propulsion system can be removed and the MHD propulsion system added to the submarine without any overall adverse mass or performance impact.

Other international contributions included the former U.S.S.R.'s theoretical and experimental investigations of helical superconducting MHD propulsion, in which the simplicity of using a solenoid coil design of the magnet was appreciated. The United Kingdom contributed in the area of superconducting homopolar machinery. China, France, Germany, and Yugoslavia discussed the theoretical aspects of MHD ship propulsion, ranging from thruster optimization, efficiency improvement, seawater electrochemistry, to analytical magnetohydrodynamics, etc.

Experimental Ship "YAMATO 1"

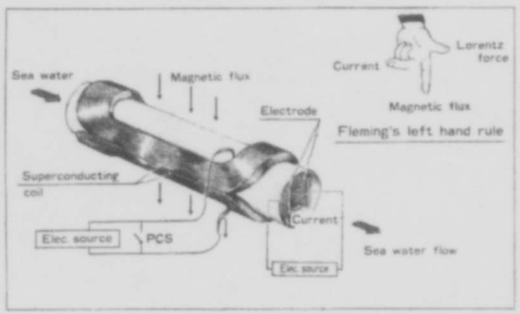


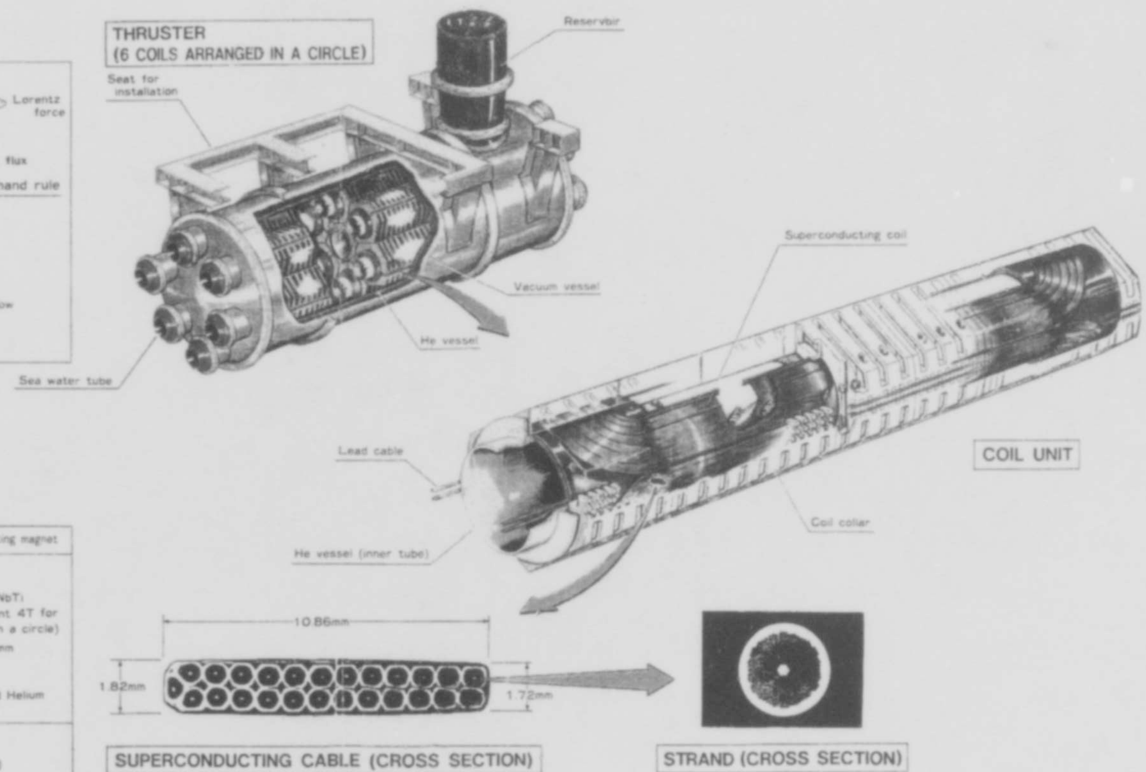
Main particulars of "YAMATO 1"

Length (overall)	abt. 30	m
Length (B. P.)	26.4	m
Breadth	10.39	m
Depth	2.5	m
Draft	1.5	m
Displacement	abt. 185	ton
Gross tonnage	abt. 280	ton
Ship speed	abt. 8	kt
Complement	10	persons

Figure 1. The YAMATO-1 experimental ship (courtesy of the Japan Ship & Ocean Foundation).

SUPERCONDUCTING ELECTRO MAGNETIC THRUSTER





MAIN PARTICULARS

Type		6 coils-round-interal magnetic field type superconducting magnet
Component	Coil	Quantity : 6 sets Type × Cable material : 2 layers dipole × NbTi Max. magnetic flux at center : abt. 3.5T (equivalent 4T for 6 coils arranged in a circle) Dia. of winding (ID × OD) : 360mm × abt400mm Eff-length of mag. field : abt. 3,000mm Coil collar : Al Alloy Cooling method : Immersed in Liquid Helium
	Cryostat	Material : Al Alloy (vacuum vessel), Stainless steel (He vessel) Outer dimension : 1.85m dia × 5.4m length
Thrust		Lorentz force 8,000N (abt. 800kg)/thruster (Current of electrode : abt. 4,000A/thruster)

THE SHIP AND OCEAN FOUNDATION
MITSUBISHI HEAVY INDUSTRIES, LTD.

