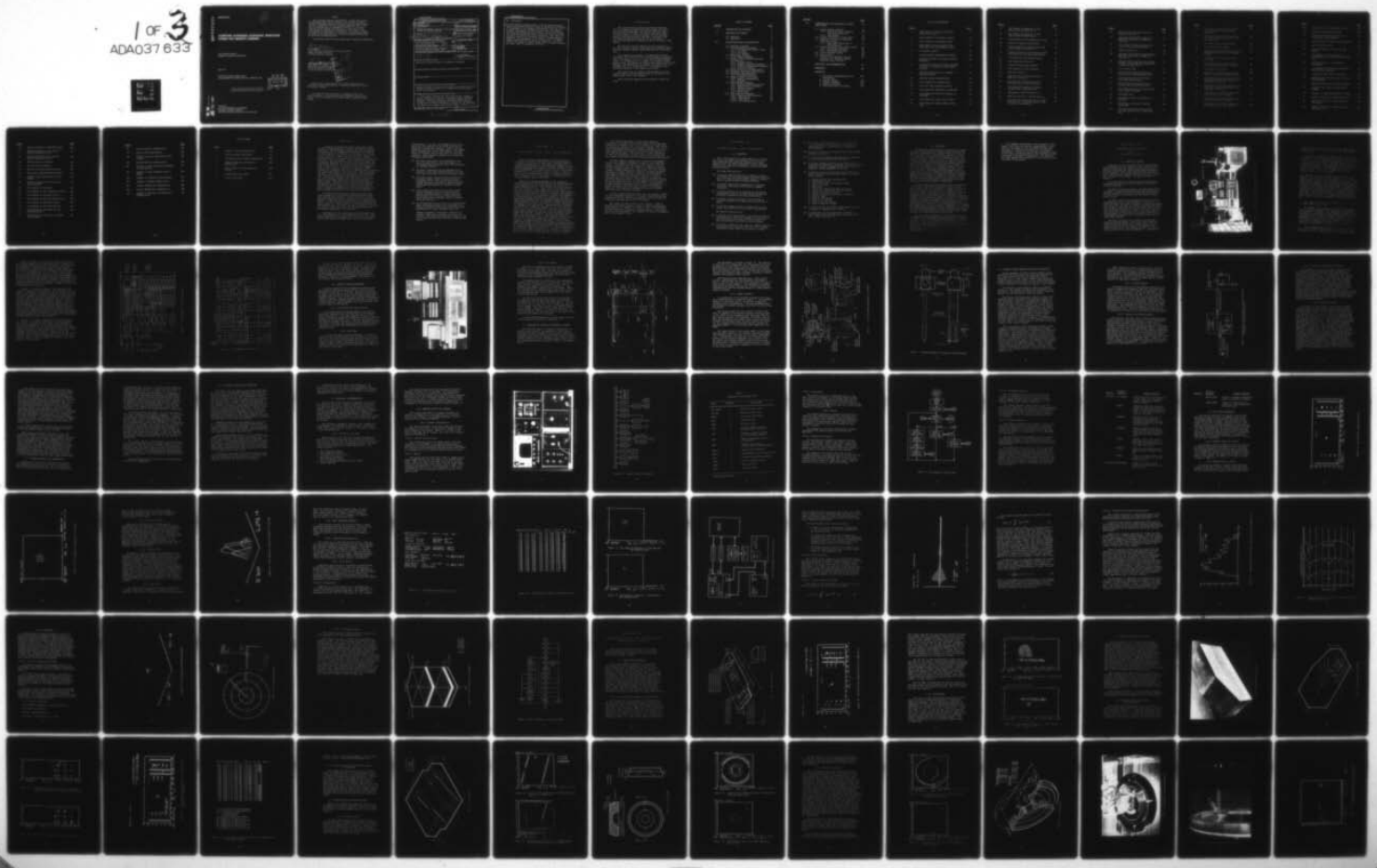
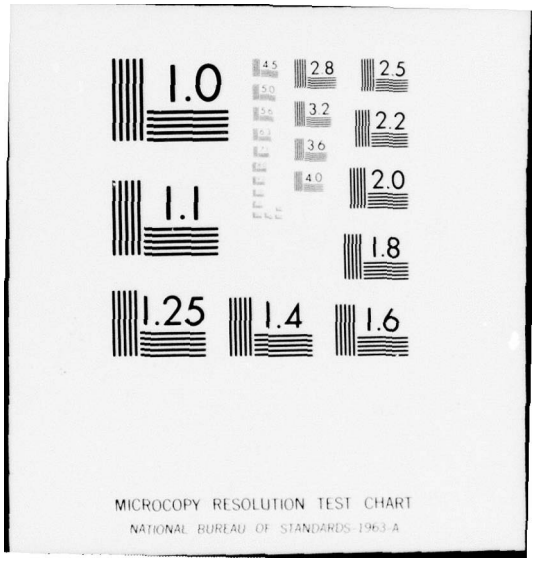
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COMPUTER AUTOMATED ULTRASONIC INSPECTION SYSTEM FOR AIRCRAFT FORGING

FORT WORTH DIVISION
GENERAL DYNAMICS CORPORATION

MAY 1975

TECHNICAL REPORT AFML-TR-75-82
FINAL REPORT FOR PERIOD JUNE 1972 - FEBRUARY 1975

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This technical report has been reviewed and is approved for publication.

K.D. SHIMMIN
Project Engineer, Nondestructive Evaluation Branch
Metals and Ceramics Division
Air Force Materials Laboratory

D.M. FORNEY, JR., CHIEF
Nondestructive Evaluation Branch
Metals and Ceramics Division
Air Force Materials Laboratory



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This report describes the work conducted on a program to design, fabricate and evaluate a prototype Computer Automated Ultrasonic Inspection System for inspecting complex aircraft forgings. This report documents the modification required to off-the-shelf ultrasonic equipment to provide all the ultrasonic flaw data for the computer and provide computer control of

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receiver gain and flaw-gate width. Also the design and fabrication of a multiple flaw gate system is described and evaluated. The development of the computer controlled five axes (X, Y, Z, θ, and ∅) with contour following is described. The computer hardware configuration and the software to acquire and process the ultrasonic and position data, control the scanner in closed loop mode, and display the data is documented. The effects of complex contours on the ultrasonic contour following system are discussed. The development of two software contour following schemes (peaking and vector drive) are described. The capability of the system to inspect simple slopes, aluminum forgings, and engine disks are documented in detail.

F O R E W O R D

This final Technical Report describes the development of a Computer Automated Ultrasonic Inspection System for Aircraft Forgings which was pursued under Air Force Contract F33615-72-C-1828. The project and tasks numbers for this program are 7351 and 735109. The work was performed in the period between June 1972 to February 1975. The work performed during the period 15 June 1972 to 1 June 1973 and reported in AFML-TR-73-194 is included in this report.

The Air Force project engineer for this contract is Lt. John Allison of the Air Force Materials Laboratory (LLP), Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

The program was performed in the Materials Research Laboratory, Fort Worth Division, General Dynamics Corporation, Fort Worth, Texas. Dr. B. G. W. Yee was the Program Manager with J. S. Kunselman and T. C. Walker as principal investigators on the development of hardware and software respectively. Valuable contributions to this program were made by Dr. J. A. Regalbuto, Dr. F. H. Chang and Dr. J. C. Couchman in the overall development of the computerized system.

The authors wish to thank Mr. Bud Weismantel with the General Electric Aircraft Engine Group for the loan of the engine disks used on this program.

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S U M M A R Y

A computer automated ultrasonic inspection system capable of inspecting most aircraft structures has been developed. The development first began with the design and fabrication of a digitally controlled X-Y bridge on a 6 feet long by 4 feet wide by 3 feet deep tank, Z axis drive, rotate (0 - 360°), and tilt (+ 90°). Digital stepping motors and incremental encoders were used for all five axes. The development, next, involved the purchase (by General Dynamics) of an off-the-shelf ultrasonic unit (Automation Model UM 771) modified for computer gain and gate - width control. Logic and circuits to maintain a constant but selectable distance of separation (DOS) between the transducer and the test specimen and to maintain the sound beam normal to the structure, using ultrasonic feedback, were designed and fabricated. The development also involved the purchase (by General Dynamics) of a PDP 11/45 digital computer with disk drive, a Tektronix memory scope (Model 4010) and a Tektronix hardcopier (Model 4610). Finally, the five axes contour following subsystem, the ultrasonic unit, the Tektronix display and the PDP 11/45 computer were integrated and the computer software was developed to form an operational computer automated ultrasonic inspection system (CAUIS).

The CAUIS has successfully inspected engine disks (sonic shape) in the reflected compressional and shear wave mode and has achieved a greater than fifty percent saving in inspection time as compared to the conventional method. It has inspected typical airframe forgings which cannot and are not being inspected ultrasonically with the conventional way. The CAUIS can scan at speeds of 10 inches per second on flat parts; but its speed decreases with increasing complexity of the structure.

The display of the inspection on the Tektronix scope is in real time and is in the familiar C-scan mode. The defect indications are displayed in their true coordinates and not the encoder readings via a real time coordinate

transformation. The real time display does not have a one-to-one size relation to the actual structure; it generally is considerably smaller. However, in post inspection analysis, any one square inch of the display can be expanded into a full scale display. This can result in a greater than one size ratio to the actual structure. Post inspection analysis also include the following capabilities:

(1) The defect indications can be displayed at any level of sensitivity or gain with respect to the original gain setting to aid in the acceptance or rejection decision.

(2) The defect indications can be displayed in an isometric B-scan mode (amplitude profile in both the X and Y direction) at any selected gain levels.

(3) Areas with defect indications are searched with the defect homing routine to obtain a set of coordinates (X, Y, Z, θ, and $\emptyset$) which yield the largest ultrasonic amplitude to determine defect orientation and detection of randomly oriented defect.

(4) Defect indications caused by top and or bottom surface irregularities can be removed by the spatial filtering routine. Defect indications from outside of the final-net shaped structure can be removed by performing a series of spatial filtering routines.

(5) The RF waveforms have been and can be digitized and signal processing schemes can be performed to increase the signal to noise ratio and/or aid in the determination of defect dimensions and types.

Computer automation of ultrasonic inspection of aircraft structures is feasible, practical, and reliable. When judiciously applied, inspection time can be significantly shortened without compromising quality.

SECTION I

INTRODUCTION AND RATIONALE

The increasing demands placed on modern aircraft structures necessitate the development and implementation of improved nondestructive inspection techniques which minimize the dependence on the individual inspector, yield real-time analysis and permanent records, perform to consistent standards, yet remain within economic and scheduling constraints. An especially critical target for improved quality of NDT inspections is that of forged parts due to their widespread use in structures of existing and forthcoming aircraft, such as the F-16.

Surveys of forging production at the request of Aeronautical Systems Division Offices has shown that ultrasonic inspection is one of the primary tools used to determine forging quality. Even though significant advances have been realized in the improvement of ultrasonic inspection during the past decade, there still exist extensive variations in ultrasonic reference standards, approaches to setup, recording and interpretation schemes, and capabilities for flaw detection throughout the community. The use of ultrasonic equipment and the attendant operation thereof are almost entirely dependent on individual inspectors and the interpretation by their organization of proper application of equipment for inspections. Instrumentation, including the ultrasonic transducers themselves, are often delicate, subject to drift and fluctuation, and characteristically offer little indication, if any, of proper operation during inspection periods. Parameters of heat treatment, alloy type, test-specimen geometry, variations in flaw type (including orientation, etc.), and specimen surface condition are for the most part lumped into a fairly broad set of reference standards and test procedures. Even the most highly qualified of production environment inspectors using the latest equipment in the best operational condition cannot be reasonably expected to interpret the complicated spectrum of ultrasonic signal responses nor to produce sufficiently detailed inspection records for the reliable determination of the quality of given inspections for subsequent review.

The obvious conclusion is that modern computer automation technology must be merged with NDT and materials technology to provide a low cost, reliable, and rapid system for ultrasonic inspections of aircraft forgings. One of the earliest programs aimed toward computer automation of ultrasonic inspection was conducted by International Harvester[1] with AFML sponsorship. This objective of this program was to rate the cleanliness of thick section steel stocks and the computer provided primarily signal processing capabilities.

In 1971, General Dynamics was contracted by NASA/MFS[2] to develop a computer automated ultrasonic weld inspection system. This system provided real time control of an X-Y scanner as well as real time display of inspection results and hard copying capability. Also in the 1970-1971 period, computer automated ultrasonic inspection systems were being developed at Sandia Laboratory[3] and at the Union Carbide Corporation, Nuclear Division, Oak Rodge Y-12 Plant[4,5]. In 1972 TRW[6] was contracted by AFML to develop a computer automated system to inspect large diameter titanium billets. One of the main objectives of this program was to develop an ultrasonic pulser/receiver system capable of penetrating several inches of titanium. A more recent development is a system by Rockwell International, Atomics International Division.[7] This system was designed primarily to inspect thick sections of pressure vessels.

All the systems described above use the computer primary for processing and analysis of ultrasonic signals while some systems provide the additional capability of controlling the transducer scanning system in the X-Y plane.

The intent of this contract is to develop a computer automated ultrasonic system to inspect complex forging which would require the computer to control a five axes transducer scanning system in a rapid and reliable manner. This report describes the development, the capabilities and the accomplishment of the system to date.

SECTION II

OBJECTIVES AND APPROACH

2.1 OBJECTIVES

The overall objective of this program is to increase the safety, reliability and integrity of Air Force aircraft structures and propulsion systems and to reduce inspection cost and time by developing reliable automated nondestructive inspection techniques to locate and assess materials defects.

The broad objectives are:

(1) To provide computerized control, analysis, process, and display of real-time scanning ultrasonic inspection data from complex forgings having changes of section, tapers, curved surfaces, fillets, and holes.

(2) To provide computerized compensation of transducer variations, electronics and ultrasonic equipment variations.

(3) To operate selectively in reflected and transmitted compressional waves or reflected shear wave with the potential of operating the eddy current method.

(4) To minimize inspection operator error and time in equipment calibration and setup and interpretation of data.

(5) To provide permanent records of inspection in a more compact and concise form to facilitate traceability.

The specific objectives are:

(1) To develop a five axes-computer controllable mechanical scanner which is capable of scanning at speeds of up to six (6.0) inches per second for think sections and three (3.0) inches per second for thick forgings.

(2) To develop a system for near real-time computer display of flaw positions and magnitude which can also be rapidly reproduced in paper copies for permanent recording.

(3) To provide real-time feedback about the functioning of the ultrasonic, electronics, and transducers for compensation and or correction due to degradation in performance.

(4) To provide computer gain and gating based upon forging thickness variations.

(5) To study signal processing and enhancement techniques to ascertain quantitative flaw information.

(6) To design, assemble, and test the prototype system using actual forged parts, acceptable reference standards, production ultrasonic equipment, and state-of-the-art computers, display equipment, and servos.

(7) To develop in the prototype system the capability to inspect forgings of the following shapes or localized portion shapes:

a. Nearly parallel flat surfaced areas
b. Cylindrical areas
c. Flat surfaces with step section changes
d. Tapered sections
e. Edge areas
f. Curved near surface with flat far surface
g. Curved far surface with flat near surface
h. Curved far and near surfaces
i. Fillets from 0.25 to 3.0 inches in diameter
j. Radii at edges
k. Holes in near surface
l. Holes in far surface
m. Holes in an edge surface
n. Holes through the forging

(8) To study near and far surface finish requirements and to attempt to compensate their effects.

(9) To demonstrate the prototype system capability to AFML program monitor and interested personnel at the end of Phase I and Phase II.

2.2 APPROACHES

Realizing that typical, large, forged parts of modern aircraft usually contain portions of nearly parallel flat surfaces, cylindrical areas, tapered sections, fillets of different size, etc., it seemed both logical and economical to approach the program in two phases in a basically sequential manner. Phase I was for the development of a computer automated ultrasonic system to inspect structures with flat-nearly parallel surfaces and tapered sections. Phase II was to advance the development of the Phase I system for the inspection of complex forgings with curved far and near surfaces, section changes, fillets, holes, etc. The Phase I prototype system was demonstrated 24 months after contract go-ahead and the Phase II prototype system was demonstrated 32 months after contract go-ahead. Machined test specimens were used for the Phase I demonstration, whereas actual forgings were selected and used for the Phase II demonstration. This included an engine disk in the ultrasonic-shaped configuration.

The prototype system was developed using standard and off-the-shelf components and equipment where possible. Some equipment had to be modified for computer control and some interfacing components had to be designed and developed. However, they were kept to a minimum to keep the total cost of the development of the system down and to facilitate the eventual development of production inspection systems. The system was developed, not only to successfully achieve the technical objectives, but also to be a potential practical production tool which can be operated by production Level II inspectors. The system developed with this philosophy, however, is not without limitations. For example, the commercially available ultrasonic equipment that was used does not have as much power to effectively penetrate as deeply into the metals and does not have as small a top surface envelope as a custom designed and built unit.

The successful development of a self-sensing contour following device was deemed essential in meeting the program objectives. After much deliberation with several potential suppliers, it was concluded that a self-sensing five axes contour following device that can meet the program requirement was not available commercially to meet the program schedule (1972-1974). A five axes mechanical scanner that can be operated under closed-loop computer control was finally designed and fabricated by General Dynamics, especially for this program.

The hardware and software were developed to meet Phase I and Plase II objectives sequentially in time. However, this approach was not always feasible and practical to follow, particularly for the hardware development. Several of the hardware components, such as the contour following device, were developed to meet both Phase I and Phase II objectives. The software was then refined and developed at a later time to meet the Phase II objectives.

SECTION III

SYSTEM EVOLUTION AND CAPABILITIES

3.1 OVERVIEW OF SYSTEM

Fabrication of the prototype computer automated ultrasonic inspection has been completed. The system utilizes standard ultrasonics and computer components and special interface items that have been custom designed and built by General Dynamics. These components have been integrated into a system and the computer software developed to achieve the objectives of the program. The system is shown in Figure 1.

The system operates primarily in the reflected compressional and shear mode, but is capable of operating in the Delta-Scan mode.

The Phase I system operating in the compressional mode is capable of inspecting forgings with surfaces that are: flat-nearly parallel, tapered, and curvature with radii of 3 inches or more on one surface with the opposite surface gently curved.

The Phase II system was designed to operate in either compressional, shear, or Delta-Scan mode. In the compressional mode, the system is capable of inspecting forgings with curved-near and flat-far surfaces, curved-far and flat-near surfaces, curved-near and -far surfaces, radii from 0.75 inch and larger, holes in near surfaces, holes in far surfaces, and holes through the forging. The system scans and indexes primarily in rectangular coordinate. However, it was expanded to include scan of rotational bodies, such as engine disk forgings.