Figure 2. The YAMATO-1's MHD thruster (courtesy of the Japan Ship & Ocean Foundation).

Superconducting Magnet

Superconducting magnets are the critical elements of MHD ship propulsion technology. Multi-tesla magnets are normally required for MHD ship propulsion. In YAMATO-1, each individual magnet was designed for 3.5 T at the center of the dipole. Because of the circular arrangement of the six magnets with alternating polarities for adjacent magnets, a compound magnetic field of 4 T could be achieved. The YAMATO-1 magnets would require an operating current of 3,288 A, an inductance of 0.55 H, and a stored energy of 3.83 MJ. The cryogenics system of the magnets will be discussed in the next session.

It has been generally suggested that, for a practical MHD ship to achieve reasonable energy conversion efficiency, superconducting magnets of 8 T or higher magnetic field are required. Considering the even higher field in the coil winding, it would appear that Nb_3Sn will become the choice superconducting material. However, it must be remembered that Nb_3Sn is a much more expensive material!

Refrigeration and Shielding

In YAMATO-1's normal operation mode, helium boil-off due to the heat leak into the cryostat must be recovered and recondensed into useful cryogen. The amount of heat leak is about 8 W for each thruster. Therefore, two 10-W-capacity helium refrigerators were designed, built, and placed onboard YAMATO-1. They recycle the helium in closed systems to avoid the loss of expensive helium. Particularly, low-vibration, low-noise micro-turbines for helium compression were developed. The refrigerator consists of a screw compressor, a heat exchanger, a Joule-Thompson valve, and a cold box housing the above-mentioned components.

High-T_c superconducting ceramic materials, in multilayer form, have been suggested as the shielding material for magnetic fields. Low-cost, lightweight, and castable polymer concrete was also suggested as another candidate for magnetic shielding. The wall of the cryostat can be designed to serve both thermal insulation and shielding purposes. In this case, it is a double-layered, fiber-reinforced plastic (FRP) material with one layer of amorphous Ni-Fe alloy and another layer of superinsulation sandwiched in-between. Based on the Japanese experience in the shielding of the magnetic levitation railroad, laminated superconducting board was suggested as an effective shielding mechanism using the Meissner effect.

Electrolysis and Electrode

The electrochemical reactions on the electrode surfaces in an MHD channel are very complex. Hydrogen bubbles are generated on the cathode and chlorine and/or oxygen bubbles are produced on the anode. Depending on the anode material, the amount of oxygen production could vary. The flow in an MHD channel of an MHD ship can be characterized to be multiphase and multicomponent. The two-phase pressure drop strongly impacts the performance of the MHD thruster. The production of bubbles is linearly dependent on the electrode current. The propagation of bubbles is affected by the turbulence intensity of the flow and the solubilities of different gases in the flow. The presence of gas bubbles displaces the conductive seawater and, hence, decreases the local conductance. To remedy such a problem, the flow rate in the MHD channel must be maintained high enough to flush away the bubbles. Conductivity enhancement by introducing strong electrolytes into the flow was also suggested. All these phenomena were discussed in the author's presentation. The author also suggested the need to investigate the two-phase turbulence of seawater under the influence of a strong magnetic field.

Electrochemical reactions on the electrode surfaces can result in electrode erosion. This poses a serious problem for the day-to-day operation of an MHD ship. The anode appeared to be more vulnerable to attack by chlorine than the cathode by hydrogen. Systematic electrode material evaluations were carried out by Japanese and American researchers. To date, it is the consensus that the dimensional stable anode (DSA) performs most satisfactorily. DSA is normally a titanium electrode coated with a rare-earth (Ru or Ir) oxide. For the purpose of enhancing oxygen and suppressing chlorine production, the Japanese have investigated the MnO_2 coating of titanium. Its initial results were encouraging. With the suppression of chlorine generation one would be able to reduce the ocean environmental pollution of chlorine discharged by the MHD thrusters. It was also suggested that nonmetal electrodes could possibly be more corrosion resistant. Therefore, further investigation is necessary for glassified graphite and silicon. For short mission marine vehicles, such as torpedoes, the problem of electrode erosion is practically nonexistent.

DISCUSSION AND CONCLUSION

The electromagnetic (or MHD) propulsion of marine vehicles was conceptualized as early as 1961 (Rice) in United States. A small model ship was built and the working principle was demonstrated in 1967 (Way). However, it remained a technical speculation due to the weight penalty and low magnetic field of electromagnets until the recent great advances in superconducting magnet technology. The Japanese are to be complimented on making significant contributions in superconducting

MHD shipbuilding. YAMATO-1 is clearly a result of Japan's well-coordinated national effort. It began as the Ship and Ocean Foundation's scientific research guideline to build an MHD experimental ship, while fully aware of the low efficiency and mediocre speed. Nevertheless, the two industrial giants (Mitsubishi and Toshiba) invested significant amounts of financial and human resources. Smaller industrial firms also took part in different projects using their own expertise, such as cryogenics, superconductivity, electrochemistry, etc. One very important link in this complex technology infrastructure is the participation of universities and academic institutions in the capacity of scientific and intellectual guidance. The Japanese achievement is not so much on YAMATO-1's speed or efficiency. They should be given more credit for the integration of the complex subsystems in MHD propulsion and for the timely completion of the experimental ship. YAMATO-1 will undergo sea trials in the spring of 1992. If it meets the expected performance and specifications, it would seem very justified for Japan to move forward and build the more efficient and higher speed YAMATO-2. Regardless, Japan is now by far the world's leader in MHD ship propulsion. It is, however, the author's observation that the Japanese programs could be strengthened in the fundamental studies of the physical phenomena associated with seawater MHD thruster flows. The subjects of multiphase seawater flow under a strong magnetic field, computational magnetohydrodynamic simulation, and direct visualization of MHD seawater flow are apparently important but were not well addressed at MHDS'91. It is the author's belief that improving the understanding of basic physical processes can only benefit the practical applications in the long run.

The Americans are also to be congratulated for taking prudent measures in investigating superconducting MHD propulsion at various organizations. The Defense Advanced Research Projects Agency (DARPA) is the primary sponsor for several MHD test facilities and conceptual studies in United States. Although the stealthy nature of the MHD ship is the main justification for the research efforts in United States, the author regretted not being able to see any in-depth quantitative papers on the acoustics of MHD thrusters. The Office of Naval Research (ONR, Code 1132P) has also sponsored various programs addressing more fundamental issues of MHD propulsion technology. The author believes that the sea trial data of YAMATO-1 will be very important for the American MHD propulsion community. It will certainly influence the American research and development policy toward MHD ship propulsion. Thus, we shall pay very close attention to the forthcoming events, the YAMATO-1 sea runs.

Finally, the international participants at MHDS'91 and the Japanese hosts are to be complimented on taking part in very constructive discussions of the subject matter. Many presentations were very well prepared, thought provoking, and properly translated from Japanese to English (and vice versa). The entire conference was extremely harmonious, which could be attributed to the hospitality and open-minded sharing of technical information of the Japanese hosts. The technical tour of YAMATO-1 was especially informative.

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SYNCHROTRON-RADIATION RESEARCH IN JAPAN: PREPARATION FOR SPring-8

Groundbreaking for Japan's newest and largest synchrotron-radiation facility took place in November 1991 at the future site of SPring-8 in Harima Science Garden City, located in the mountains west of Kyoto. While the huge 8-GeV storage ring and associated facilities are under construction, a series of annual international symposia are being held to discuss candidates for the scientific program to be undertaken after final commissioning of SPring-8 for research to begin in 1998. The Third International Synchrotron-Radiation Symposium held in Kobe, 18-19 March 1992, is reviewed here.

by Victor Rehn

INTRODUCTION

As construction of the $900M SPring-8 synchrotron-radiation (SR) facility begins in earnest with a scheduled commissioning date for the beginning of user research on 1 April 1998, the Third Annual International Symposium on Synchrotron-Radiation Facilities and Advanced Science and Technology was held in Kobe. This year's symposium specialized in the use of SR in research in surface and interface science. Twelve 45-minute papers were presented, each illustrating the enormous potential of synchrotron-radiation-based experimentation with high-brightness, third-generation SR sources in studying the complex physics and chemistry of solid surfaces and interfaces.

BACKGROUND

Over the past 10 years, synchrotron radiation emitted by high-energy, high-current stored electron beams has proved to be an extremely powerful tool for studying the structure of the matter and various physical and chemical processes. Japan's first electron storage ring dedicated as a synchrotron-radiation source was built in 1975 by the Institute of Solid State Physics, University of Tokyo, a 0.35-GeV ring. Later a 0.66-GeV storage ring was put into operation at the Electrotechnical Laboratory in 1981, and a 2.5-GeV ring at the Photon Factory, National Laboratory for High Energy Physics, in 1982. In 1984 a 0.7-GeV storage ring was built at the Institute of Molecular Science. All these facilities have been used for research in a large number of fundamental disciplines as well as for applied research in industry. Several other storage rings have been built by private industry in Japan for use (eventually) in developing x-ray lithography as a production tool for semiconductor devices.*

The need for a high-brilliance** synchrotron-radiation source that covers the hard x-ray domain has been envisaged among the scientific community. Japan's Council for Aeronautics, Electronics, and Other Advanced Technology, part of the Science and Technology Agency (STA) of the Japanese Government, proposed construction of a high-brilliance synchrotron light source in the report on "Policy for Promoting the Comprehensive Research and Development for Opto-Science and Technology" in July 1987

* See, for example, the JTEC Panel Report on *X-Ray Lithography in Japan*, J.T. Clemens, Chairman (Loyola College in Maryland, 1991).

** Note that the traditional optical term for electromagnetic intensity emitted by an extended source, normalized to unit source area and unit solid angle of emission, is "brightness." However, due to some non-unanimity in the use of the term "brightness," many synchrotron-radiation scientists have now adopted the term "brilliance" for the same concept. In this article, the terms will be used interchangeably.

after extended discussions. It may be noted that the U.S. Department of Energy commissioned a similar report, the Eisenberger-Knotek report on "The Need for New Synchrotron-Radiation Facilities," in 1983, which reached similar conclusions and led to the construction of two new "third-generation" SR facilities: the Advanced Light Source (ALS) in Berkeley, California, and the Advanced Photon Source (APS) at the Argonne National Laboratory in Illinois.