The Phase II system also includes basic ultrasonic signal processing schemes to aid in the identification of flaw type and flaw dimensions in limited cases. The RF signals reflected from the flaws can be digitized and Fourier-transformed to the frequency domain. From the frequency spectra of the reflected signals, it is possible to

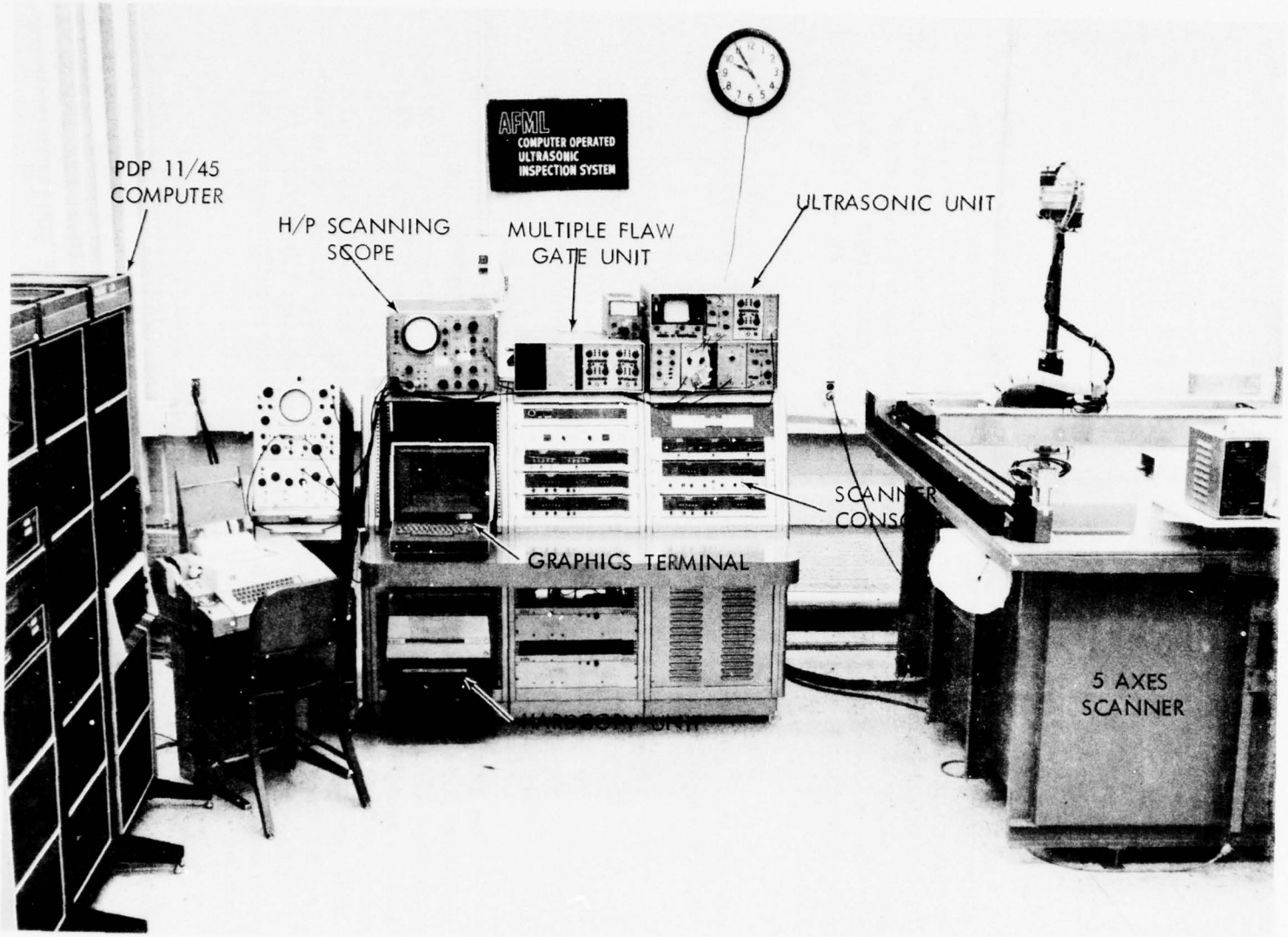


Figure 1 AFML Computer Automated Ultrasonic Inspection System

obtain additional information on the flaw width and the acoustic impedance of the material at the discontinuity or the flaws.

The system developed for Phase I would only record the largest flaw amplitude if several flaws occur in the sound path. After considerable evaluation, it was decided to use a sequential multiple flaw gate approach with software to determine what is the back surface and what are the flaw signals. Software would also be used to determine if the signals were multiple reflections. The Phase II system can record the amplitude of the two largest signals in the sound path.

The system utilizes a Digital Equipment Corporation (DEC) PDP 11/45 general-purpose computer for real-time control, data acquisition, data processing, data recording, and flaw-data display of the ultrasonic inspection. Any indication of anomalies above a predetermined threshold level, of the incoming ultrasonic signals, is detected and recorded by the computer as a flaw. The coordinate of all 5 axes where the indication occurred is recorded along with other pertinent parameters. The computer control of the scanner was changed from open loop drive to a full 5 axes closed loop control. The system also includes computer control of scan speed based on the rate of change of Z.

The system can be operated manually, console control, or fully computer controlled.

The computer also controls the sensitivity setting on the ultrasonic equipment to compensate for transducer and equipment variations. This operation provides a means to monitor the performance of the transducer with time. The computer also monitors the liquid coupling between the transducers and the component under inspection. Inspection will not commence until the computer verifies the sound energy is adequately coupled into the component by checking the amplitude of the top surface reflection.

In the standard compressional wave mode, the thickness of the test material and depth of a flaw are used to determine where the computer will set the flaw-gate width.

When the signal from the bottom surface reflection is loss or the system is in a shear wave mode of operation, the computer automatically sets the width of the flaw gate to accommodate a predetermined length of sound travel within the test specimen. This predetermined length must be fed to the computer prior to the start of each inspection. By calibrating the system for both compressional and shear wave inspection, the system can be programmed to perform consecutive compressional and shear wave inspections of a given test specimen without stopping. Furthermore, the shear wave inspection can be repeated for several angles of sound incidence on the test specimen. Example of these will be discussed in Section 4.4.

Figure 2 is a block diagram of the ultrasonic and computer components of the system. The ultrasonic unit consists of an Automation Industries Type UM 771 reflectoscope and special computer interface circuits in another chassis. This unit supplies the electrical pulses, at 500 pulses per second, to the transmitting transducer and logic circuits for starting and terminating electronic gates. It also amplifies and processes the ultrasonic signals received by the transducers. The signals are processed by logic circuits to separate the various reflected signals and condition them for computer processing via analog or digital inputs. After processing of the information by the computer, the required outputs are displayed on the Tektronix Computer Terminal Display, Model 4010. The display can be hardcopied with the Tektronix copier, Model 4610.

Figure 3 is a block diagram of the electrical circuit for the X-Y scanner, manipulator, gimball assembly, and computer components of the system. The manipulator moves the transducer in the Z and Phi ($\emptyset$) directions and contains the motors for the Theta (θ) movement. The gimball assembly provides the (θ) movement and a translation of the transducer such that the point of sound entry to the material is at the same relative location as the X-Y encoder reading. Thus, a flaw will always be located at the same reference point on the X-Y bridge and normal to the curved surface of the specimen.

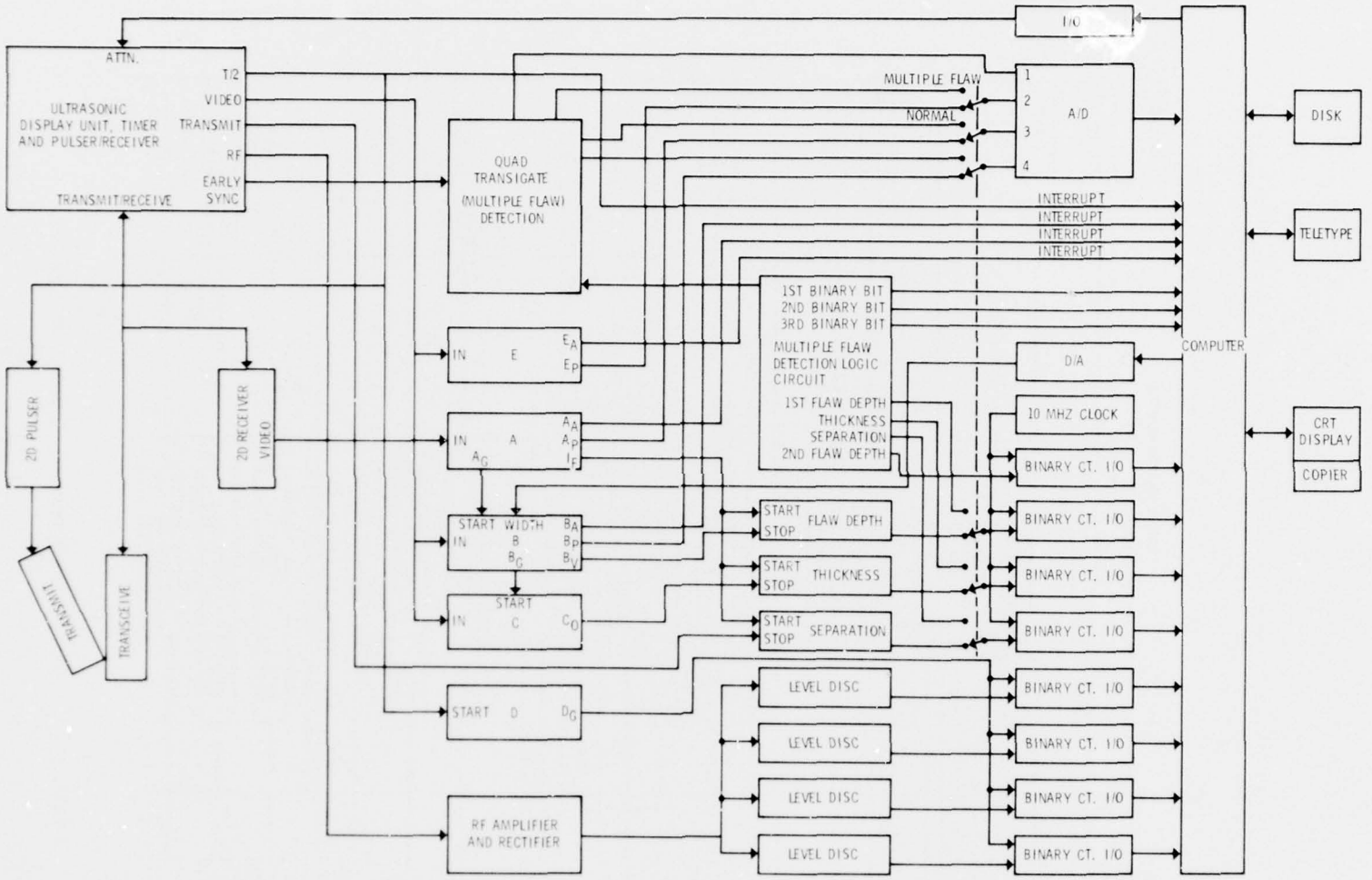


Figure 2 Block Diagram of Ultrasonic System

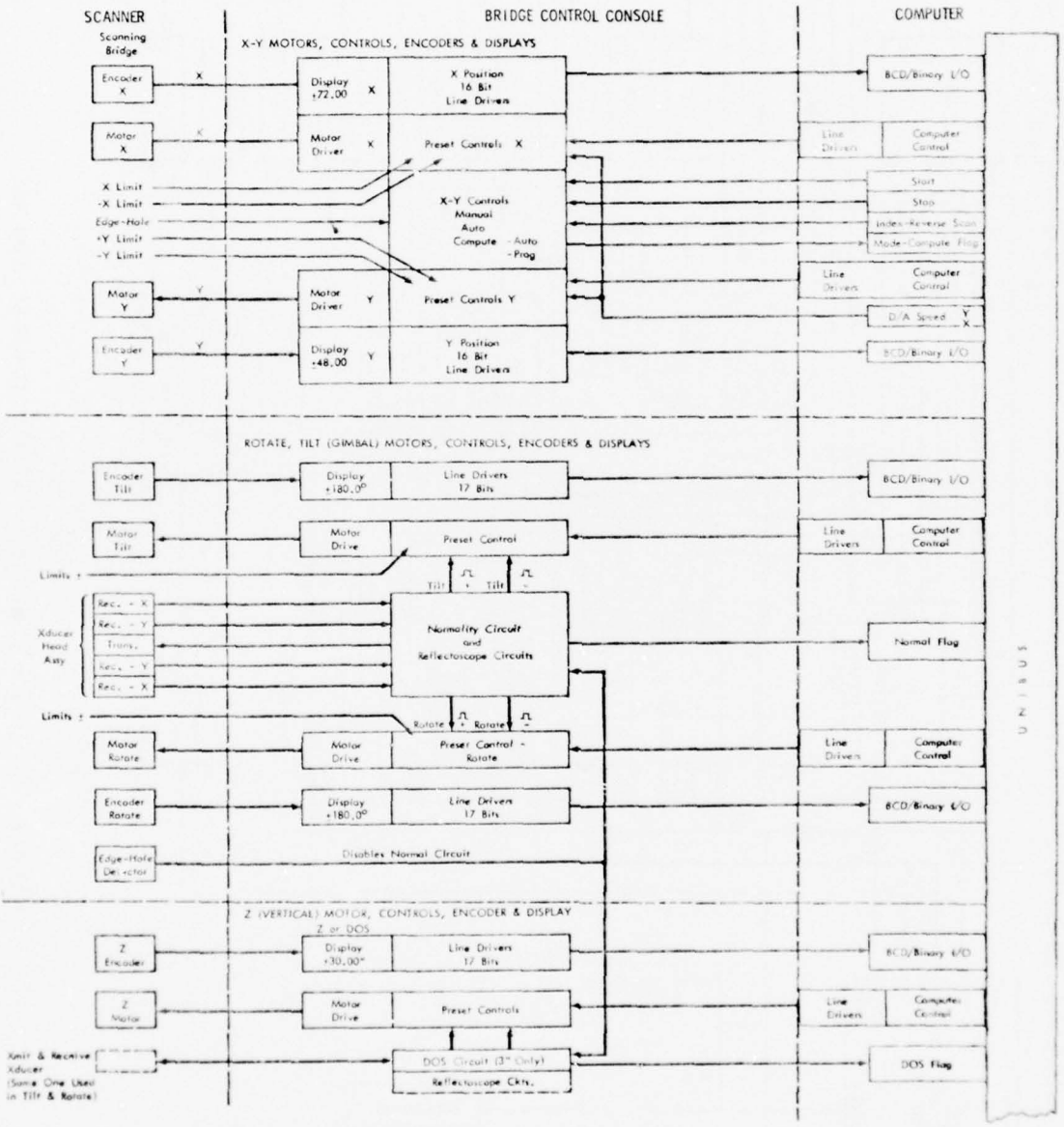


Figure 3 Block Diagram of Scanning System

DC stepping motors are used to drive the 5-axes (X, Y, Z, θ, ∅) and position encoders are used to provide the position of the five coordinates. The X, Y, Z, θ, and ∅ drive motors can be controlled in manual, automatic, or computer modes. The Z, ∅, and θ can also be controlled automatically from special ultrasonic and electronics servo feedback circuits which maintains standoff and normalcy. Figure 4 is a photograph of the scanner control console and ultrasonic unit.

3.2 SCANNING SYSTEM DEVELOPMENT

A scanner system has been designed to scan the complex shape of aircraft forgings and to provide accurate location of flaws (X, Y, Z, θ, ∅). The rate of scan can be faster than 6 inches second on relatively simple-shaped forgings, but it will be slower than 6 inches second for complex forgings. This section describes the X-Y mechanical scanner, test tank, gimbal assembly, normalcy control, and Z, θ, ∅ controls. Total hardware cost for the scanner and control system is $26,384.00.

3.2.1 X-Y Mechanical Scanner System

A prototype digital scanning system to be made by Automation Industries was selected early in the program. After negotiations on the exact characteristics of the system, Automation Industries submitted a tentative delivery schedule of late December 1973. This was unacceptable for the program schedule; therefore, only the tank was purchased from them; the bridge was built at General Dynamics and the electronics and motor were purchased as off-the-shelf or standard items.

3.2.2 Test Tank

The test tank has an inside dimension of 4 feet in width, 6 feet in length and 3 feet in depth. The tank has one 1-foot by 1-foot "see-through" window installed in the front for visual inspection inside the tank. The tank is rugged enough to hold a 3,000 pound forging for inspection. Provisions have been made to level and hold the forging off the bottom of the tank.

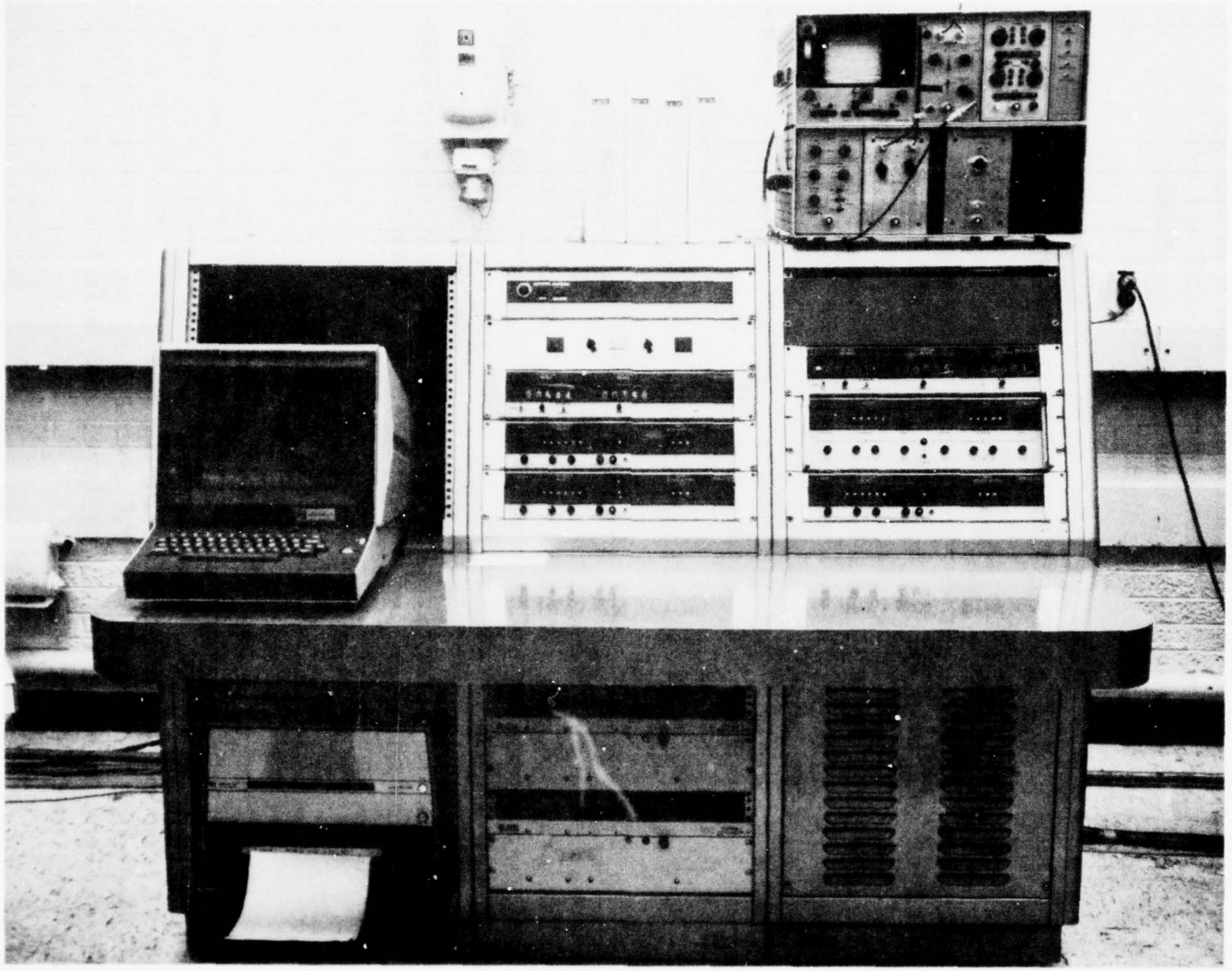


Figure 4 AFML Scanner Control Console with Ultrasonic Unit and Display System

3.2.3 X-Y Scanner

The general configuration of the scanner is shown in Figure 5. It will scan in either the X or Y axis and index in the other axis. The unit was assembled primarily from purchased parts, but some parts were manufactured by the Tooling Department, and the Tooling Department also assembled the unit.

The scanner frame is constructed from aluminum U channel and bolted to the top of the tank. The X-axis ways consist of diameter steel shafts, one inch in diameter, and support block made by Berg, Inc. Four ball bearing support brackets carry the bridge. These are fastened to two aluminum blocks that carry two one inch ground rods that act as supports for the Y-axis movement (platform).

The drive motors and gear boxes are positioned on the support frame and drive the bridge and platform through three sets of POW-R-TOW cable chains. Two sets of chains, one on each side of the bridge, are driven from a common line shaft to reduce the bending movement on the bridge. One long chain is wound around in the pattern shown in Figure 5 to drive the platform. As the bridge moves, the platform stays in the same relative position with respect to Y movement.

A more detailed description of the scanner and its control system is presented in Appendix B.