In June of 1987, STA convened an ad hoc committee to discuss the necessity for the new-generation SR source and to examine the requirements for the new facility. The committee was chaired by Haruo Kuroda (recently retired from the University of Tokyo, and now at the Tokyo University of Science). The Kuroda committee established that a high-energy storage ring capable of providing highly brilliant synchrotron radiation (SR) in the x-ray spectral region was a high priority. Such a facility would promote a research and development (R&D) program in the fundamental disciplines such as physics, chemistry, biology, and materials science in the 1990s, according to the Kuroda committee. The importance of the high-brilliance light source that covers vacuum ultraviolet (VUV) and soft x-ray (SXR) domains was also noted. The energy of the storage ring was tentatively set to be 6 GeV. The Kuroda committee stressed that research and development should be carried out in a nationwide collaboration to overcome the technical difficulties associated with low-emittance, high-brightness storage rings.

RIKEN (the Institute of Physical and Chemical Research, an STA laboratory) started the design study and R&D work on the low-emittance storage ring in 1986. In the fall of 1987, JAERI (the Japan Atomic Energy Research Institute, another STA organization) joined with RIKEN in the design work. Preliminary results of the design effort as well as the R&D for the 6-GeV design were issued as the first draft of the *Conceptual Design Report* (first edition) in May 1988.

In October 1988, JAERI and RIKEN established a joint design team to support the construction of the facility. At this stage, the design energy of the storage ring was raised to 8 GeV, and the two institutes organized an Advisory Committee for the 8-GeV SR Facility Project, chaired by Kazutake Kohra. Subcommittees on Accelerators (Kazuo Huke) and on Applications (Taizo Sasaki) were formed. In the Subcommittee on Accelerators, the necessity of straight sections longer than the regular 6.5-meter straight sections was strongly urged. The Advisory Committee submitted two interim reports in August 1989 and in February 1990 concerning the basic configuration of the facility, its use, etc. In Figure 1, the organization of the SPring-8 project team is shown. In the summer of 1989, the nickname and logomark of the facility were determined by public suggestions to be "SPring-8" (Super Photon ring-8 GeV).

Harima Science Garden City in Hyogo Prefecture was selected as the construction site for SPring-8 in June 1989. This new city has been under development since 1986 as a part of the "Nishi-Harima Technopolis." The site has 141 hectares (348 acres) and is located about 100 km to the west of Osaka. The Faculty of Science, Himeji Institute of Technology, opened in April 1991. The grand site preparation was started in March 1990 by the Hyogo Prefectural Government, who made the site available to SPring-8 in April 1992. Construction of a part of the storage ring building is underway at this time.

The major purpose for building the large "third-generation" SR sources such as ESRF (European SR Facility), APS, and SPring-8 is to provide research scientists with x-ray sources of far higher brightness than any existing today. Conventionally, SR x rays are taken from the "bending magnets" which determine the quasi-circular orbit of the stored electrons (or positrons) in the storage ring. These magnets are of relatively low magnetic field and provide a quasi-continuous spectrum of electromagnetic radiation (ER) from infrared to x rays. The SR x-ray source brightness typically is four orders of magnitude greater than laboratory x-ray sources. That was the thrill of the 1970s for x-ray scientists.

Of the storage rings utilized for SR sources in the 1970s, most were built for high-energy physics. In these designs, care was taken to provide the narrowest possible beam only in the interaction regions where the high-energy experiments were carried out. The SR beam lines utilized other parts of the orbit as source points, however, where designers had minimized costs.

Second-generation SR sources such as the Photon Factory in Japan and the National Synchrotron Light Source in the United States, were designed for dedicated SR sources, and significant improvements in beam quality were included. The SR x-ray source brightness was increased by another one to two orders of magnitude by introducing high-field "wigglers" into the electron orbit. The wiggler provides several bends of the electron beam within the source region, thereby multiplying the source brightness. Use of higher magnetic fields in the wigglers also shifts the spectrum toward harder x rays without requiring a higher electron beam energy.

Third-generation storage rings use "low-emittance" designs in which the transverse distributions of electron position and momentum are minimized all the way around the orbit, and long straight sections are included for insertion of wigglers and undulators.