3.3 MANIPULATOR ASSEMBLY AND NORMALCY CONTROL

Two different types of commercial manipulator assemblies were studied. The approach selected used a modified Automation Industries US 743 search tube and manipulator top with a special transducer head and gimbal assembly built by General Dynamics. The method of maintaining normalcy for the stringent angular requirements of the program necessitated a special design of the manipulator.

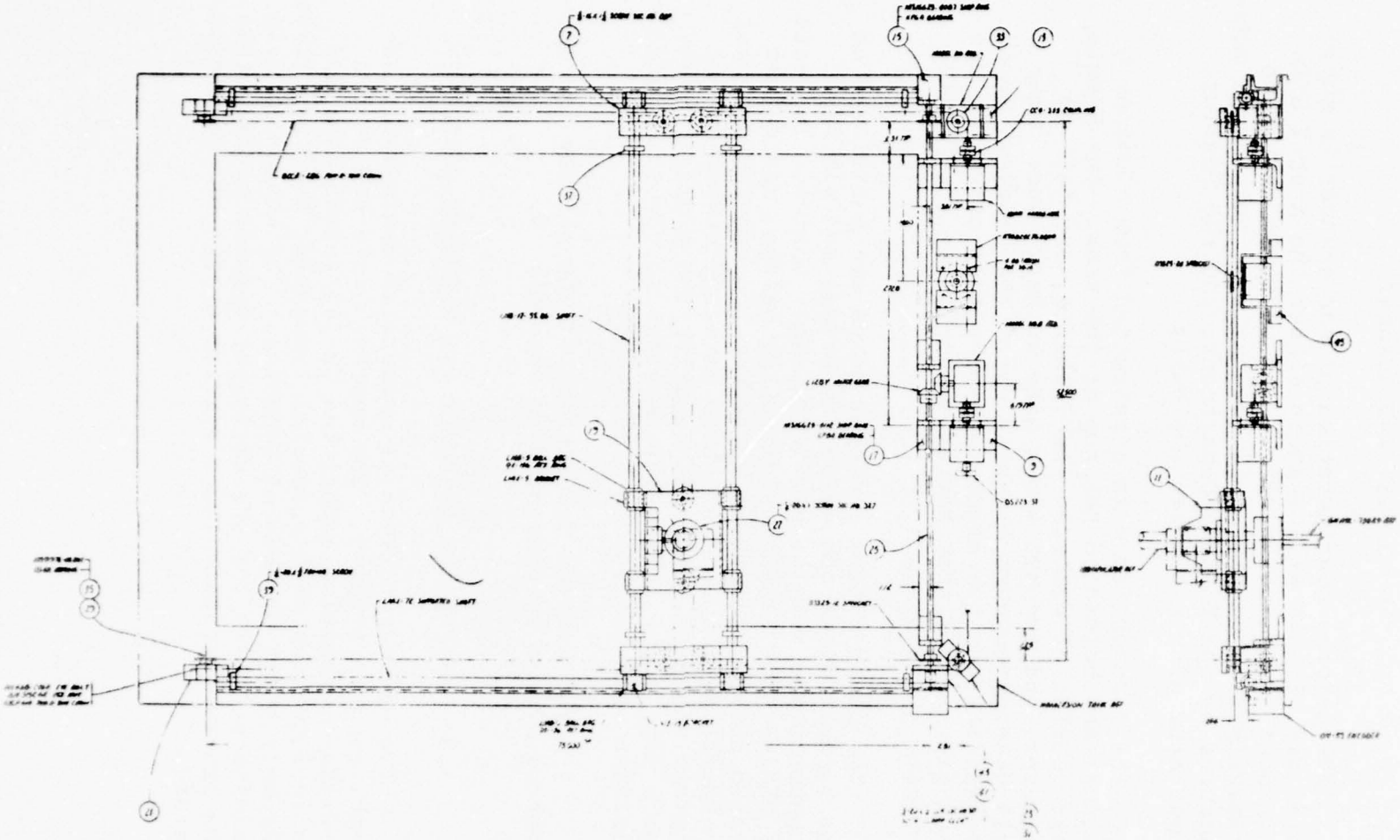


Figure 5 X-Y Scanner System

The manipulator is shown in Figure 6. The function of this unit is to manipulate the transmitting/receiving transducers in three axes, vertical, rotation, and tilt. Each function can be accomplished manually with independent and separate controls, or all of them can be operated together as a system to give automatic transducer standoff distance and normality (90°) control.

Each function has a separate motor, motor control encoder, and display that are discussed individually later. Position data from all three functions are fed by line drivers to the computer. The manipulator assembly, which moves vertically and does not include the vertical stepping motor and the casting housing it, weighs approximately 16 pounds.

3.3.1 Gimbal Assembly

A reproduction of the assembly drawing of the transducer head mechanism is shown in Figure 7. The mechanism attaches to the lower end of the modified Automation Industries UM 743 manipulator. The head mechanism which was designed by General Dynamics, was built by the Tooling Department.

The design allows the lower section of the Z-axis shaft to translate horizontally through a distance equal to the offset of the transducer axis intercept with the part surface whenever the transducer is tilted. That is, when the transducer axis rotates about a horizontal axis situated at a distance about the part surface, an offset (of the transducer axis intercept with the surface) is generated equal to " sin θ," where (θ) equals the tilt angle.

The lower section of the Z-axis shaft is then translated an equal amount in the opposite direction, keeping the transducer axis intercept on the Z-axis, independent of θ. A mechanical sine generator (Scotch yoke) accomplishes the horizontal translation as a function of θ. The system uses standard machine elements and includes a floating rack to transmit and transform rotary-to-linear motion from the stationary transducer tilt motor located on the Z-axis shaft.

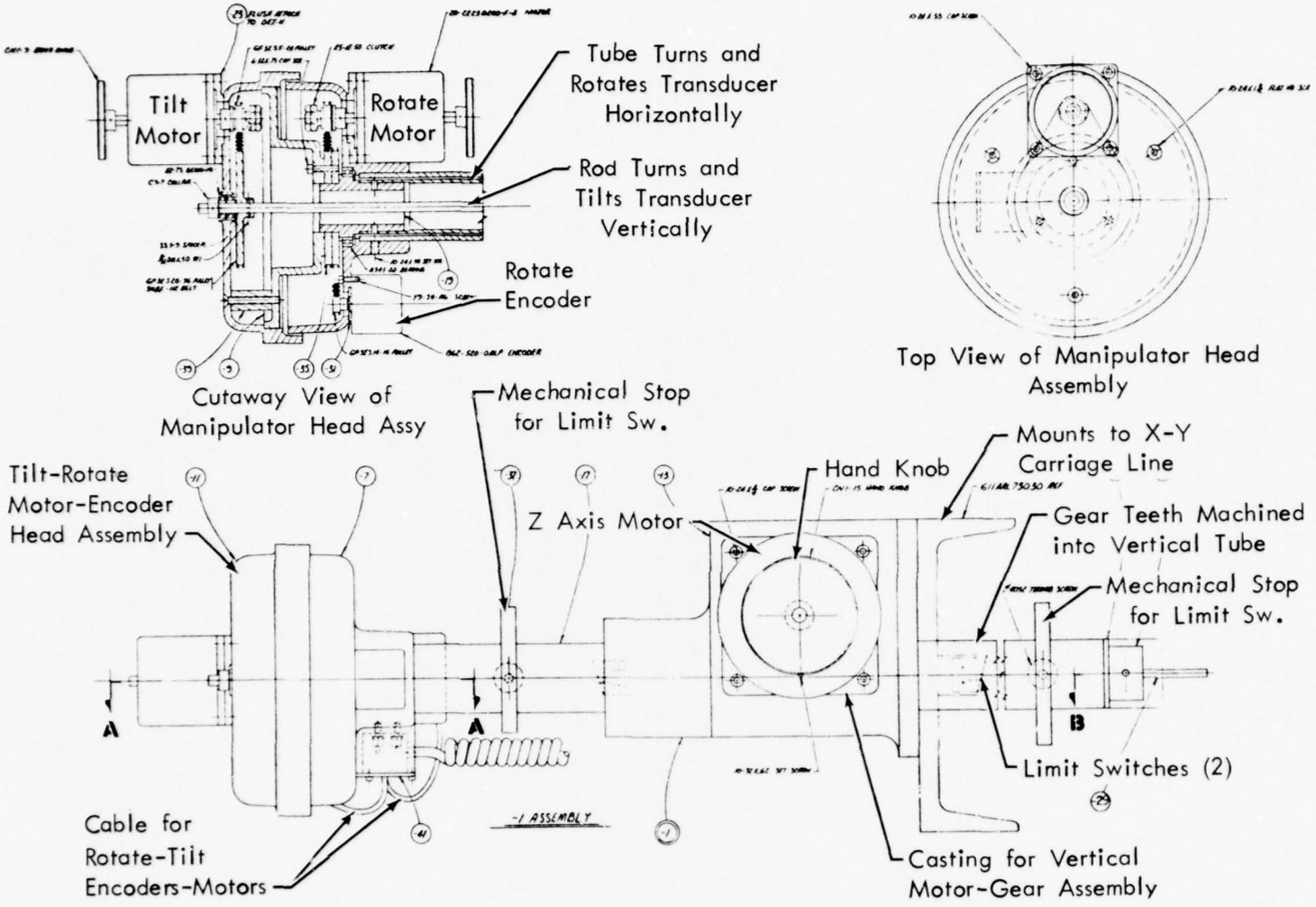


Figure 6 Vertical-Gimbal Manipulator Assembly

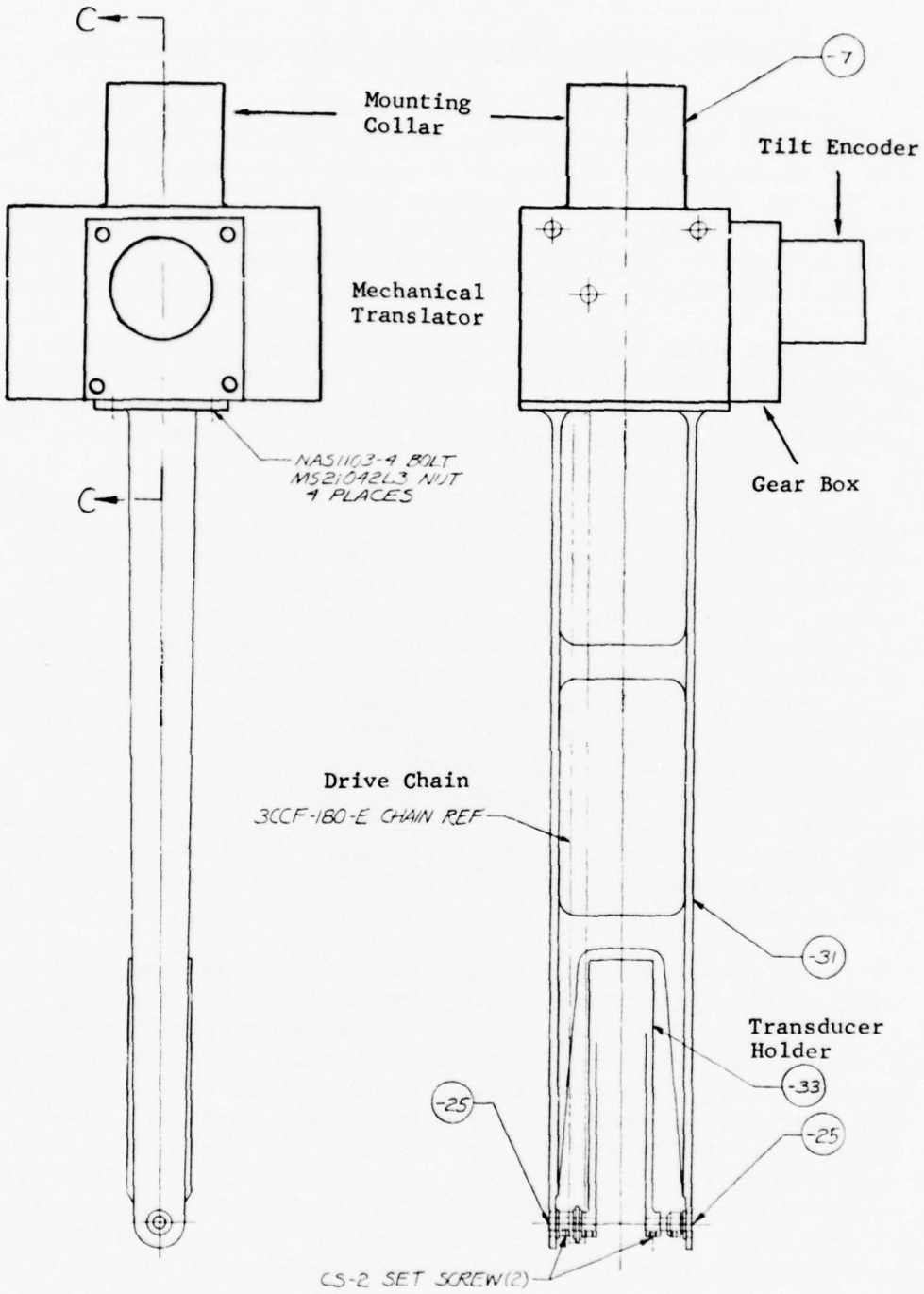


Figure 7 Assembly Drawing of Transducer Gimbal Mechanism

3.4 NORMALCY CONTROL METHOD EVALUATION AND SELECTION

General Dynamics considered several methods of maintaining the 90° angle between the scanning transducer and the forging before selecting the method described in paragraph 3.4.1. Some of these methods used capacitance probes, ultrasonics, and LVDTs. Another method uses microswitches whose actuators slide over the face of the forging. A brief discussion of the methods is given in this section.

Two methods of controlling the angles and standoff distance of the scanning transducer were evaluated in the laboratory. The methods are called (1) surface contacting sensors and (2) non-surface contacting sensors.

The surface contacting sensor consists of three small mechanical probes surrounding the scanning transducer at 120° increments. Each probe is mechanically coupled to a microswitch that controls a stepping motor. These three probes, switches, and motors control the rotation and tilt attitude or angle of the scanning transducer. The probes contact the test specimen or forging at all times except over holes and after specimen edges have been passed. The advantages of this type of attitude control are that it worked successfully as demonstrated in another General Dynamics program and it controlled the angle of the scanning transducer to $\pm 1/3$ of a degree. A disadvantage is the fact that it must contact the test specimen at all times and this limits the scanning speed to less than 6 inches per second on flat, smooth forgings.

The non-contacting sensor evaluated consists of three commercial capacitance probes surrounding the scanning transducer at 120° increments. Each capacitance probe, when placed near a conducting surface, forms a certain value of capacitance. This capacitance so formed is connected into the overall feedback loop of a high-gain amplifier whose input is a 16 KHz signal from an internal oscillator. Therefore the voltage level output of the amplifier is directly proportional to the capacitance value formed by the nearness of the probe to the conducting surface. This ac voltage output is proportional to the distance between the test specimen (forging) and the probe. The ac voltage is converted to a dc voltage and used to control a servo loop and stepping motor.

These capacitance probes responded faster than the mechanical probes; however, the capacitance probe servo systems would be more complex than the mechanical probe servo systems. The capacitance probes are also more susceptible to external noise than the mechanical probes, but they do not touch the test specimen, which is advantageous for high speed scanning.

3.4.1 Normalcy Method

The method selected for maintaining normalcy has one primary transmitting transducer and four receiving transducers located in a circle around the transducer. Two of these receiving transducers are in one axis (θ) and the other two are in the other axis (ϕ). If the transmitter transducer puts out a pulse that is reflected from the surface back into two of the receiving transducers, these receivers each put out an energy pulse. These pulses are shaped and fed into gating circuits which control a stepping motor. The stepping motor runs one way or the other, depending on which receiving transducer receives the reflected pulse first. Two more receiving transducers and a stepping motor control the second axis in the same manner.

3.4.2 Normalcy Receiving Transducer

The normalcy tilt and rotate sensing transducers were changed from 0.25 inch-diamter units to 0.125 inch-diameter units because the larger transducers resulted in the scanning head assembly being too large. The 0.125 inch diameter transducer produced signals approximately one-third as large as those from 0.25 inch-diameter units. Additional amplification had to be provided for the smaller transducers. This additional amplification was provided by wide band preamplifiers, which were inserted in the transducer cables. The preamplifiers receive power for operation and send output signals over the same 75 ohm coaxial cable. Figure 8 is a circuit schematic of the preamplifier showing its connection to the transducer and amplifier. Voltage gain of the preamplifier is approximately X5 or 14 db.

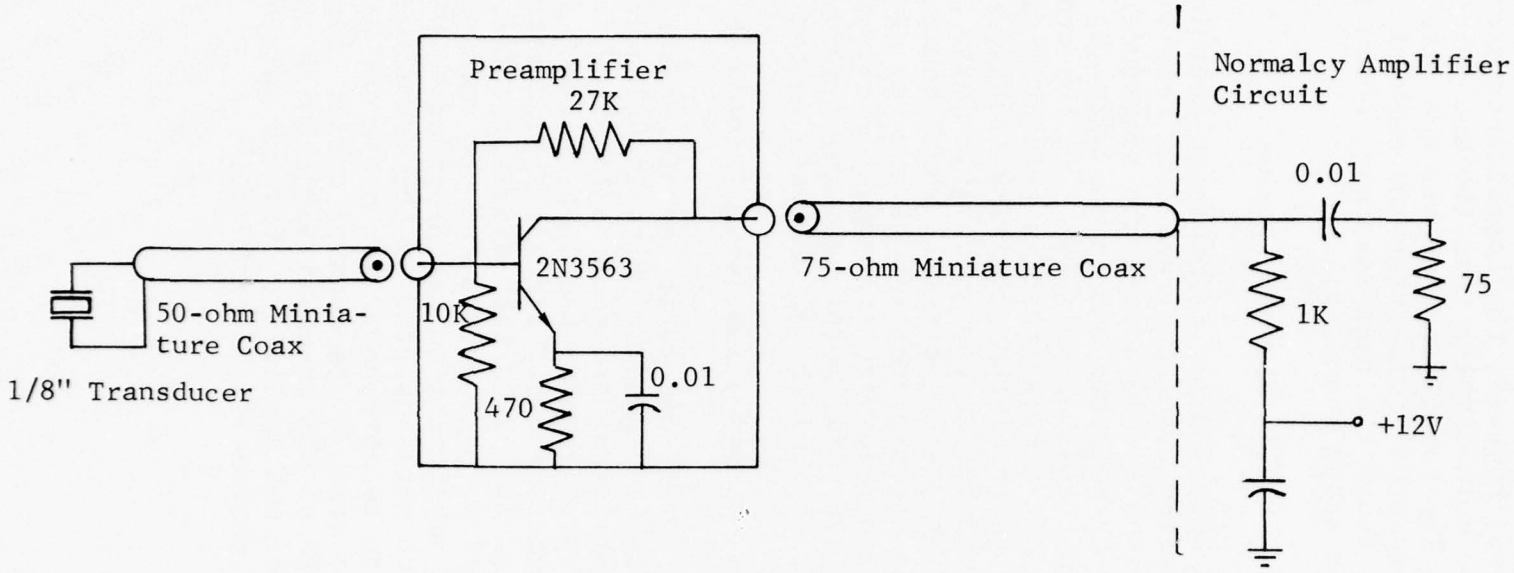


Figure 8 Preamplifier Circuit Schematic Showing Connection to Transducer and Normalcy Circuit

3.4.3 Normalcy Transmitting Transducer

The standard 2.7 inch focal length transducer used for reflection mode transmitting and receiving was replaced with a transducer with a convex lens with its center portion ground flat. This transducer was required to get the normalcy circuits to operate over the concave portion of the mound-type specimen. With the standard transducer over the concave surface, most of the energy reflected back between the two normalcy sensing transducers. The amount of signal received was too low and loss of control resulted. The special transducer caused broader scattering of the energy and more of it was received by the normalcy sensing transducers over the concave surface area. The reflection mode received signal is not as strong from the special transducer, and tests have shown that the sensitivity was not high enough to operate satisfactorily at maximum depths.

3.4.4 Contour Following

The amount of sound energy reflected from a discontinuity depends on the incident energy density, and the incident energy density depends, among other variables, on the distance between the transducer and the top of the test specimen and on the angle that the sound beam makes with the top surface of the test specimen. Hardware and software were developed to minimize the influence of these two variables, which will be called distance of separation (DOS) and normalcy for short. DOS was maintained constant but selectable during a scan. The details of hardware development to maintain a constant DOS is discussed in Appendix B. Almost all of the results discussed in this work were obtained with a DOS of 3 inches. The influence of angle of incidence was minimized by maintaining the sound beam normal to the top surface of the test specimen. The decision to do this was made even though the energy reflected from a discontinuity is influenced by the curvature of the test specimen. A detailed discussion on the effects of transducer size, radius of curvature, and depth of sound travel on the energy reflected from flat bottom holes is contained in report AFML-TR-703-107.[8] The effects of these parameters were not corrected for in this work.

Three schemes were used to maintain the sound beam normal to the test specimen. They are ultrasonic feedback, peaking of the top surface reflection using vector drive. The details of the hardware and software development for the ultrasonic feedback scheme are discussed in subsection B.2 and for the peaking of top surface reflection and vector drive schemes will be discussed in paragraph 4.6. The ultrasonic feedback scheme works well and is rapid, if the test specimen contained no radii smaller than 1½ inches. This scheme has been made operable on radii as small as 3/4 inch. However, the scan speed is extremely slow and thus renders the scheme unacceptable and not cost effective. Either the peaking or vector drive scheme can be and has been used for radii smaller than 1½ inches. Both schemes have been used successfully to maintain normalcy in scanning over 3/4 inch radii. A flat faced ½ inch diameter transducer was used in all the results described in this report. The vector drive scheme is faster and more effective than the peaking scheme.

All three schemes can be used to scan a test specimen. However, the operator has to select the scheme and input it into the computer before the scan is made.

Radii equal to and smaller than 3/4 inch in a test specimen are skipped over and not inspected during the initial scan. After the initial scan is completed the small radii can be inspected with either compressional or shear waves in subsequent scans. These subsequent scans do not require the operator to position the transducer over the inspection area. The computer is pre-programmed to return to the radii by noting the positions where the top surface reflections were lost and to scan the radii with either compressional or shear wave. The effectiveness in flaw detection with compressional wave at radii of 3/4 inch or smaller has not been tested in work. Elox slots placed on 3/4 inch and smaller radii have been found by shear wave.

3.5 SYSTEMS CORRECTION AND COMPENSATION

Parameters or factors other than those discussed in the previous section affect the uniformity of sensitivity and reliability of flaw detection. Two of these factors that will be discussed in this section are attenuation and

sound beam spread. In order to obtain an equal amplitude signal from a discontinuity of equal size but located at different depth in the test specimen, the effects of attenuation and sound beam spread have to be compensated. A hardware distance-amplitude compensation (DAC) instrument was tried. This instrument was the DAC unit built by Automation Industries for their UM 771 reflectoscope. The DAC unit can be and has been made operable. However, it required too many adjustments and was too sensitive to small changes of several parameters. Since the unit was found to be impractical and it has not been used in conjunction with any of the results obtained in this work.

A software DAC was developed. It can be operated in real time or during post-inspection analysis. It consists of a table of minimum flaw amplitude (MFA) as a function of flaw depth. If the flaw amplitude is smaller than the MFA at a given depth, it is not displayed as a flaw. If the flaw amplitude is larger than the MFA, it is diminished to the level of the MFA. The reason for this procedure is dictated by the calibration procedure that was used. In this work, a desired size flat bottom hole located near ($\frac{1}{4}$ inch) the bottom of the thickest section of the test specimen under inspection was used. A same size FBH with the same orientation located anywhere in the test specimen will produce an amplitude larger than the one used for calibration.

The software DAC unit only partially corrects for the size or cross-sectional area of a flaw or FBH in the C-scan presentation. That is, the size of the C-scan presentation for a same size FBH located near the top surface will be different from the one located near the bottom surface of a test specimen. The radiation pattern and beam spread of the transducer have to be controlled to correct for this effect.

The flow diagram and the details of the software DAC are presented in Appendix D.

3.6 TRANSDUCER SELECTION AND CORRECTION

Flat-faced, 0.50 inch diameter, and 5 MHz medium damp (2 to 3 cycles of oscillation) transducers were found to be the most appropriate or the compromised choice in satisfying the objectives of this work. Transducers of 0.25, 0.50 and 0.75 inch diameters with flat, concave, and convex lens were evaluated. Focused transducers (concave and convex) produced highly variable energy density within the test specimens as a function of material thickness and surface contour. Attempts to obtain equal flaw detection sensitivity met with considerable difficulty. Further, they cannot be operated as near the edge or holes of the test specimen as the flat-faced transducers can. They produce a reflected signal from the edge further away from the edge than flat transducers. They also complicate the logic circuits used for the ultrasonic feedback scheme to maintain the sound beam normal to the test specimen.

Transducers with a 0.25 inch diameter were found to be only partially effective in detecting flaws between 3 to 6 inches deep in the test specimens. Use of a 0.75 inch diameter transducers cause the transducer housing assembly to be too large to effectively scan or follow contours with radii equal to and smaller than 0.75 inch.

Lightly damp transducers have too much ringing to be usable for detecting flaws near the top surface (0.25 inch) of the test specimen or for inspecting thin materials (0.25 inch). For many applications, it is highly desirable to inspect 3- or 4-inch-thick materials and still be able to detect flaws located about 0.05 inch from the top surface. Highly damp transducers generally do not have sufficient energy to penetrate and detect flaws located several inches (4 to 6 inches) deep in most metals.

Flat-faced, medium damp, and 0.50-inch-diameter transducers operating with center frequency of 2.25 and 10 MHz have also been used, and they have been found to be effective in meeting the objectives of this work.

Transducers with the sound beam slightly off the axis or the normal to the plane of the transducer can be and are corrected for before each inspection by peaking the reflected signal from the bottom surface of a parallel calibration test specimen.

3.7 ULTRASONIC INSTRUMENTATION

The function of the ultrasonic equipment is to generate pulses of ultrasonic energy, couple this energy into the specimen under test, couple the reflected energy to a receiver, and process the received information for interfacing to a computer. A certain amount of signal conditioning, synchronization, and chronometry are necessary to prepare the data for computer interfacing. The system block diagram is shown in Figure 2. The system will operate in three modes of inspection: reflection, shear-wave and Delta Scan.

The ultrasonic equipment consists of the transducers, an ultrasonic test instrument, and interface circuits to couple data to and from the computer. The system consists of the following units.

3.7.1 Ultrasonic Test Unit

The ultrasonic test unis is an Automation Industries Type UM 771 reflectoscope that has circuit modifications and circuitry added to make it perform the desired functions. This unit was selected for the program because it was all solid state and required the least modification. The system consists of

- UM 771 Display Chassis
- Type AGIFM Timer Module
- Pulser/Receiver Type 10S DB
- Dual Type H Transigate
- Special-Function Chassis
- Distance-Amplitude-Compensation Unit (DAC)
- Pulser Type 10S

The system outlined above was purchased by General Dynamics in support of the contract. The modification and additional circuits required for interfacing the ultrasonics with the computer were made by General Dynamics. The total cost of the ultrasonic system including modifications was $24,721. A complete description of interface circuits and modifications is detailed in Appendix A. A photograph of the ultrasonic system is shown in Figure 9.

3.8 COMPUTER SYSTEM AND SOFTWARE

This section describes the computer hardware and software configuration at the completion of technical phase of the contract, the standard equipment, and subsystems built by General Dynamics.

3.8.1 Hardware Configuration

The Digital Equipment Corporation (DEC) PDP 11 Model 45 Computer is the center of the system. Figure 10 is a block diagram of the system. Table 1 is a list of the devices that make up the system. The cost of the computer system is $69,855.00.

3.8.1.1 Central Processor Unit

The central processor unit (CPU) controls the time allocation of the UNIBUS for peripheral and performs arithmetic and logic operations and instruction decoding. The processor can perform data transfers between I/O devides at a maximum rate of 2.5 million 16-bit words per second.

3.8.1.2 Memory

The system utilizes 20K 16-bit words of random-access memory (RAM) divided into two types - core and MOS solid-state. There are 16K of core (900 nsec) and 4K of high-speed solid-state memory (450 nsec). The 4K of MOS memory resides in the upper 4K of the system (16K to 20K). This configuration was chosen to take advantage of the faster operation speed in the program execution sections of the memory stack.

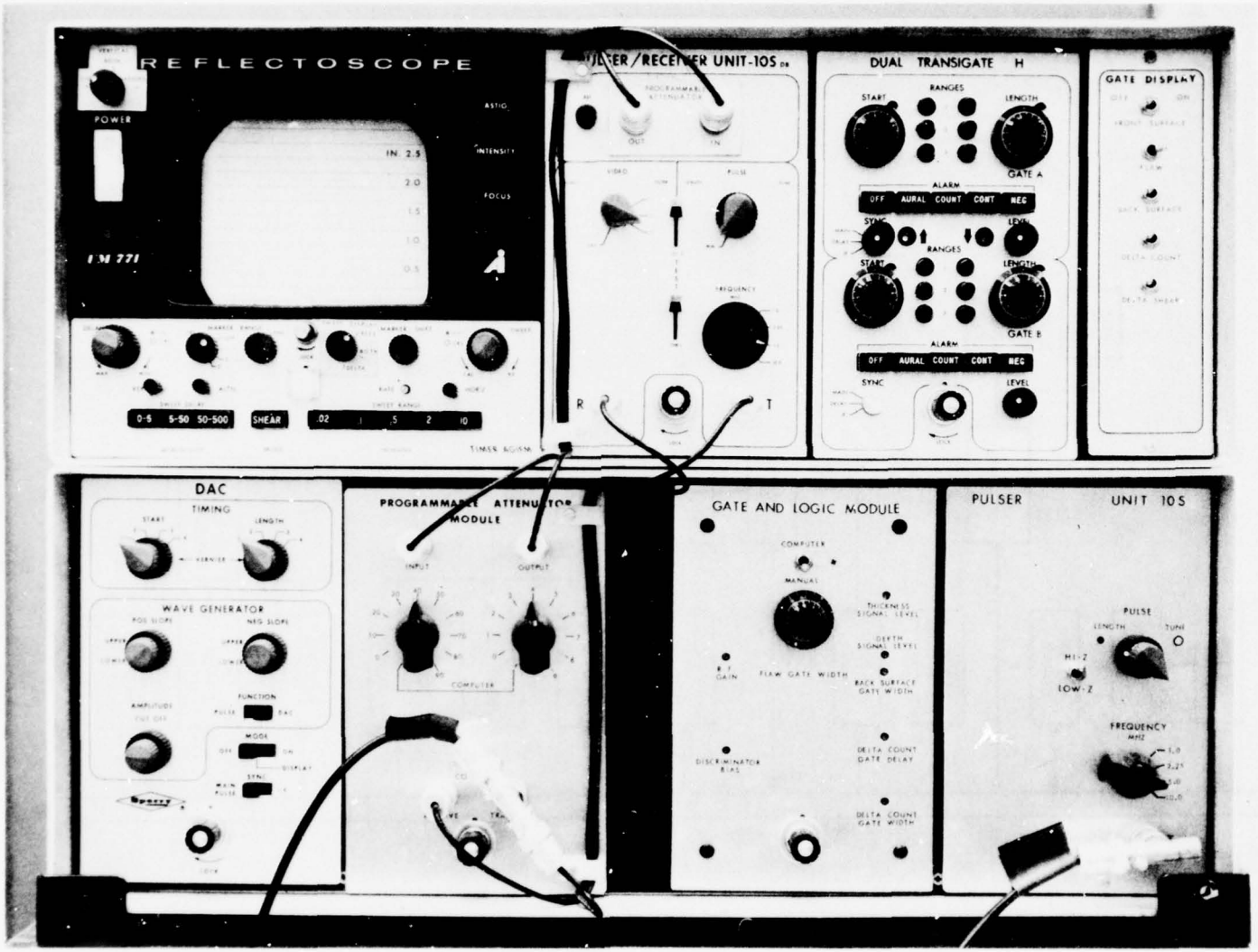


Figure 9 Ultrasonic Test Unit for Computer Automated System

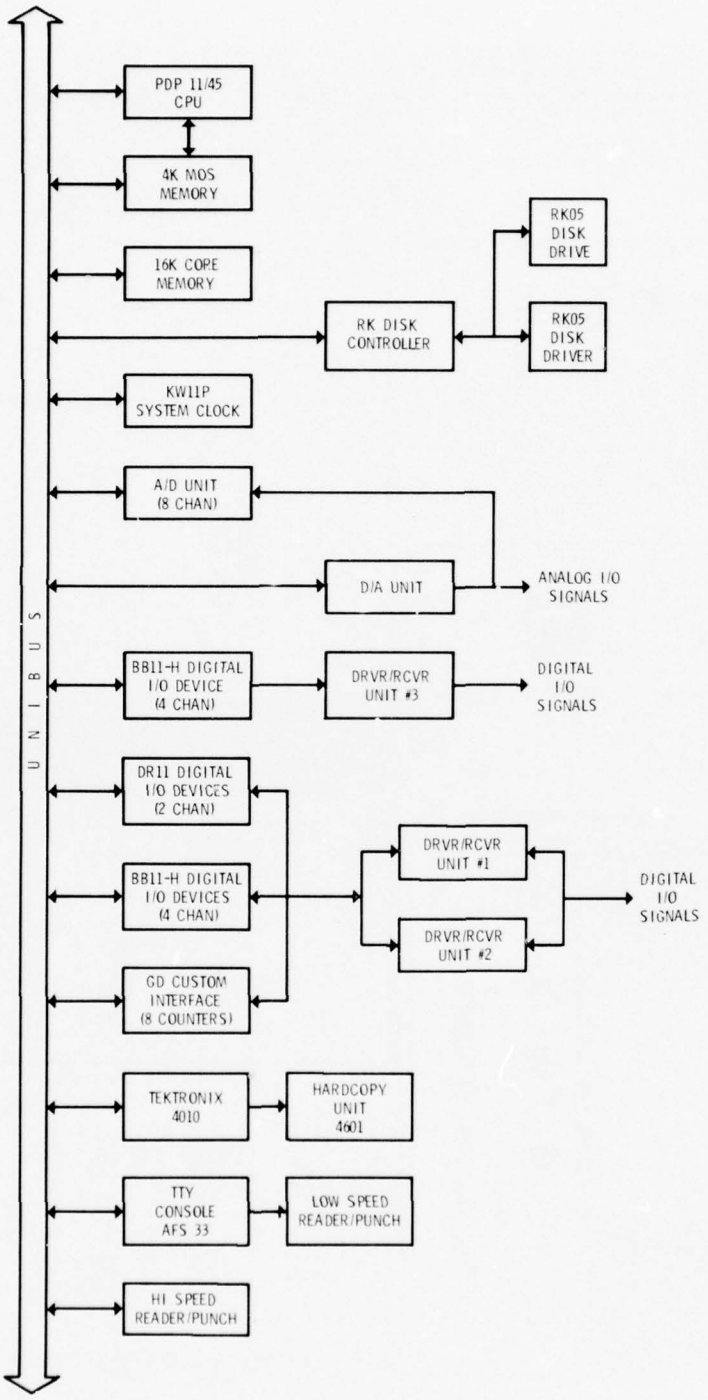


Figure 10 Computer System Configuration

TABLE 1

COMPUTER SYSTEM EQUIPMENT LIST

ITEM	QUANTITY	DESCRIPTION
PDP 11/45A	1	Central Processor Unit
MS11-BM	1	MOS Memory (4K Words)
MELL-L	1	Core Memory (16K Words)
RK11	1	Disk Controller
RK05	2	Disk Drive Units
AD11	1	Analog-to-Digital Subsystem (8 Analog Input Channels)
AA11	1	Digital-to-Analog Subsystem (4 Analog Output Channels)
DD11	1	Digital Input/Output Devices (2 Channels)
BB11	3	GD Custom Interfaces (Counter Unit and RCR/DRVR Unit)
BB11-H	2	Digital I/O (7 Channels)
KW11-P	1	Programmable Real Time System Clock
PC11	1	Hi-Speed Reader/Punch Subsystem
4010*	1	Graphi Display Terminal
4601*	1	Hard Copy Device
ASR33	1	Teletype Console

*Tektronix Part Number

3.8.1.3 Disk System

The RK disk system is a standard DEC device. The RK11 controller is capable of controlling eight (8) RKØ5 drive units, each of which has an average access time of 70 milliseconds, data transfer time of 11.1 microsecond per word and a storage capacity of 1.2 million 16-bit words. This system has two (2) RKØ5 drive units, for a total storage capacity of 2.4 million words.

3.8.2 Software

The software necessary to automate the inspection of components with ultrasound (using three different ultrasonic techniques and two schemes) to perform analysis on inspection results, and to process ultrasonic information (RF signals) for spectroscopic analysis resulted in the development of two data acquisition programs and three analytic programs.

The programs were developed using Digital Equipment Corporation disk operating system version 8.02 on a PDP 11/45.

3.8.2.1 Discussion of Programs

The programs were developed for specific scanning schemes. Two programs, 'AFML A' and 'AFML C', are used for rectangular scans. Their counterparts, 'AFML B' and 'AFML D', are used in circular scan modes. The 'Fourier' program is used for flaw orientation and characterization, and as such, it performs an optional search pattern.

The program size in certain cases made the use of overlays necessary. A program that uses an overlay structure is divided into functional segments that need not be in computer memory (core) at the same time. As each function is required, the overlay is loaded into memory. Figure 11 shows the overlay structure used in this program.

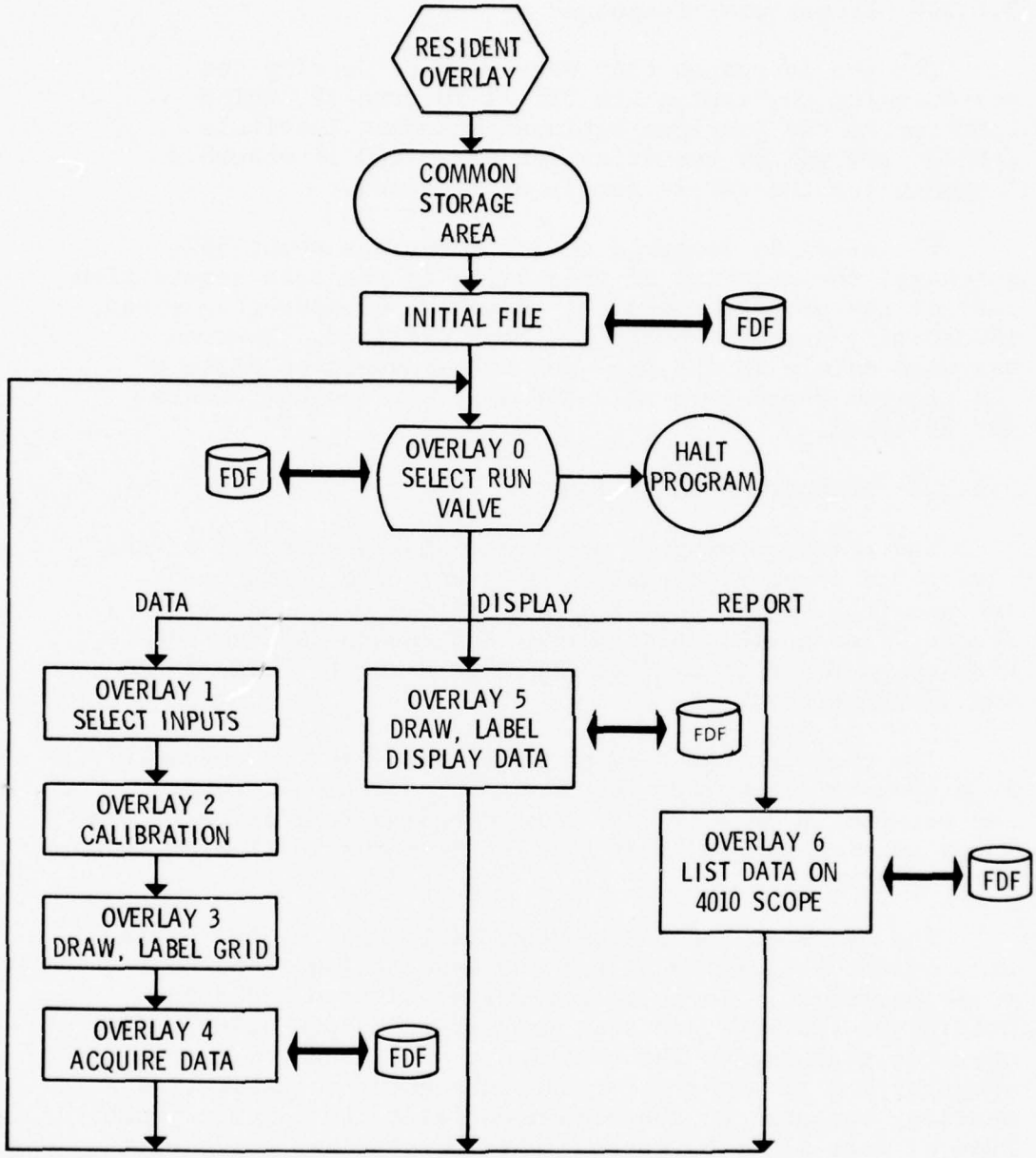


Figure 11 Flow Diagram for Resident Main

3.8.2.2 Programming Languages

The two languages that were used to develop the software for the system are PDP-11 Fortran IV, which conforms to the American National Standard Institute (AMSI) FORTRAN IV specification and MARCO 11 assembly language for the PDP-11 family of machines.