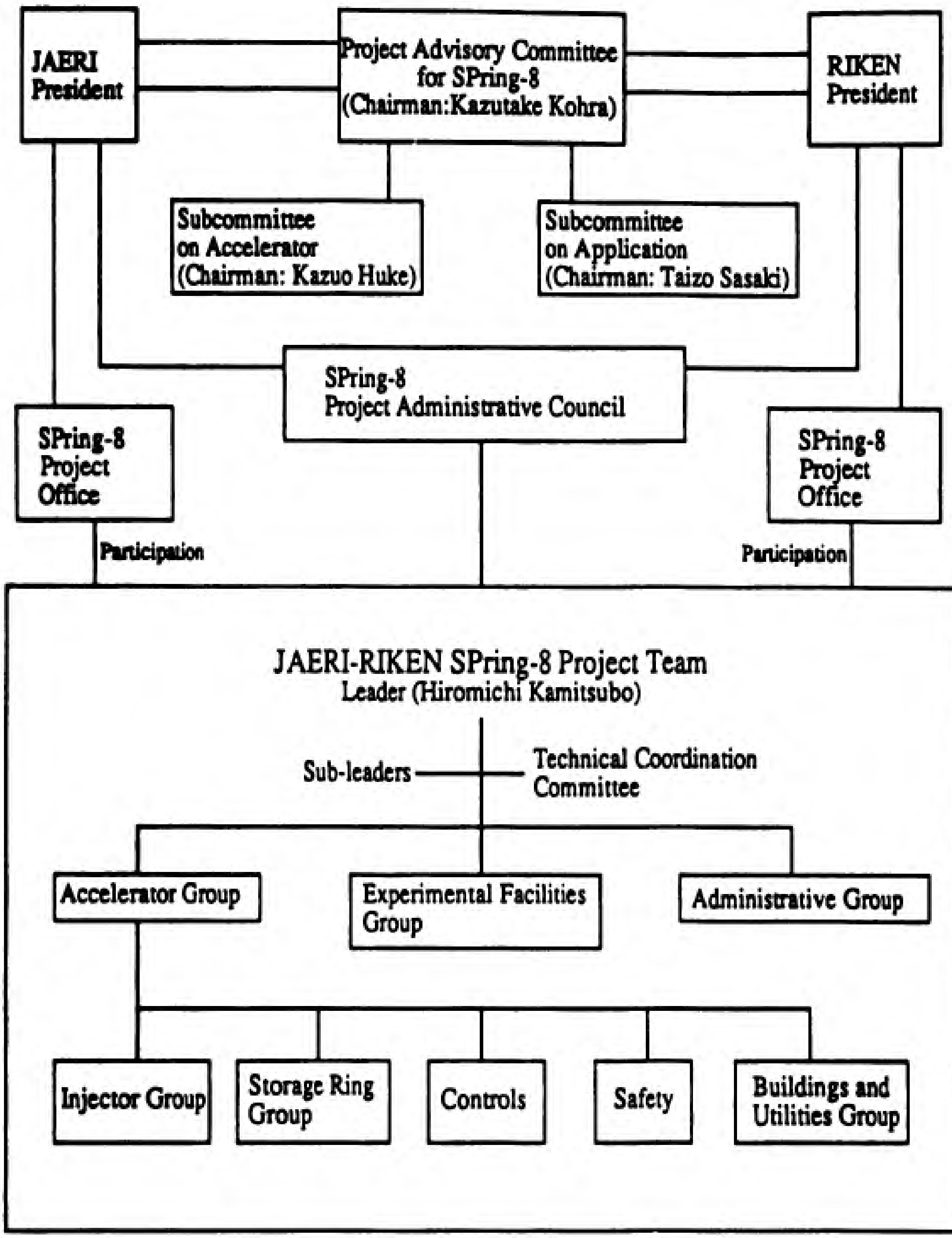

Figure 1. Organization of the JAERI-RIKEN SPring-8 project team.

In the high-precision orbits of third-generation facilities, it is possible to insert long, short-period, high-field undulators. Undulators cause the electrons (or positrons) to undulate many times as they pass through the source region, albeit with very low amplitude. The resulting undulator radiation (UR) has a distinct, quasi-resonant, spiked spectrum; increased coherence; and greatly increased peak intensity.

The third-generation high-energy storage ring with long, high-field undulator x-ray sources is now the highest brightness source of soft and hard x rays by another one to four orders of magnitude over the wiggler sources. That makes the undulator x-ray source 9 to 11 orders of magnitude brighter than the once-powerful, rotating-anode, laboratory x-ray sources. Needless to say, new scientific progress is easily visualized with the astounding x-ray brightness to become available with the commissioning of third-generation facilities. Also needless to say, there are sure to be technological problems in the design of beam lines and experimental apparatus for use with such highly brilliant beams.

The aim of the SPring-8 project is to promote the basic research and development of advanced technology by using high-brilliance UR in the x-ray domain. The facility will be opened equally to research groups of universities, national laboratories, and industries.

The storage ring energy was determined by the requirement for a fundamental UR x-ray photon energy up to the K-absorption edge of element number 40 (Zr, K-alpha energy = 18 keV). Preliminary suggested undulator designs with a 3-cm period, 4-meter length in the SPring-8 beam show the fundamental peak about 13 keV for K=1.0. Harmonic UR will allow research with UR x-ray photon energy up to 40 keV or higher.

A 2-meter-long, 18-period, 1.5-T wiggler source in SPring-8 will provide quasi-continuum SR of high brightness up to photon energies of 800 keV. The brightness of this wiggler will be as much as 1,000 times that of the 54-pole wiggler installed at the Stanford Synchrotron-Radiation Laboratory several years ago.

THE THIRD SYNCHROTRON-RADIATION INTERNATIONAL SYMPOSIUM ON SYNCHROTRON-RADIATION FACILITIES AND ADVANCED SCIENCE AND TECHNOLOGY: SURFACE AND INTERFACE SCIENCE

Opening Remarks and Facility Reviews

The titles and authors of scientific papers presented are as follows:

- "Status of APS," David E. Moncton, APS
- "Present Status of SPring-8 Project," Hiromichi Kamitsubo, SPring-8 Project Team
- "Surface Science and Synchrotron Radiation," Akio Yoshimori, Okayama University of Science
- "Surface Structure at Electrochemical Interfaces," Ben Ocko, Brookhaven National Laboratory
- "Time-Resolved X-Ray Studies of Epitaxial Growth," Paul H. Fuoss, AT&T Bell Laboratories
- "X-Ray Diffraction Study of Fatty Acid Monolayers at the Water Surface," Tadashi Matsushita, Photon Factory, National Laboratory for High Energy Physics
- "Surface Structure Determined by X-Ray Diffraction: Metal on Si(111) Surface," Toshio Takahashi, Institute for Solid State Physics, University of Tokyo
- "X-Ray Standing Wave Atom Location and Thermal Vibration Amplitudes of Adsorbed Surface Atoms," Jamshed R. Patel, AT&T Bell Laboratories
- "XAFS Studies of Molecular Adsorbates on Metal Surfaces," Toshiaki Ohta, Hiroshima University
- "Photoelectron Scattering and Advanced Techniques in X-Ray Photoelectron Spectroscopy with Next-Generation Light Sources," Brian P. Tonner, University of Wisconsin-Milwaukee
- "Photoemission Spectroscopy of GaAs Surfaces and Interfaces," Masaharu Oshima, NTT Interdisciplinary Research Laboratories
- "Surface and Thin Film Magnetism Studied by Spin-Resolved Photoelectron Spectroscopy," Jürgen Kirschner, Freie Universität, Berlin
- "Perspective of Surface and Interface Sciences," Yoshitada Murata, Institute for Solid State Physics, University of Tokyo

The opening address was given by Minoru Oda, President of RIKEN and member of the Japan Academy. Prof. Oda traced the earliest history of synchrotron-radiation science, beginning with war-time theoretical prediction by J. Schwinger in 1943 and continuing with a discussion of the applications to understanding the visible and x-ray radiation from the Crab Nebula. Kazutake Kohra, Vice

President, Japan Synchrotron-Radiation Research Institute, founder of the Photon Factory and Chairman of the SPring-8 Project Advisory Committee, followed with a brief history of the Photon Factory and SPring-8. Kohra also emphasized the international cooperation that has developed within the synchrotron-radiation community world wide. Although the organizing committee invited the directors of both ESRF in Grenoble, France, and APS in Argonne, Illinois, Kohra relayed the regrets of Ruprecht Haensel of ESRF. Thus progress on the first of the three new giants of the SR world was not presented at this symposium.

David Moncton reported, however, that ESRF has recently achieved its first circulating current in its 6-GeV storage ring, and commissioning by late 1993 or early 1994 seems probable. Commissioning of the APS is scheduled for the fall of 1996, and Moncton foresees no major obstacles to achieving that schedule. At this time, the APS construction project is on schedule and under budget, Moncton reported with obvious pleasure. Total construction cost for the APS is estimated to be $465M, but adding research and development costs, early operating costs, etc. brings the total cost to approximately $800M between 1988 and 1996.

Moncton was asked several questions concerning project management. How, for instance, would employment of construction personnel be handled at the completion of the project? How many staff members will be employed in beam line development? How will project scientists obtain beam time for their own experiments? How will the workload of staff scientists be balanced between support of user scientists and personal research? What will be the first experiment conducted on APS and how is that decided?

The current status of SPring-8 was reviewed by Hiromichi Kamitsubo. He described the technical progress thoroughly. Great care is being given to minimizing thermal fluctuation and mechanical vibration. The Harima Science Garden City site is considerably more stable geologically than the site of the Photon Factory, where realignment following earthquakes has been required frequently. SPring-8 will be built on bedrock, surrounding the top of a small mountain. At the Photon Factory, 40-meter-deep support pilings were used, which footed on an ancient stream bed, not on bedrock.

Following Kamitsubo's discussion of progress, Moncton asked why SPring-8 will not open until 1998. The reply was that if funding were permissive, SPring-8 could be finished 1 year early. Reporters in the audience picked up the possibility and reported it in the next day's newspaper as a fact. However, the approved funding profile is considered unchangeable. Sasaki stated that the SPring-8 management team has no expectation that an early opening will be possible, although rescheduling of various elements within the construction may be possible as long as the overall funding profile is not affected.

Research Presentations

Following the theme started by Akio Yoshimori, most of the research papers concerned the general problem of understanding the atomic and electronic structure of various types of surfaces or interfaces. Many presenters utilized one of the several complex surfaces of silicon, such as the Si(111) 7x7, or one of the Si(100) surfaces as examples of the power of synchrotron-radiation x-ray experiments to determine surface structures. Both clean and "contaminated" surfaces were discussed as important surfaces to understand, especially in process situations such as cleaning, epitaxial growth, metalization, passivation, or etching.