The assembly language coding comprises about 58% software, the majority of this being in the data acquisition part of the program where the advantage of operating speed, flexability and core usage are best utilized. Fortran was used mainly in the pre- and post-inspection phase of the program where core size and speed of operation were not critical.

3.8.2.3 Software Description

The software program provides computer control of the ultrasonic inspection system in a real-time environment, analyzes the sensor data for indications of anomalies, records flaw anomalies on disks, and generates flaw data - displays and reports. (See Appendix D for the algorithms and flow charts).

The computer has been programmed to aid the operator in preparing a complete record of the ultrasonic test. The program is versatile so that needless repetition of the input parameters can be avoided by proper selection of the command string.

The operator has two selections to make at the beginning of the program to select the type of input and test to be performed. These selections are listed under the heading of run mode and scan mode as presented below. The operator response to the question or run mode tells the computer how to prepare for the subsequent operation. The operator response to the scan mode tells the computer what type of data is to be taken. The operator can reply with any of the following responses (depending upon the mode selection made).

Question	Operator Response*	Computer Response
Run Mode =	IN (ITIAL)	Prepare new data files and prepare for new input test description files. Remove data from DK1. Cleans the disk.
	DA(TA)	Prepare to take data using the previously input test description files. A new run number must be given to each scan to separate the files for retrieval.
	RE(PORT)	Prepare a table on the CRT of the 4010 of any input test description files and test data for any described area and flaw threshold level.
	DI(SPLAY)	Prepare a graph on the CRT of selected input test description files and test data for any described area and flaw threshold level.
	LI(ST)	Prepare a list of the run and part name, scan mode, and % of disk used for the disk pack that is on DK1 (top drive).
	DE(LETE)	Deletes the last data run and specimen input information from DK1.
	HA(LT)	Stops the program operation and returns the computer to the DOS monitor control.
Scan Mode=	RE(FLECTION)	Prepare for reflection test operation or data display from a previous scan.

Question	Operator Response*	Computer Response
	MU(LTI-GATE)	Prepare to operate in multi-gate mode for test data or display.
	SH(EAR WAVE)	Prepare for shear wave test operation or data display from a previous scan

3.9 DATA DISPLAY TECHNIQUES

This section describes the different types of flaw display modes that the system is capable of providing. The primary display for the original inspection is the conventional C-scan recording. The post-inspection mode allows the operator to expand a particular area to full screen size for more detailed examination, to perform flaw amplitude discrimination, and to perform spatial filtering to remove flaw indications from any portion of the component. The system also has an isometric display mode that has all the features mentioned above plus, it provides the amplitude profile in X and Y direction. The system is also capable of performing a flaw homing routine to determine the flaw orientation.

3.9.1 Original Inspection Records

The original real-time inspection record for both the rectangular and circular scan modes are the C-scan type. The scan area display is orientated on the screen to provide a maximum size display. The information pertaining to the inspection such as, time, data, attenuator setting, type of scan, and part description are displayed on the bottom of the screen. An example of this type of display is shown in Figure 12.

3.9.2 Magnification of Display

The system can magnify or expand a particular area of the test specimen. Figure 13 shows a post-inspection display of the area from 3.5 to 4.5 in the X axis and 3.5 to 4.5 in Y axis, which contains a 5/64 inch FBH 3 inches

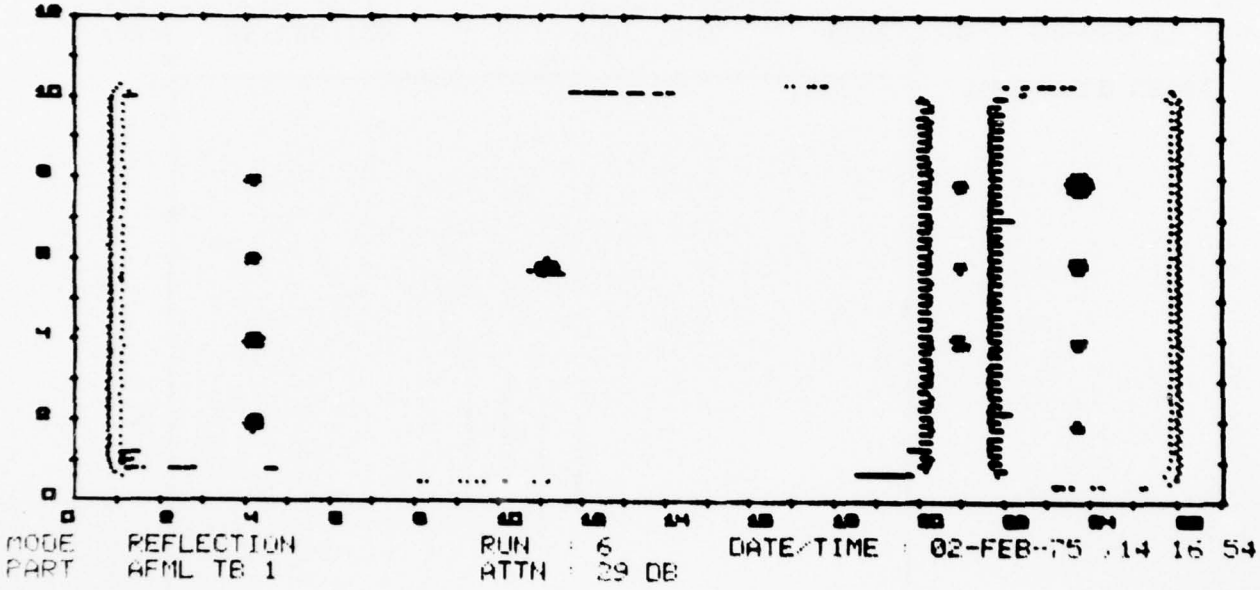


Figure 12 Near-Real Time Inspection Record

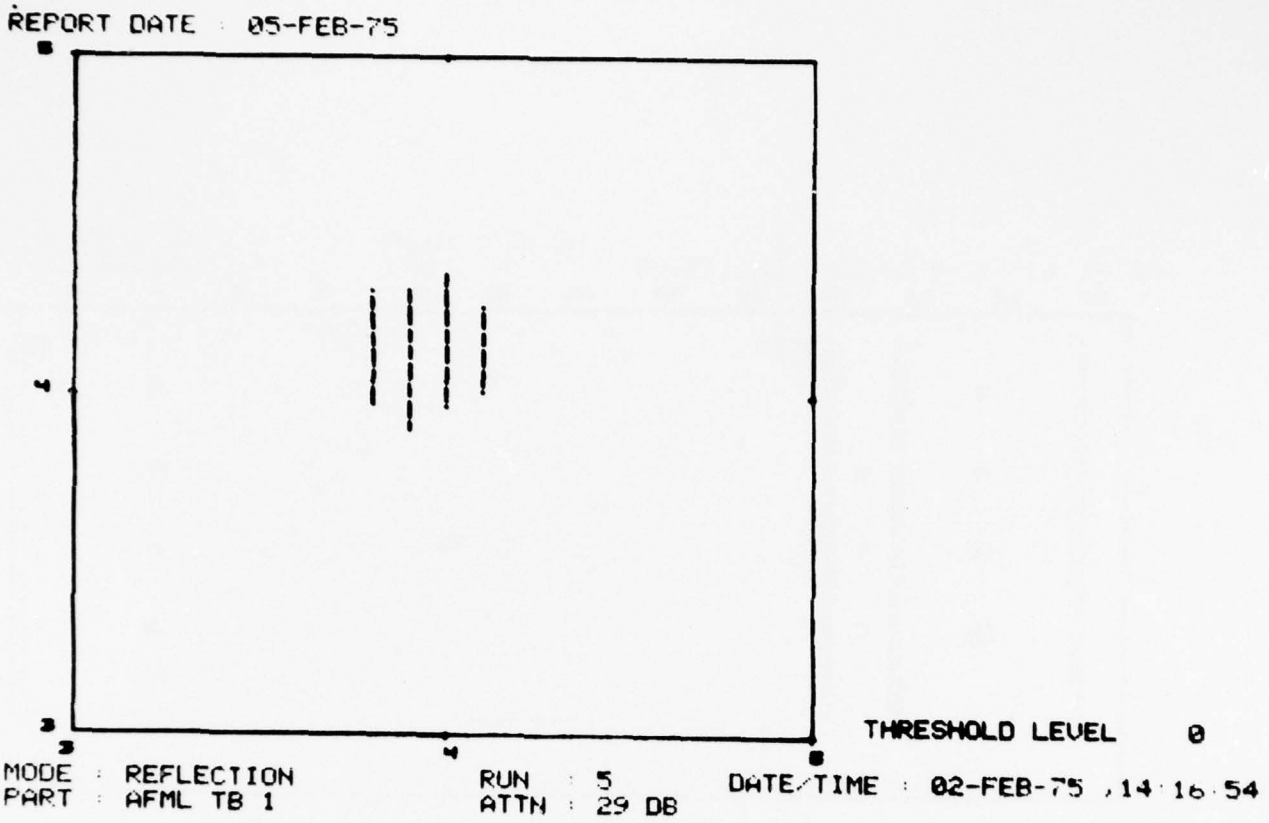


Figure 13 Post-Inspection Expansion of 5/64 FBH

deep, of the real-time inspection shown in Figure . This provides a magnification of 2X. This display is for all flaw indicators above 20% of the calibrated reflectoscope screen height.

3.9.3 Isometric Display

This form of display was developed to aid in visualizing flaw size and shape. It displays the amplitude profile over a potential flaw area. The conventional C-scan recording describes a potential flaw area with a fixed but selectable amplitude level. The isometric display presents the maximum amplitude above a threshold level over a potential flaw area. Figure 14 is an isometric display of the 5/64 inch FBH as shown in Figure 13. The pertinent run information is displayed on the screen. Amplitude discrimination and spatial filtering can also be applied to the isometric display as well as to the conventional C-scan presentation.

3.9.4 Spatial Filter

A spatial filtering technique was developed for use in examining the inspection results in more detail. This technique enables flaw indications existing in any portion of the test specimen under inspection to be deleted from the C-scan display. Since the computer records the coordinates (X, Y, Z, θ and ϕ) and the depth of the flaw indications, deletion of flaw indications from any portion of the test specimen can be accomplished by simple computer instructions. Flaw indications from surface irregularities, edges, etc. can be filtered from the display. Spatial filtering can be developed to fit the final or net shape of a component to a rough forging that contains flaws. Applications and usefulness of spatial filtering to aid in data interpretation are described in subsection 4.5 Inspection Results.

3.9.5 Report Mode

The report-generating routine is used to display the pertinent inspection information in tabulated form. It provides a cover sheet containing all the pertinent parameters

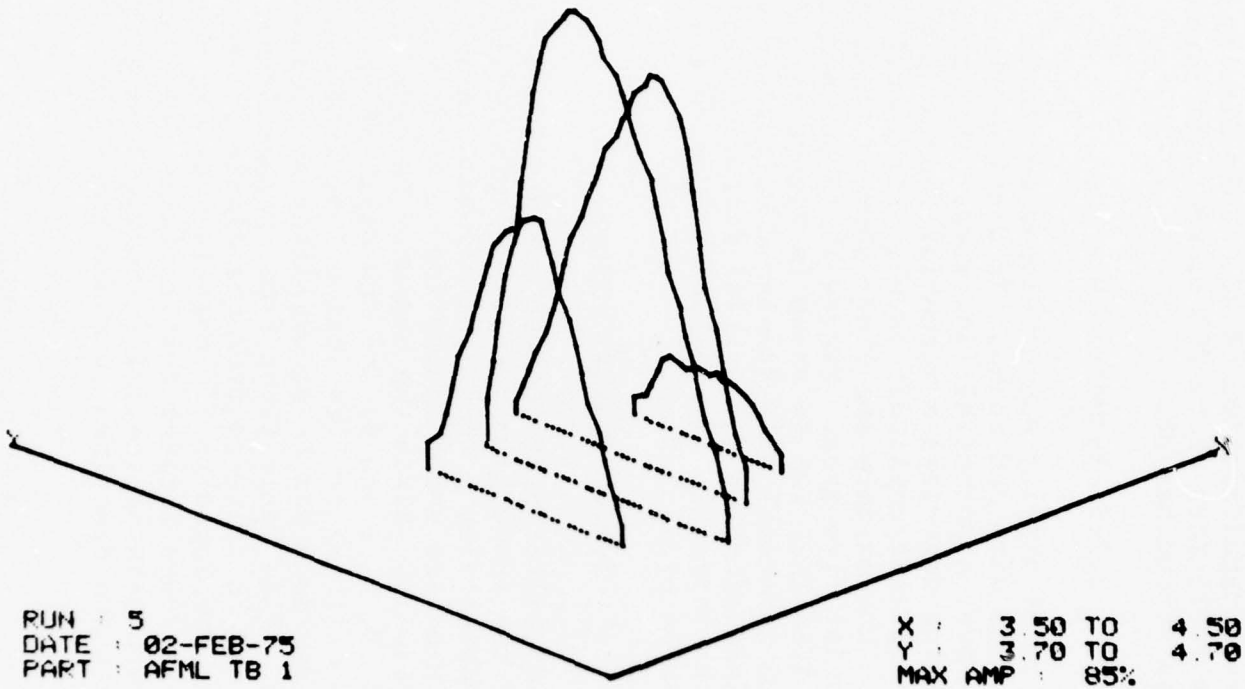


Figure 14 Post-Inspection Isometric Display of 5/64 FBH

about the inspection such as operator name, run start time, run stop time, frequency of inspection, transducer serial number, etc. Figure 15 is a display of the cover sheet. Figure 16 is a display of a typical page of data for the compressional mode.

3.10 POST INSPECTION ANALYSIS

This section describes the different types of post-inspection analysis that can be performed. These include amplitude discrimination and filtering of the stored data, flaw homing to determine flaw orientation, and ultrasonic spectroscopy to determine size and shape of flaws.

3.10.1 Amplitude Discrimination

The system can do amplitude discrimination. That is, the C-scan recording can be displayed at any less sensitive but selectable amplitude level with respect to the initial gain setting. The data displayed in Figures 17 and 18 are for the same 5/64 inch FBH as in Figure 13; however, the display in Figure 17 is for 40% of screen height and Figure 18 is for 80% of screen height. Amplitude discrimination provides a very expedient means to automatically reject flaw indications without operator intervention.

3.10.2 Spectroscopy

Ultrasonic spectroscopy is the study of modifications in ultrasonic frequency spectra caused by interactions between a sound beam and a scatterer. It was suggested by O. R. Gericke[9] as a means for determining the size and shapes of the scatterer. Although still in its infancy with successes limited to highly idealized shapes and sizes, its measurement potential has been extended to include the material properties of the scatterer.

3.10.2.1 RF Digitizer

Figure 19 is a block diagram of the equipment used to obtain ultrasonic spectroscopy data. The equipment consists of (1) an oscilloscope (Tektronix Type 555), (2) a scanning scope (HP 175A with 1726A plug in), (3) a digital

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REFLECTION MODE DATA REPORT      19-MAR-75   13:18:09     PAGE   1

 RUN INFORMATION

 RUN NUMBER   :  5                      PART NAME     :  AFML TB 1
 DATE         :  02-FEB-75              PART NUMBER   :  #1
 START TIME   :  14:16:54               OPERATOR      :  JSK
 STOP TIME    :  14:29:20               TEST SITE     :  GD/FW/AML

 CALIBRATION INFORMATION

 MATERIAL THICKNESS   :  3.70 IN.    TEST MATERIAL   :  ALUMINUM
 TEST FREQUENCY       :   5.0 MHZ.   TRANSDUCER NO.  :  1003
 ATTENUATOR SETTING   :    29 DB.    REFERENCE STD.  :  5/64 FBH
 FLAW AMPLITUDE @80%  :  3314

 SCAN INFORMATION

 SCAN TYPE        :  RECTANGULAR     SCAN LIMITS   :  X =  0.00 TO 12.00 IN.
 SCAN DIRECTION   :  Y                               Y =  0.00 TO 27.00 IN.
 INDEX INCREMENT  :   100 MILS
 SCAN SPEED       :  6.00 IN/SEC

 FILTER LIMITS FOR REPORT

 AMPLITUDES ABOVE :     0            AREA INSIDE   :  X =  7.00 TO  8.00 IN.
 DEPTHS ABOVE     :  3.70 IN.                        Y =  3.00 TO  5.00 IN.
 DEPTHS OUTSIDE   :  0.00 TO  0.00 IN.
 DEPTHS OUTSIDE   :  0.00 TO  0.00 IN.
```

Figure 15 Post-Inspection Report Cover Sheet

REFLECTION MODE DATA REPORT 19-MAR-75 13:19:09 PAGE 2

X	Y	Z	ROTATE	TILT	THICK	DEPTH	AMPLT	FS/BS GATE
7.80	4.09	-0.03	0.0	0.0	3.49	2.54	62	
7.80	4.10	-0.02	0.0	0.0	3.49	2.55	148	
7.80	4.11	-0.02	0.0	0.0	3.49	2.54	199	
7.80	4.12	-0.02	0.0	0.0	3.49	2.55	245	
7.80	4.13	-0.02	0.0	0.0	3.49	2.54	243	
7.80	4.15	-0.02	0.0	0.0	3.49	2.55	227	
7.80	4.16	-0.02	0.0	0.0	3.49	2.54	177	
7.80	4.17	-0.02	0.0	0.0	3.49	2.55	123	
7.90	4.25	0.03	0.0	0.0	3.49	2.54	163	
7.90	4.24	0.03	0.0	0.0	3.49	2.54	354	
7.90	4.23	0.03	0.0	0.0	3.49	2.54	543	
7.90	4.22	0.03	0.0	0.0	3.49	2.54	732	
7.90	4.20	0.03	0.0	0.0	3.49	2.54	959	
7.90	4.19	0.03	0.0	0.0	3.49	2.53	1104	
7.90	4.18	0.03	0.0	0.0	3.49	2.54	1284	
7.90	4.17	0.03	0.0	0.0	3.49	2.54	1454	
7.90	4.16	0.03	0.0	0.0	3.49	2.54	1547	
7.90	4.14	0.03	0.0	0.0	3.49	2.54	1613	
7.90	4.13	0.03	0.0	0.0	3.49	2.54	1630	
7.90	4.12	0.03	0.0	0.0	3.49	2.53	1628	
7.90	4.11	0.03	0.0	0.0	3.49	2.53	1562	
7.90	4.09	0.03	0.0	0.0	3.47	2.54	1476	
7.90	4.08	0.03	0.0	0.0	3.49	2.54	1373	
7.90	4.07	0.03	0.0	0.0	3.49	2.54	1229	
7.90	4.06	0.03	0.0	0.0	3.49	2.54	1141	
7.90	4.05	0.03	0.0	0.0	3.49	2.53	1012	
7.90	4.03	0.03	0.0	0.0	3.49	2.53	891	
7.90	4.02	0.03	0.0	0.0	3.49	2.53	776	
7.90	4.01	0.03	0.0	0.0	3.49	2.54	681	
7.90	4.00	0.03	0.0	0.0	3.49	2.53	578	
7.90	3.98	0.03	0.0	0.0	3.49	2.53	466	
7.90	3.97	0.03	0.0	0.0	3.49	2.54	393	

Figure 16 Post-Inspection Typical Report Data Sheet

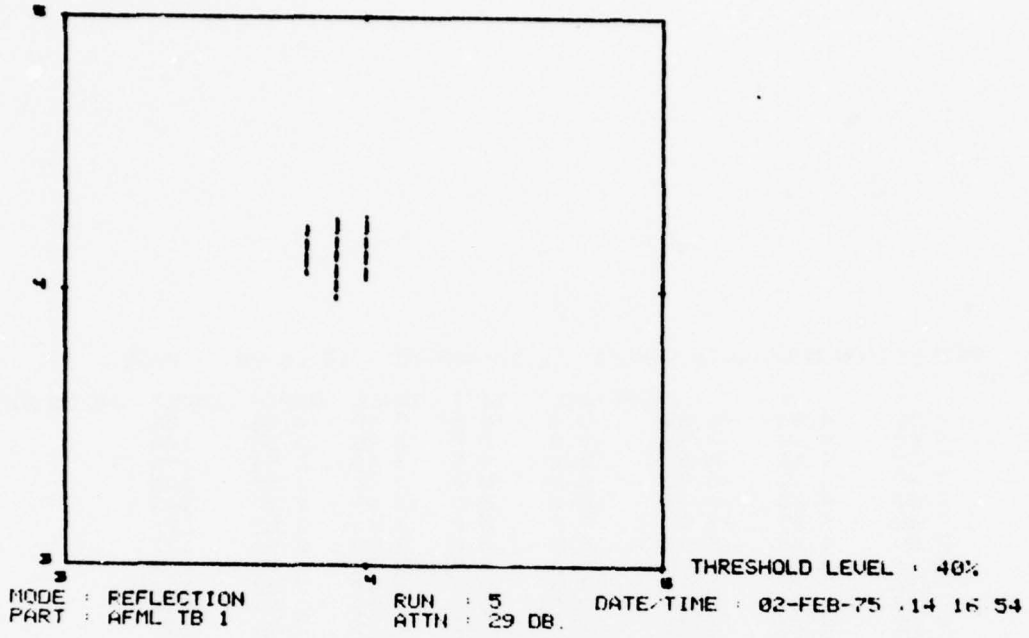


Figure 17 Post-Inspection Expansion of 5/64 FBH with 40% Threshold Level

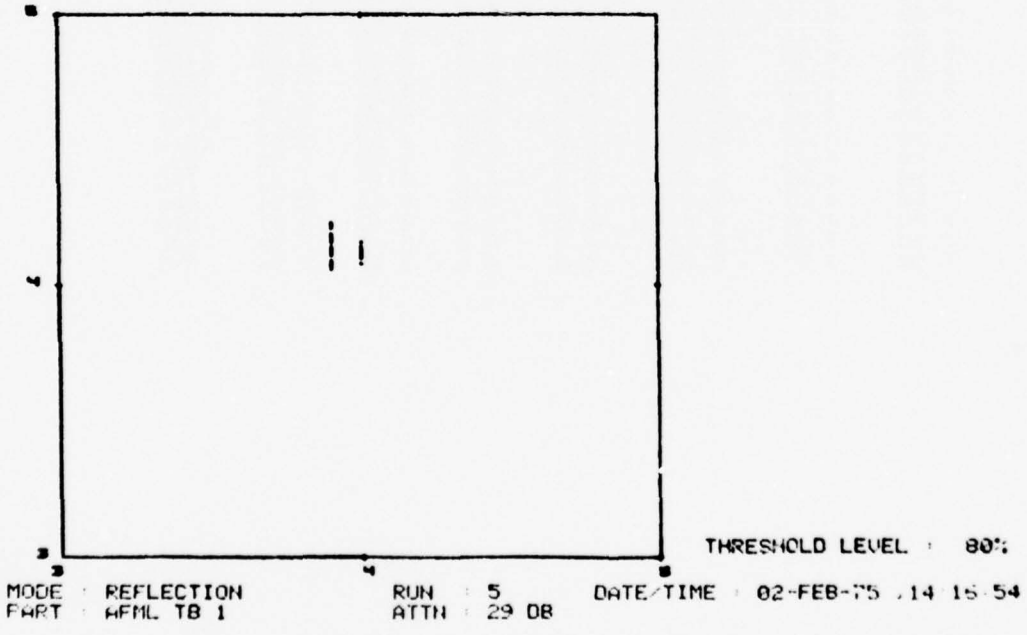


Figure 18 Post-Inspection Expansion of 5/64 FBH with 80% Threshold Level

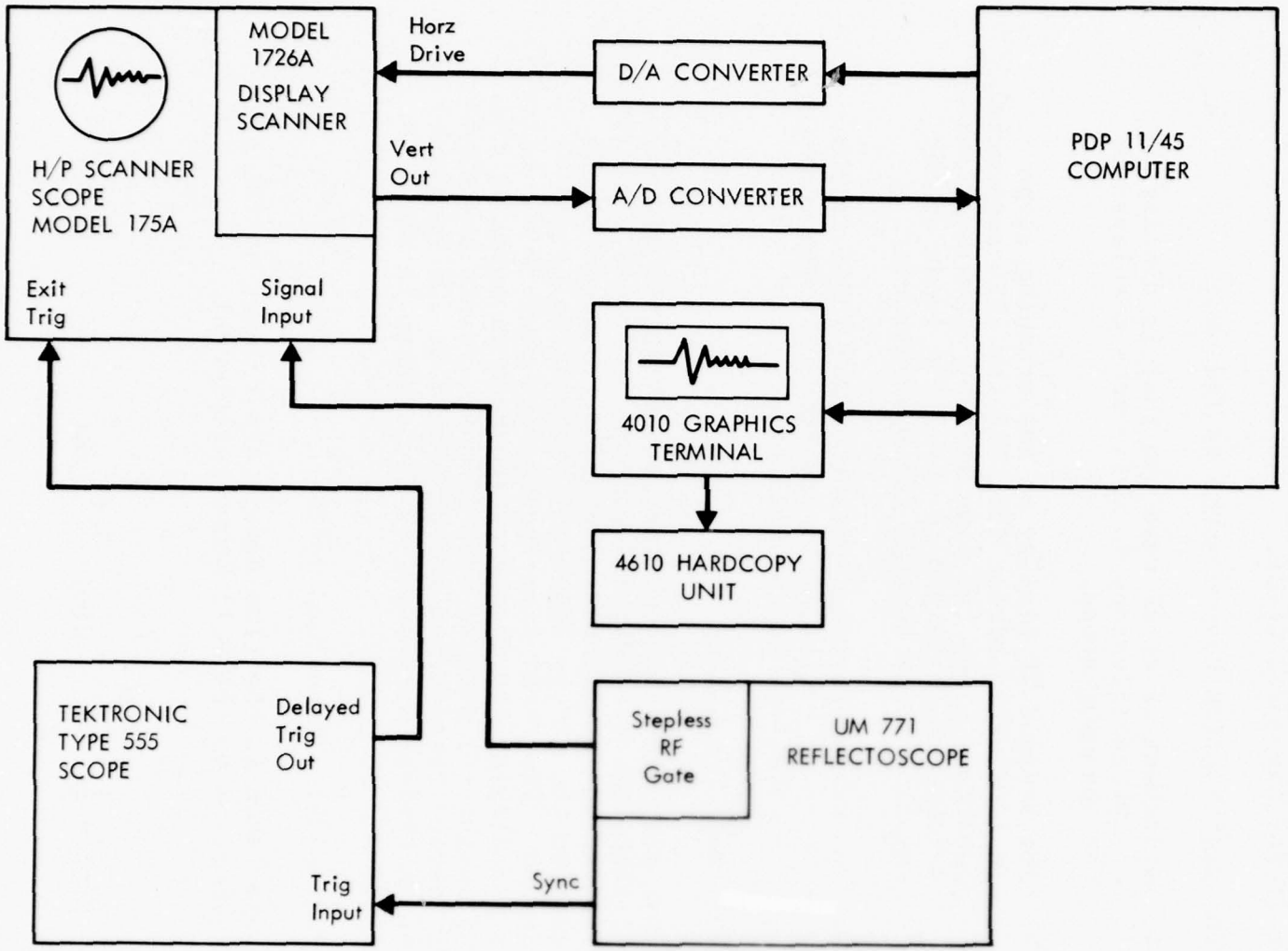


Figure 19 Block Diagram of the RF Digitizer Set-Up

computer (Digital Data Corporation PDP 11/45), (4) a digital-to-analog converter (PDP 11/45 D/AC interface), (5) an analog-to-digital converter (PDO 11/45 A/DC interface), (6) a memory scope (Tektronix Model 4010), and (7) a hard copier (Tektronix Model 4610).

The digitization system works as follows:

1. A segment of an RF waveform that is displayed on the oscilloscope is delay mode displayed on the scanning scope.

2. The delayed RF display on the scanning scope is sampled at either 256, 512, or 1024 sequential positions along the time axis by a computed analog voltage which is fed to the 1726A input of the sampling scope through the D/A converter.

3. The analog vertical output of the 1726A is converted to digital data and stored in the computer memory at each sequential time.

3.10.2.2 Data Processing

Once stored in the computer, the digitized RF can be Fourier transformed by digital computer software. Both the digitized RF and the resulting Fourier transform can be displayed on the memory scope and (if desirable) can be hard copied. The total time required to perform the calculation and display the frequency spectrum is normally the order of eight (8) seconds when 256 data points are digitized, Fourier transformed and displayed at 200 frequency points. A typical display of an RF waveform is shown in Figure 20.

3.10.2.3 Fourier Transform Software

Data taken in the time domain are related to the frequency spectrum by the well-known relationship

$$F(t) = \frac{1}{2} \int_{-\infty}^{\infty} G(\omega) e^{i\omega t} \, d\omega \qquad (1)$$

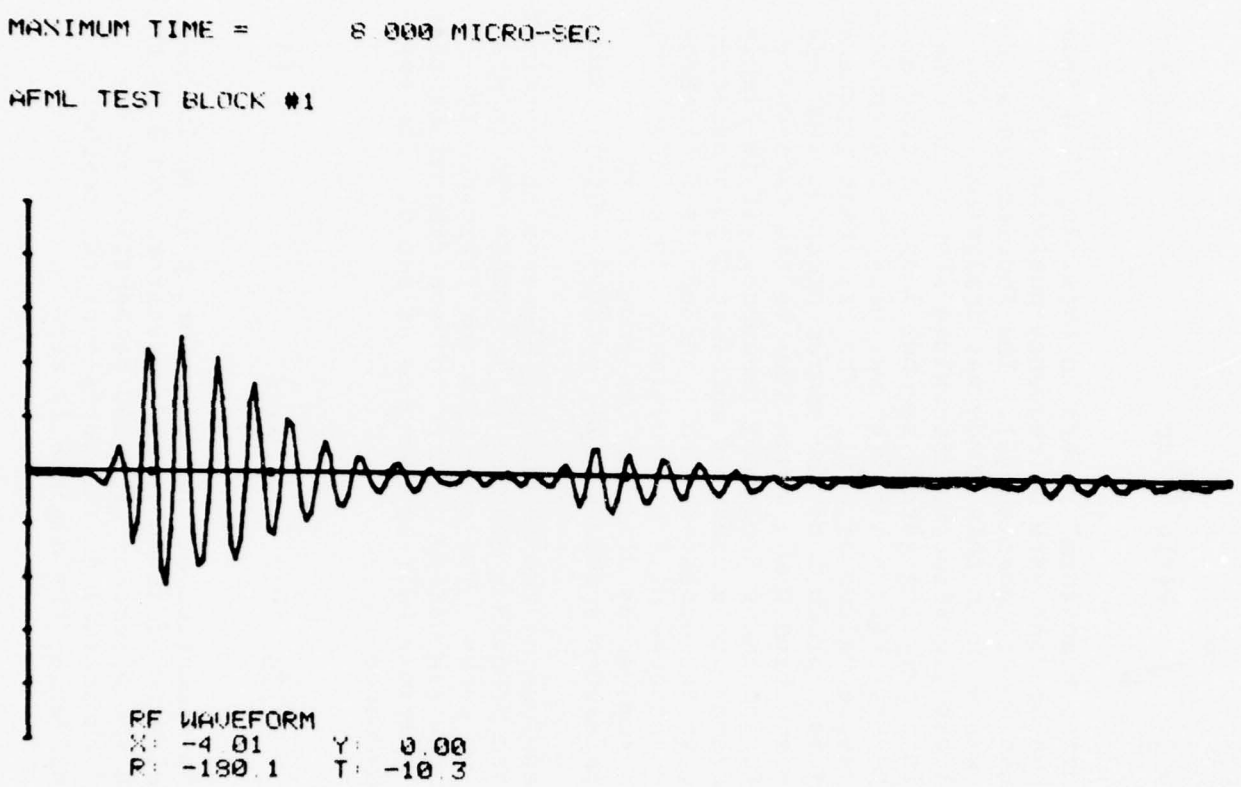


Figure 20 Display of Digitized RF Waveform

The frequency spectrum $G(\omega)$ can be obtained from the integral

$$G(\omega) = \frac{1}{2} \int_{-\infty}^{\infty} F(t)e^{-i\omega t}dt \qquad (2)$$

The term "Fourier transform"[10] refers to obtaining $G(\omega)$ from $F(t)$, which can be done with a frequency analyzer or by direct integration of equation (2). The Fourier transform of $F(t)$ that was used in this study was analytical. The waveform $F(t)$ was digitized as 256 values with equal time spacing within a sampling gate T seconds long. A quadratic-fit of the form $F(t) = A+Bt+Ct^2$ was used to interpolate between successive values of $F(t)$. The resultant frequency spectrum $G(\omega)$ is a product of the source spectrum $S(\omega)$ and the reference spectrum $R(\omega)$, where $R(\omega)$ is the transducer and electronic component frequency response. It is highly desirable to remove this unwanted modulation in nondestructive testing, so the dependence on transducer and electronic component response will be minimized. This undesirable modulation is removed by dividing the resultant spectrum $G(\omega)$ by the reference spectrum $R(\omega)$, or $S(\omega) = G(\omega) / R(\omega)$.

The dimensions of the resonating elements are obtained simply from the frequency spacing (Δ) between the interference dips or peaks. The condition for resonance to occur is for the resonating element to have dimensions that are integral multiple half-wavelengths of sound. The condition for resonance is

$$t = \frac{n\lambda}{2\cos\theta} \quad (n = 1, 2, \ldots) \qquad (3)$$

where t is the dimension of the resonator, n is an integer, λ is the wavelength of sound in the resonator, and θ is the angle between the direction of sound propagation in the resonator and the normal to the surface of the resonator. For normal incidence, the angle θ is zero.

3.10.2.4 Obtaining Flaw Types and Dimensions

This section represents a typical application of the signal processing capability for characterization flaws. New applications are being discovered every day.

If parallel gap openings ranging from 0.001 inch to 0.10 inches are filled with several different liquid media and the gap width can be measured by ultrasonic spectroscopy. Either compressional and shear waves can be used in the measurements.