Ben Ocko of Brookhaven National Laboratory discussed the possibility for understanding of the electrochemical interfaces using angle-dependent x-ray diffraction (XRD) and x-ray reflectivity for separating the surface layer from the underlying bulk. Interface layers contribute only 10^{-6} of the bulk XRD signal, so that high-intensity SR x rays are needed to obtain good interface data. X-ray reflectivity taken near a core-level x-ray absorption edge of a known interface contaminant is very sensitive to interfacial layers.

Ocko showed correlations of XRD and x-ray absorption with cyclic voltametry in iodine layers on Au(111). Bias dependence of these electrochemical interfaces has been shown to influence the surface atomic construction, but the theory is understood only in a general way from the general theory of Heine.

Paul Fuoss, AT&T Bell Labs, illustrated beautifully the power of x-ray studies of epitaxial growth mechanisms. In a collaboration with Kisker of IBM and Brennan of the Stanford Synchrotron Radiation Laboratory (SSRL), all three of the essential ingredients of the organometallic vapor-phase epitaxy process were studied in the same chamber: x-ray spectroscopy of the organometallic vapor and its fragmentation, grazing-incidence XRD, and x-ray scattering of the growing surface and substrate. For example, a growth surface cut only 0.5° off the (100) Bragg plane shows a splitting of the truncation rods in x-ray scattering. Observing these quantities in a time-resolved way requires very high intensity x rays, Fuoss declared.

In temperature dependent studies, it was possible to determine conditions under which nucleation sites are correlated so that high-quality, single-crystal epitaxial layers will result. GaAs, InP, and the As/InP growth surface have been studied by Fuoss and collaborators.

Toshio Takahashi of the Institute for Solid State Physics, University of Tokyo, reported studies of the growth of several metallic systems on Si(111), using similar techniques. Detailed structures were reported for partial monolayers, full monolayers, and multiple monolayers of B, Al, In, Sn, Ag, Sb, and Bi. By studying the angular symmetry of the x-ray scattering about the Bragg angle, the vertical distance of the overlayer above the substrate is obtained, and the phase change of the x ray upon Bragg reflection is determined. A highly detailed structure of the metal overlayer is obtained, but the experiment requires 12 days of data taking! The large increase in intensity which will be available at SPring-8 will be welcome, indeed, if many such studies are to be made.

Another method for studying atomic location, and also obtaining the thermal-vibration amplitudes of surface atoms, was presented by Jamshed Patel of AT&T Bell Labs. Patel uses the x-ray standing wave, as obtained from the x-ray fluorescence that occurs concurrently with XRD. As the sample is rocked slightly through the Bragg condition or the x-ray wavelength is scanned through the Bragg condition, the XRD and the x-ray fluorescence are monitored. The x-ray standing wave within the crystal surface layers moves in phase, and the fluorescence yield varies according to which layer of atoms lies at the peak of the exciting standing wave. Thermal vibration of the atoms determines the width of the angular or wavelength range of fluorescence excitation. The results are analyzed using the Debye model, which shows quite low Debye temperatures (< 100 K) for surface atoms.

In his crystal ball, Patel sees great advantages for higher intensity x-ray sources of the future. Experiments on not-so-perfect crystals, experiments nearer 90° Bragg angles, use of higher monochromator resolution, and studies of low-Z adsorbates will all become possible and offer exciting scientific opportunities.

An excellent presentation of x-ray absorption fine-structure (XAFS) studies of organic adsorbents on Ni(100) was presented by Toshiaki Ohta, currently of Hiroshima University but soon to take the professorship of the retiring Haruo Kuroda at Tokyo University. Ohta used both the x-ray absorption near-edge spectra (often referred to as XANES or NEXAFS) and the extended XAFS (EXAFS), along with temperature variation from cryogenic to 1,000 K, in his studies of thiophenol, thiophene, and CS_2 adsorbates on Ni(100).

These experiments were carried out near the K absorption edge of sulphur near 2.5 keV, a soft x-ray spectral region that has been difficult to access in the past, due to the need for large d-spacing monochromator crystals and a vacuum environment. Ohta's results illustrate the danger in extrapolation of behavior of one molecular adsorbate to another, even similar adsorbate. The surface structure, effective coordination, dissociation, and desorption of thiophene and thiophenol on the Ni surface behave quite differently as a function of temperature.

Science is far from an adequate experimental or theoretical understanding of molecule-surface interactions, and experiments such as Ohta's need to be conducted on many molecule-surface systems of importance in technology.

Brian Tonner, University of Wisconsin-Milwaukee and Synchrotron-Radiation Center, Stoughton, followed the theme of x-ray based analysis of surfaces and interfaces. He presented results of "Ultra" ESCA (electron spectroscopy for chemical analysis), photoelectron diffraction (PED) holography, and photoelectron microscopy in a three-part presentation.

In ultra-ESCA, Tonner pointed out that intrinsic line widths for low-Z elements are as low as 10 meV, which can be observed using very high resolution x-ray excitation instead of the customary electron beam excitation.

PED holography, usable on metal, insulator, or semiconductor surfaces, has the capability of imaging the surface with a resolution of 0.05 to 0.5 Å, which is competitive with scanning tunneling microscopy. The technique detects the angular dependence of the photoelectrons emitted from the surface as a hologram of the surface. Holographic reconstruction of the surface produces a high-resolution, three-dimensional image. This image is compared with computed holographic images to obtain quantitative atomic positions and to eliminate artifacts.

As examples of PED holography, Tonner showed results of studies of the Cu(111), Ir(111), and Cu/Ir(111) surfaces. These results indicate the promise of x-ray-generated holographic techniques and illustrated the importance of increased x-ray flux if these techniques are to be used extensively in surface science.

Both photoemission microscopy and x-ray absorption microscopy were discussed by Tonner. In the former case, Tonner showed studies of a patterned layer of Al, 50 nm thick, on GaAs. As an example of x-ray absorption microscopy, Tonner showed results of studies of yttrium-barium-copper oxide using the Ba 4d x-ray absorption edge. The ability to select x-ray wavelengths above or below core-absorption edges, or at peaks of near-edge x-ray absorption spectra, and to microscopically image that data will help answer many detailed chemical and physical questions about surfaces of importance technologically.

Masaharu Oshima, self-styled "Samurai Spectroscopist" of the NTT Interdisciplinary Research Laboratory, Tokyo, showed his application of photoemission spectroscopy to three interfacial systems of technological importance: CaF_2/GaAs, metals on sulphur-passivated GaAs, and InAs/SF_2/$EuBa_2Cu_3O_7$. Using photoemission near the Ca(3p) absorption edge at 114 eV, Oshima studied the surface construction versus growth temperature during epitaxial growth of CaF_2 on GaAs(111)A & B, and GaAs(100). Ultimately, Oshima obtained an MS (metal-semiconductor) structure that was free of pinning on the GaAs(111)B surface.

Additional studies of the noise performance of this MS field effect transistor (FET) were made using x-ray standing wave excited fluorescence spectra of the S(K) absorption edge. The locations of the S atoms at the interface were determined for GaAs(100), GaAs(111)A, and GaAs(111)B surfaces. Binding-energy shifts of the S-Ga bonds were obtained and correlated with 1/f noise associated with the interfacial region.

The effects of sulphur passivation on aluminum layers on GaAs were studied using similar techniques. It was found that metallic Ga is formed, along with Al-S bonds. These surfaces appear to have considerable promise in GaAs electronic devices.

Finally, Oshima discussed his exciting studies of superconducting transistor structures: GaAs/EBCO/InAs, where the GaAs will serve as the emitter, EBCO ($EuBa_2Cu_3O_7$) as the base, and InAs as the collector. First, GaAs was oxidized and EBCO deposited. Then SrF_2 was deposited, and finally InAs was deposited. In depositing the InAs, only three monolayers were deposited at the low temperature of 200 °C, followed by the In layer before heating to the deposition temperature of InAs. The SrF_2 interlayer prevented the formation of InO prior to the higher temperature InAs deposition.

In the future, a higher photon flux from SPring-8 will allow combination measurements, real-time analysis of growth situations, imaging of growing structures, and spatial resolution of characterization measurements.

Studies of surface and thin-film magnetism were discussed by Jürgen Kirschner of the Freie Universität Berlin. Kirschner used polarized and unpolarized VUV synchrotron radiation to excite spin-polarized photoelectrons from thin films of Fe(100), Cu(100), Co/Cu(100), and multiple layers of Cu and Co. These studies show that a few monolayers of Co on Cu induce polarization of the Cu(3d) electrons and the Cu s-p bands. Co films nine monolayers thick show square domains polarized along the <110> directions.

In the Fe films, the Fe(2p) levels at 680 and 695 eV are split by spin-orbit interaction into spin-up and spin-down components. However, spin splitting of S-core states is very small. Kirschner reported that the spin polarization of s- and p-levels is not well understood theoretically.

The question of a possible spin-polarized scanning tunneling microscope (STM) was brought up by a questioner. Kirschner indicated that, although he has thought about it, no ideas have occurred yet. He reported a rumor from Basel, Switzerland, that someone is working on such a device, but emphasized that the rumor has not been verified.

The final paper of the conference was presented by Yoshitada Murata, Institute of Solid State Physics, University of Tokyo. He summarized the study of surface and interface science. Up to the present, problems undertaken have been oriented toward the study of interface physical structure, electronic structure, and interface absorption spectra. A prime example is the Si(111) 7x7 surface, including the second layer studies by STM.

Murata projects that in the future problems undertaken will utilize angle-resolved and time-resolved synchrotron-radiation techniques such as ARUPS (angle-resolved ultraviolet photoemission spectroscopy), SXAFS (surface x-ray absorption spectroscopy), spin-polarized (SP) UPS, or SPARUPS for the study of complex structures such as O/Ni(100) or for the production of new materials utilizing surface properties. Dynamical processes, phase transitions, surface reconstruction dynamics, and absorption-induced restructuring will be important areas for research effort.

Absorption, diffusion, desorption, and reaction will be studied from the quantum-mechanical viewpoint. Nearly elementary processes, thermal reactions, and nonthermal processes will be important to study.

Photodesorption and photon-stimulated desorption will be pursued in order to understand high-reaction-rate processes with high selectivity. Murata suggested a strong need for exclusive SR beamline facilities or for compact, individual-laboratory SR sources for VUV experiments, especially for complex systems involving laser and SR beams and the like.