Figure 21 is a Fourier spectrum of a 0.086 inch wide waterfilled slot in AFML specimen number 1 which is slanted at 45^{o} with respect to the parallel surfaces. The resonant wavelength is obtained by dividing the velocity of sound in water the (0.35 MHz) frequency spacing between minima dips of the frequency spectrum. Dividing by 2 yields a slot width of 0.083 inch in this example.

Figure 22 shows the source spectrum along with the spectra of waterfilled slots having dimensions of 0.023-inch width by 0.20-inch depth and 0.043-inch width by 0.20-inch depth cut into a 0.50-inch thick aluminum plate. The source spectrum was obtained by a Fourier transform the normally incident top surface echo from the test specimen. The frequency spectra were obtained using shear waves in the aluminum. The slot width (obtained by dividing the resonant wavelength by 2) agrees to within 2 per cent of the actual slot width. Fill media such as glycerin, air, and mercury have been studied with comparable results. Waterfilled gaps a few mils wide have easily been measured through 8 inches of metal travel (4 inches eacy way) by using compressional wave at normal incidence.

The procedures for measuring slot width has also been successfully applied to measuring the diameter of a right cylinder. In all cases the velocity of sound in the slot has to be known or assumed in order to determine the dimension. The converse is also true that knowledge of the dimensions allows one to compute ultrasonic velocities.

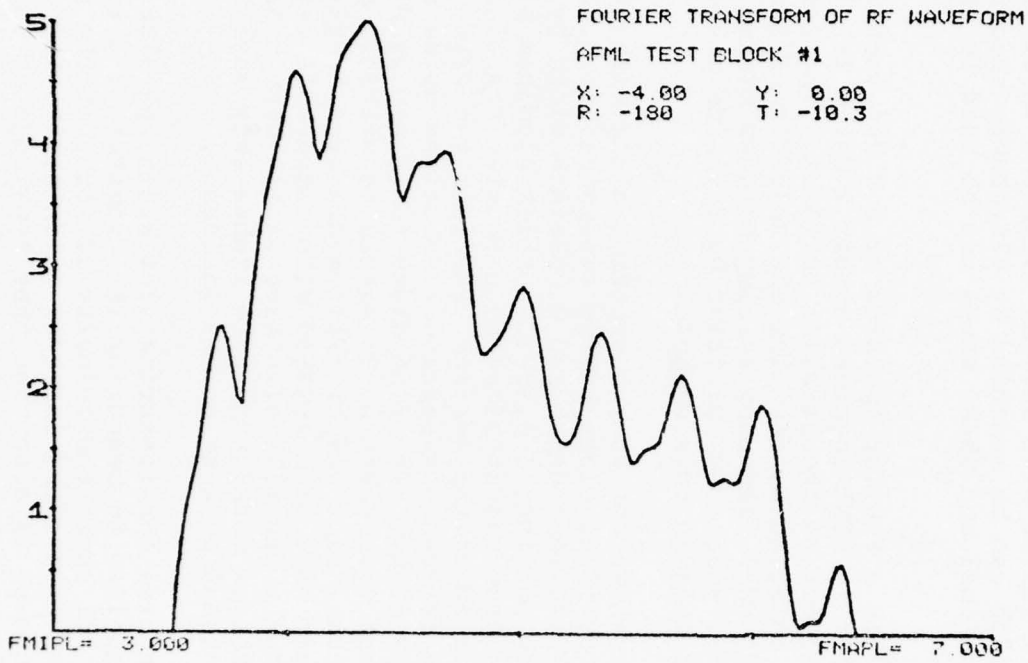


Figure 21 Frequency Spectra of Water Filled Elox Slot in AFML TB # 1

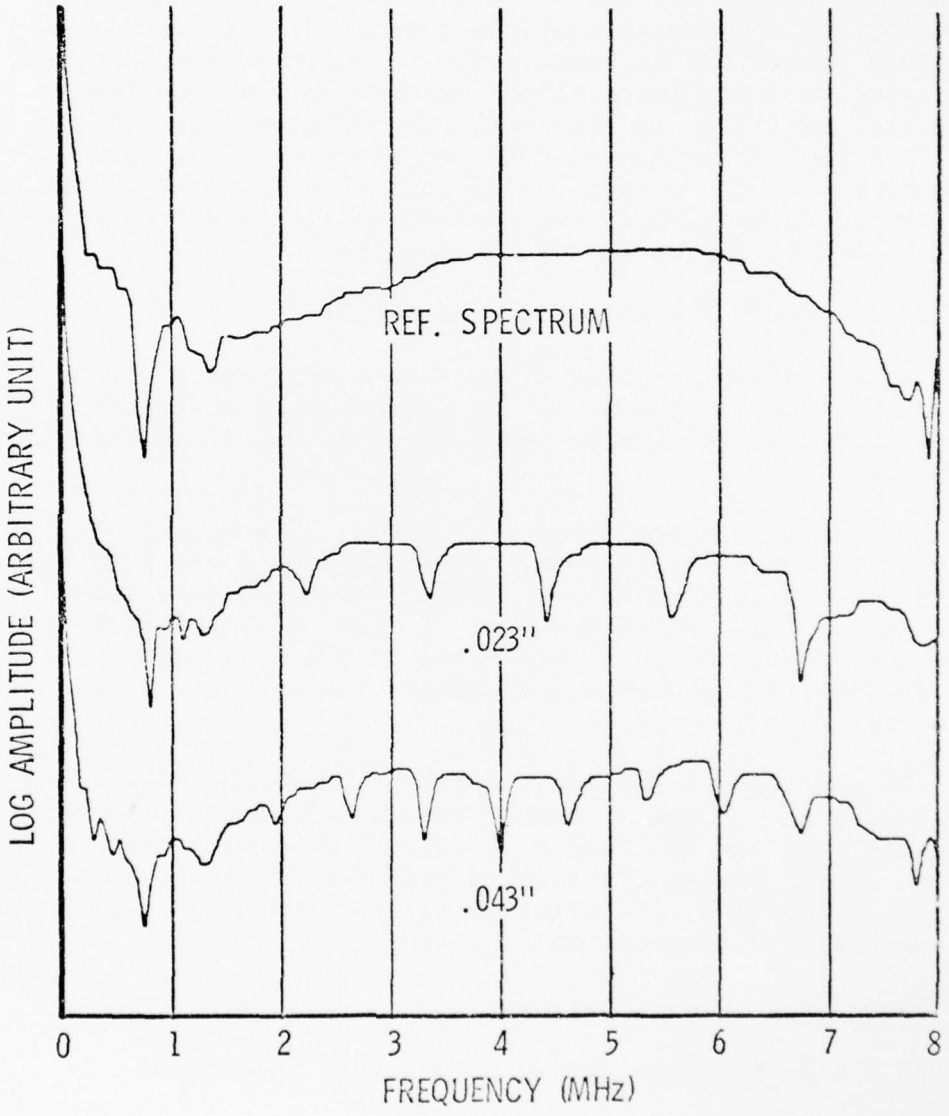


Figure 22 Frequency Spectra of the Reference 0.023 Inch and 0.043 Inch Water Filled Slots

3.10.3 Flaw Homing

Flaw homing is a technique developed to detect randomly oriented flaws and determine flaw orientations. During post inspection analysis, a software routine automatically returns the transducer to areas having flaw indications and sudden loss of bottom surface reflections and performs a search routine. The search routine consists of scanning the transducer over the suspected area with many possible directions of sound entry to the test specimen and recording the coordinate of the transducer where maximum reflected amplitude is recorded. The display over a 45^{o} inclined slot in specimen AFML Test Block No. 1 is shown in Figure 24. Interpretation of this display is difficult, but the coordinate where the maximum amplitude was obtained, is recorded at the bottom of the display.

3.10.3.1 Search for Inclined Flaw (SFIF)

This routine performs a pre-programmed search. The search pattern is similar to the one depicted on Figure 25. The variables which can be input are, Radius, Delta, Alpha 1, Alpha 2.

The search is performed as follows: The scanner is driven to each numbered point, at these points the TILT is driven from Alpha 1 to Alpha 2; the computer stores the maximum amplitude and the number of times a flaw signal is detected; the scanner is then moved to the next point, and the process is repeated. The numbers indicate the scan sequence.

In order to obtain the coordinate at which the optimum incident angle occurs, a number (N) is formed from the maximum amplitude and the number of detections during that radial scan. The radial scan is selected on the basis of the largest value of N, the point along that radius is determined on the basis of the maximum amplitude.

$N = 3 * NN * K + \text{Max. Amp.}$

K = 4-96/(Maximum number of possible detection)

NN = Number of detections

Max Amp = Maximum amplitude

The value of N ranges from 0 to 16383.

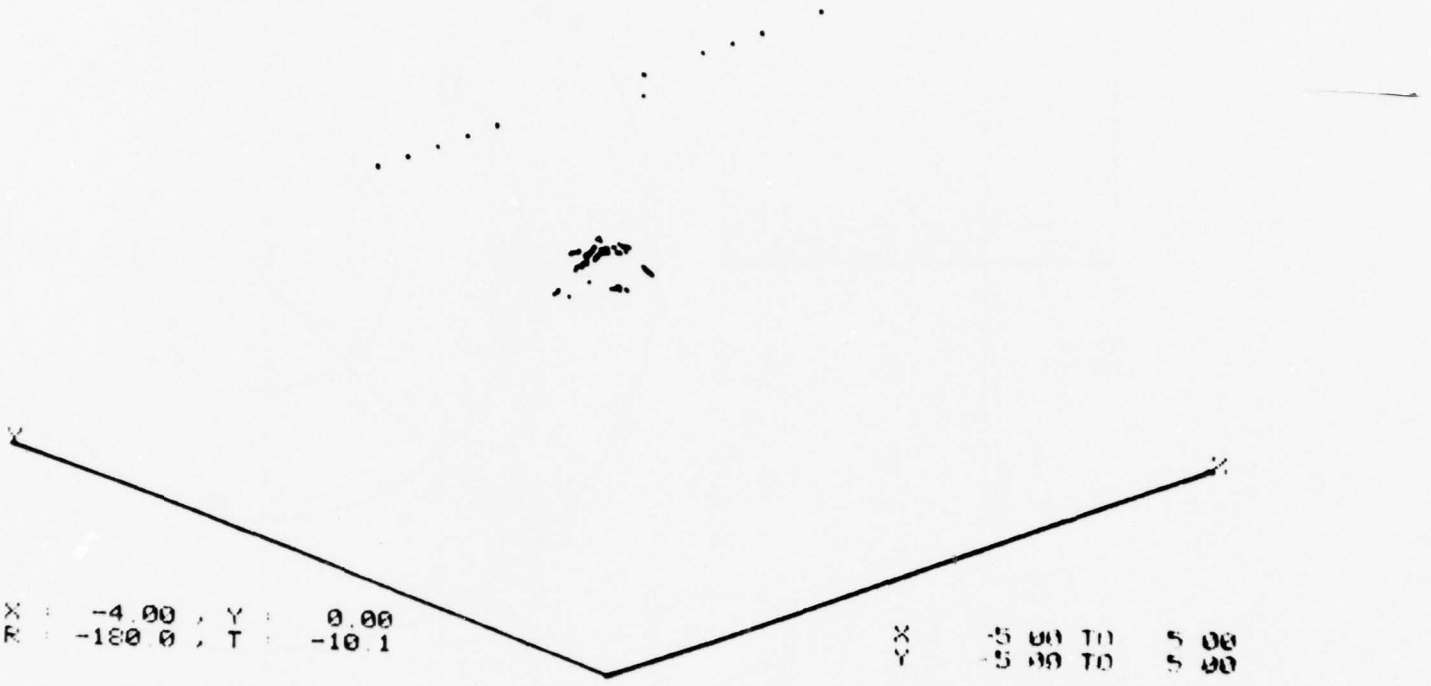


Figure 23 Post-Inspection Flaw Homing Display

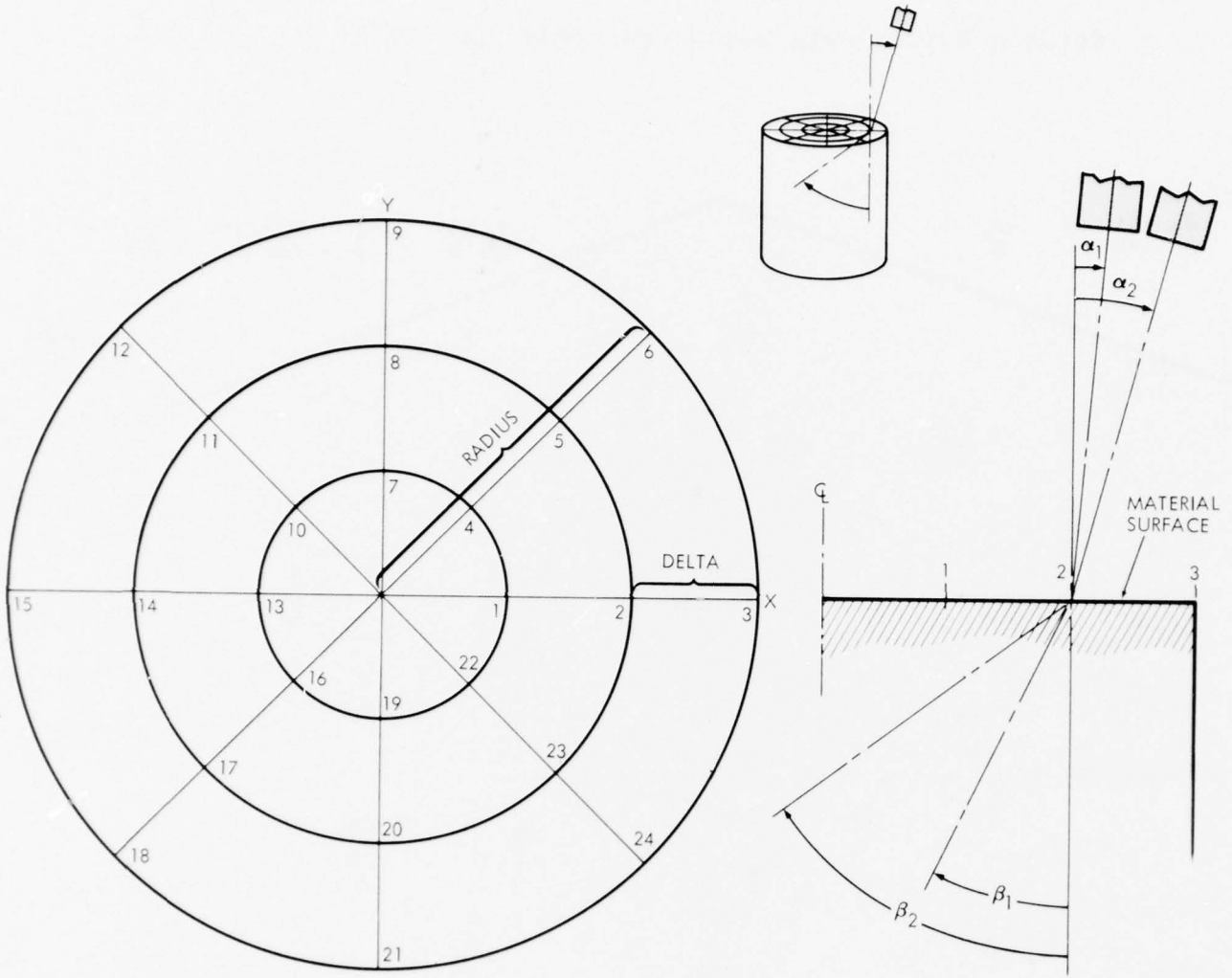


Figure 24 Flaw Homing Search Pattern

3.10.4 Filtering Routines

The software routines 'REJECT' and 'RJ' comprise the major elements of the filtering capability.

The filters, in effect, reject or force plotting or listing of data. All filters except the 'Flaws with Back Surface Switch' remove data from the output. Any or all of the filters may be bypassed. The filters act in sequence, the first being the volume filter. This volume is defined by (XSTART-XSTOP) (YSTART-YSTOP), MAX DEPTH. This is shown in Figure 25. (If the inspection used was multigate the routine 'RJ' is used to remove depths within two layers. (No further filtering is performed with multigate). The next filter applied is the Back Surface Filter. If the flaw being examined has been declared a back surface, it is deleted from the plot. If the flaw has a back surface associated with it, the flaw is plotted. There are three tests for amplitude discrimination, amplitudes greater than an input value, amplitudes equal to a certain value, or amplitudes less than an input value. Amplitudes meeting these criteria are not plotted. Last, there are the layer filters for remaining flaw with depths within certain layers. The flow diagram for the filter routine is shown in Figure 26.

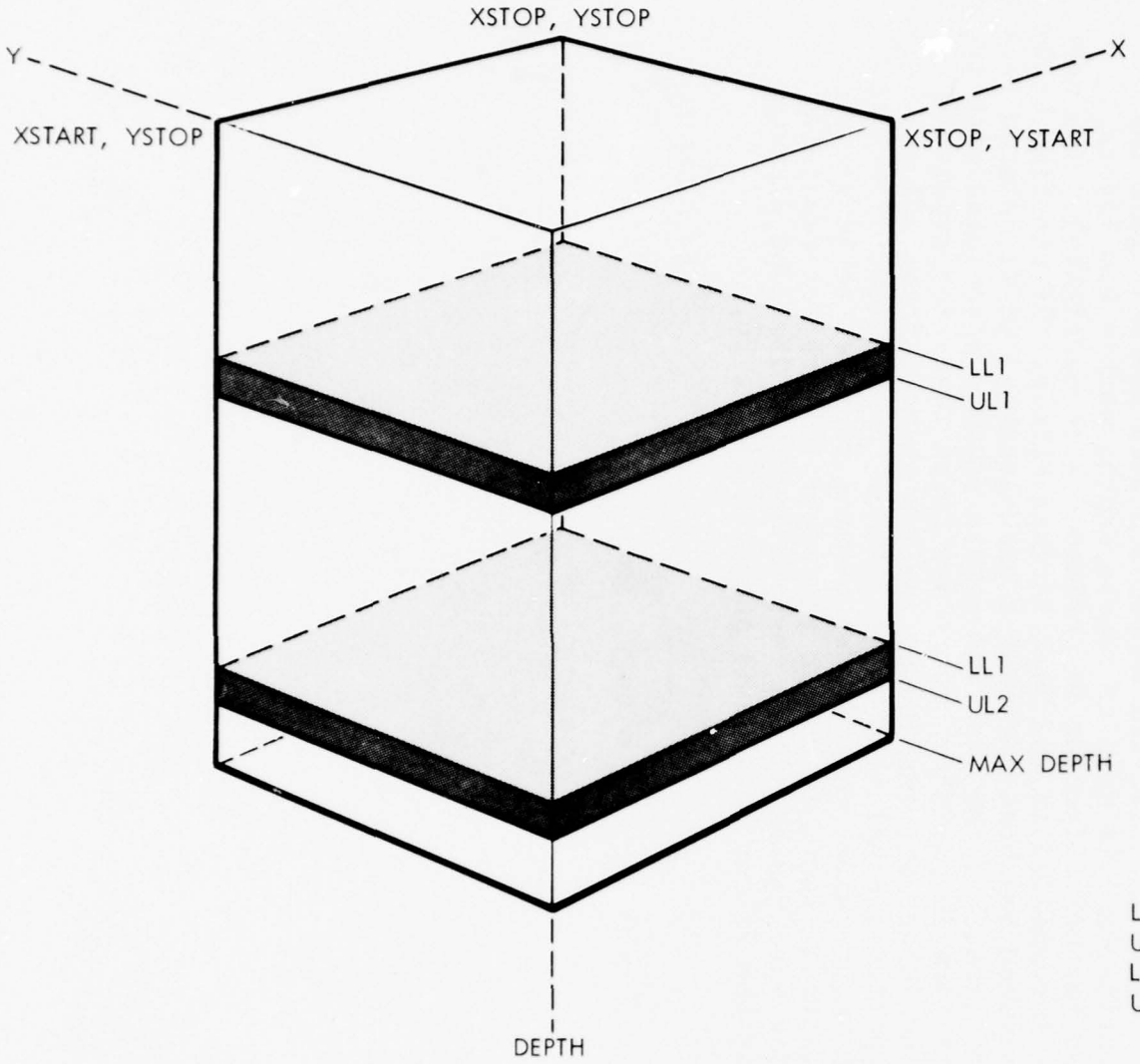


Figure 25 Volume and Layer Filter Diagram

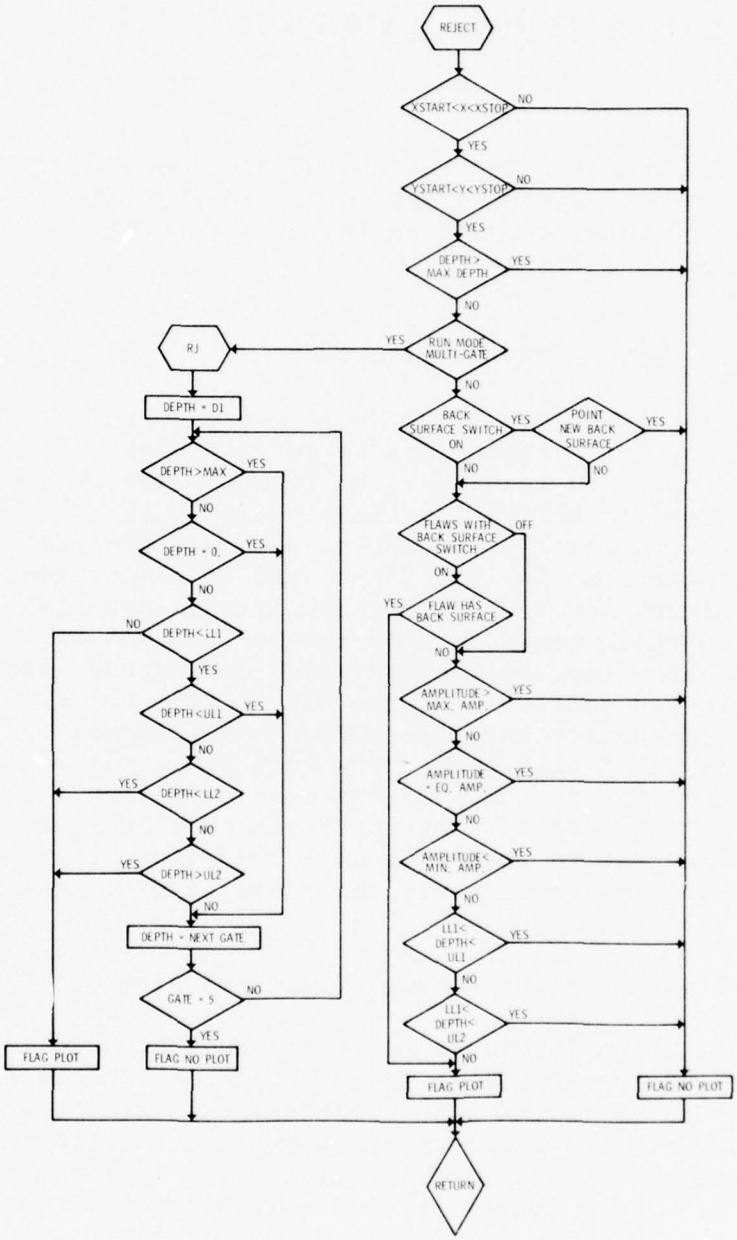


Figure 26 Flow Diagram for Filter Routines

SECTION IV

DEMONSTRATION AND EVALUATION PROTOTYPE SYSTEM

This section demonstrates the use of the computer automated ultrasonic inspection system for inspecting simple-shaped structure, complex engine disk forging, and complex aircraft forgings.

4.1 SIMPLE-SHAPED STRUCTURE

Test specimen AFML Test Block No. 1 was used to demonstrate the system's capability to perform high speed scanning (up to 10 inch/sec), to recover from the loss of a back surface reflection (BSR) by means of computer control of flaw gate width, to scan off the edge of a part, to detect two in-line flaws, and to demonstrate flaw homing. Figure 27 shows the layout of specimen AFML Test Block No. 1 which has a section change from 2.5 to 3.5 inches and has a tapered section which causes the loss of BSR. The tapered section contains flat bottom holes normal to the top surface and flat bottom holes normal to the taper. This block also has a 3/64 inch FBH drilled inside a 8/64 inch FBH to simulate the case of a flaw above a flaw. This block also has an inclined slot at a 45^{o} angle with respect to the surfaces. This large inclined slot is used to demonstrate the value of flaw homing.

4.1.1 Reflection Mode: Computer Control Flaw Gate

The display shown in Figure 28 is the annotated inspection record of the AFML Test Block No. 1 test specimen. The inspection was performed with compressional wave at a frequency of 5 MHz. All the inspection results discussed in this report were obtained at 5 MHz, using a 0.1 inch scanner index, with a 5/64 inch FBH as reference flaw located near the bottom of the thickest section of a test specimen. The amplitude of the FBH was set to 80% of screen height, and indications above 20% of screen height were recorded (unless otherwise stated). The inspection for AFML Test Block No. 1

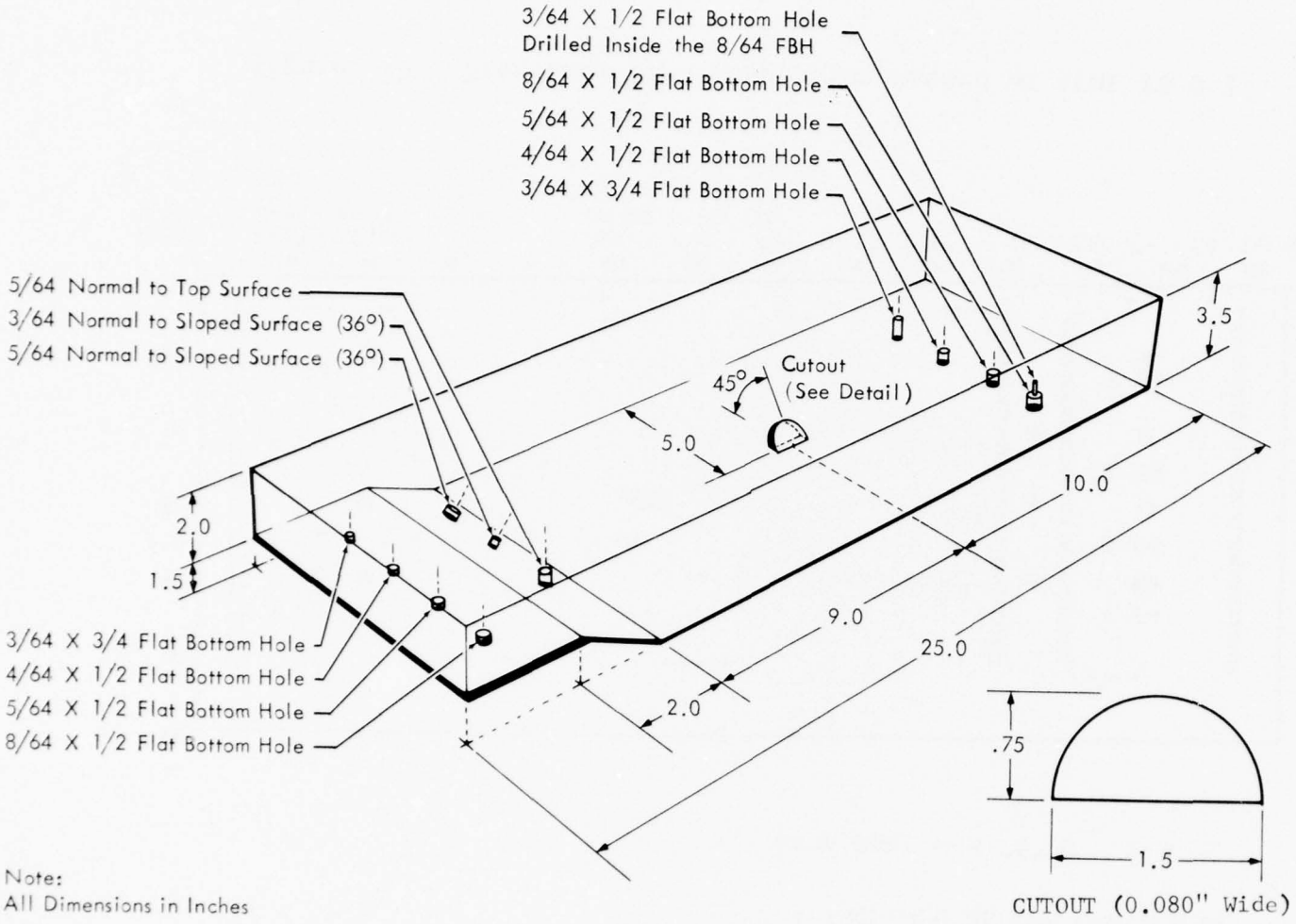


Figure 27 AFML Test Block # 1

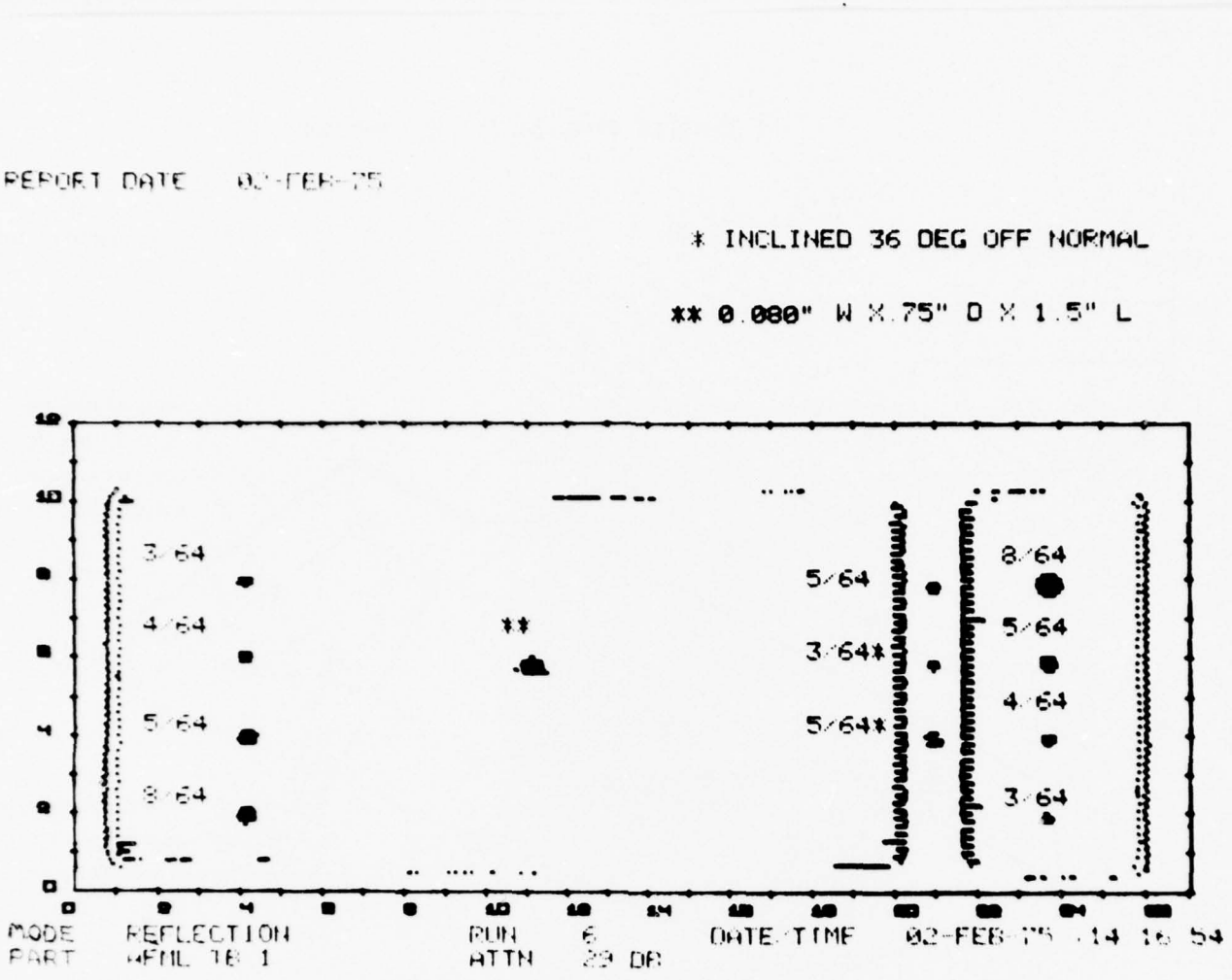


Figure 28 Near-Real Time Inspection Record of AFML TB # 1

was scanned from the flat side and at a speed of 6 inches per second. When the transducer traverses from the 3.5 inches section, through the taper, and to the 2.5 inches section, under computer control the flaw gate width adjusted to these changes in real time while scanning at 6 inches per second. At the taper section, the BSR is lost. In this case, the computer automatically sets the flaw gate width to accommodate the thickest section of the test specimen under inspection. In this case, the maximum thickness is 3.5 inches. It took the system 12 minutes to complete the inspection of this test specimen with a scanning speed of 6 inches per second.

The two rows of flaw indications on either side of the taper are not flaws. They are back surface reflections which can be removed from the display by using the spatial filtering routine. However, they are useful in outlining section changes within a given test specimen. When the BSR is lost due to tapers, large flaws, etc., the first signal that appears after the top surface reflection signal is recorded as a flaw over a distance of $\frac{1}{4}$ inch. This precaution is taken to avoid missing a large flaw or a small flaw that might occur near the edge of a section change or a taper section.

All the FBHs, including the two that are located on the taper section and off normal to the top surface of the specimen by 36^{o}, were detected clearly. The 45^{o} inclined slot was also detected.

4.1.2 Flaw Homing

The search for an inclined flaw was performed on the large elox slot in AFML Test Block No. 1 during post inspection analysis. The scan pattern as described in paragraph 6.5.8 was executed, and maximum amplitude was obtained at a tilt angle of -9.9^{o} at an X position of 5.0 and Y position of 10.0 for the 45^{o} inclined slot. Using this angle of -9.9^{o}, a scan was made over the suspected area. The results of this scan are shown in Figure 29. The value of flaw homing is demonstrated by comparing the results obtained with the scan at the preferred angle (shown in Figure 29) with the expanded display of the results obtained with a scan at normal incident (shown in Figure 30).

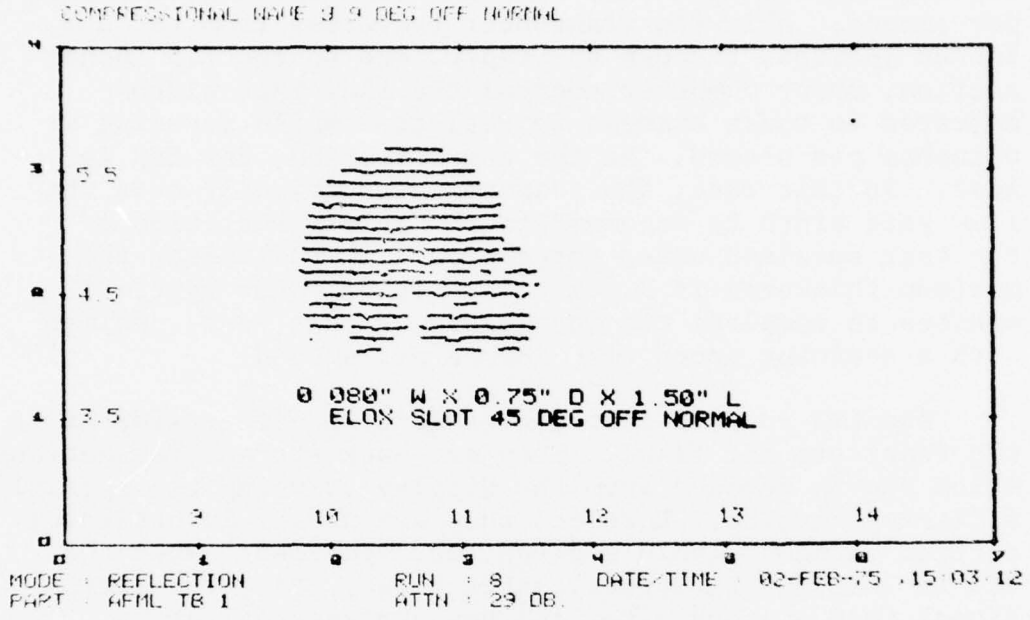


Figure 29 Near-Real Time Inspection Record of Inclined Flaw at -9.9° Tilt Angle

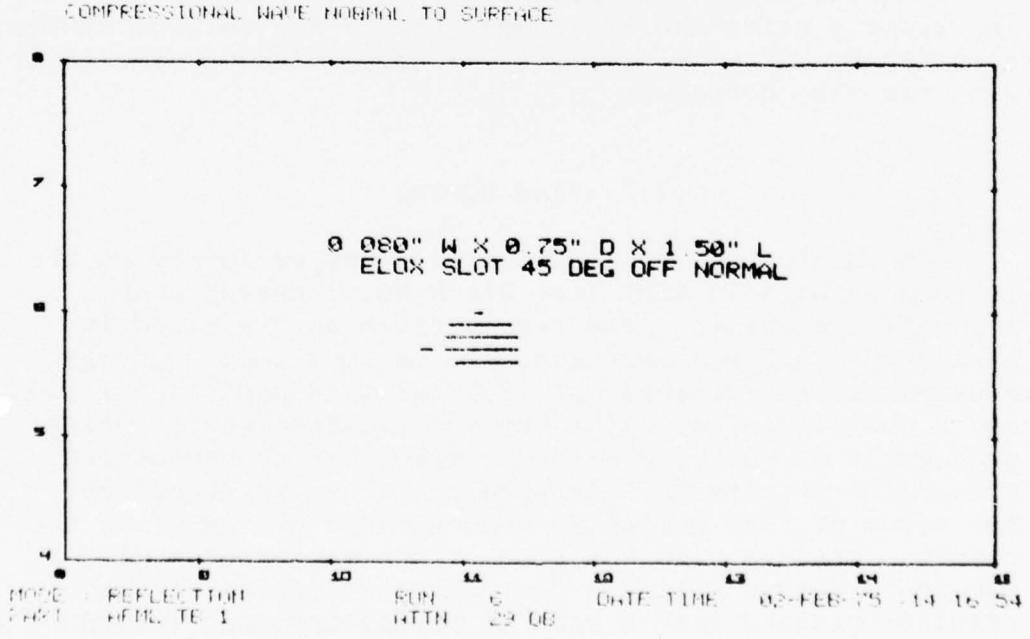


Figure 30 Post-Inspection Expansion of Normal Incident Wave of Inclined Flaw

4.2 CONTOUR FOLLOWING OF LARGE RADII

AFML Test Block No. 3 (see Figure 31 and 32) was used to demonstrate the use of the ultrasonic feedback scheme for contour following of a large radii (3 inches), perform coordinate transformation when the transducer is off angle, and control scan speed. Figure 33 is a display of the inspection record for AFML Test Block No. 3 scanned at 2 in/second while operating under speed control on the curved and sloped section. The scanning time for the inspection was 22 minutes. Changing the direction of scan from the long dimension of AFML Test Block No. 3 to the direction with the short dimension (see Figure 34) reduced the scan time to 13 minutes while scanning along the long dimension of the test specimen, speed control had to be used everytime the curved section was traversed. While scanning along the short dimension of the test specimen, speed control is invoked only on the index cycle.

When scanning on the taper section of this specimen, the FBHs located near the bottom of the specimen do not have the same coordinates as the point of sound entry on the top surface of the specimen. A real-time software coordinate transformation routine was developed and implemented to display the flaw indications at their true coordinate. Flaw indications from this test specimen and others with taper and curved surfaces were all displayed in real-time at their true coordinates.

With further development in a complex-shaped specimen where a discontinuity can be detected from several coordinates, the dimensions of the discontinuity could be reconstructed.

4.3 INSPECTION RESULTS FOR MULTIPLE FLAW GATE SYSTEM

The multiple flaw gate system is used to detect two or more in-line flaws, provided the first flaw does not mask the other flaws. Figure 35 is an annotated multi-gate display of AFML Test Block No. 1. Figure 36 is one page of the report from over the area of the 3/64 inch FBH drilled inside the 8/64 inch FBH. Software routines were developed to discriminate if a signal is a multiple reflection of the back



Figure 31 Photograph of AFML Test Block #3

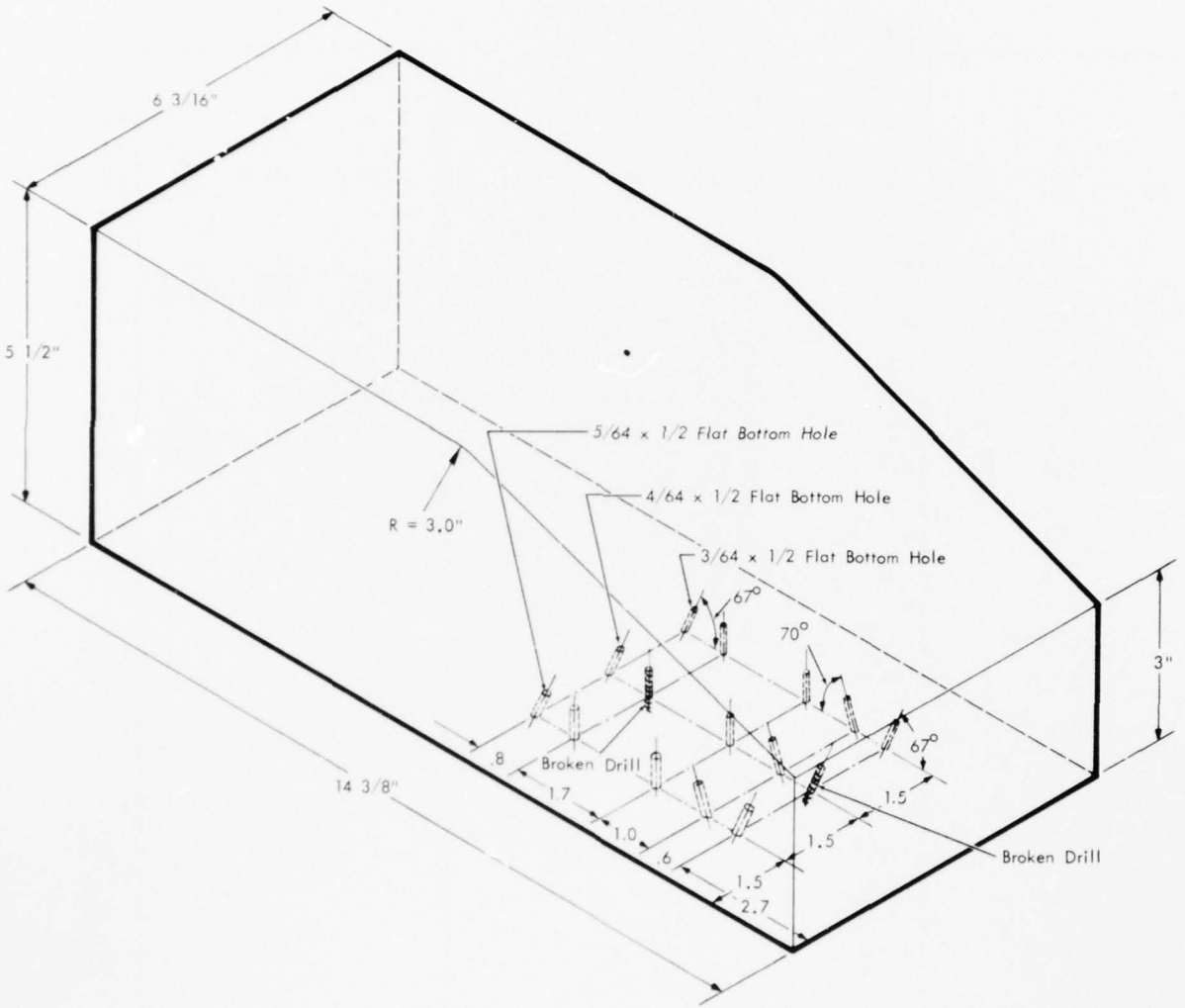


Figure 32 AFML Test Block #3 Showing Defects

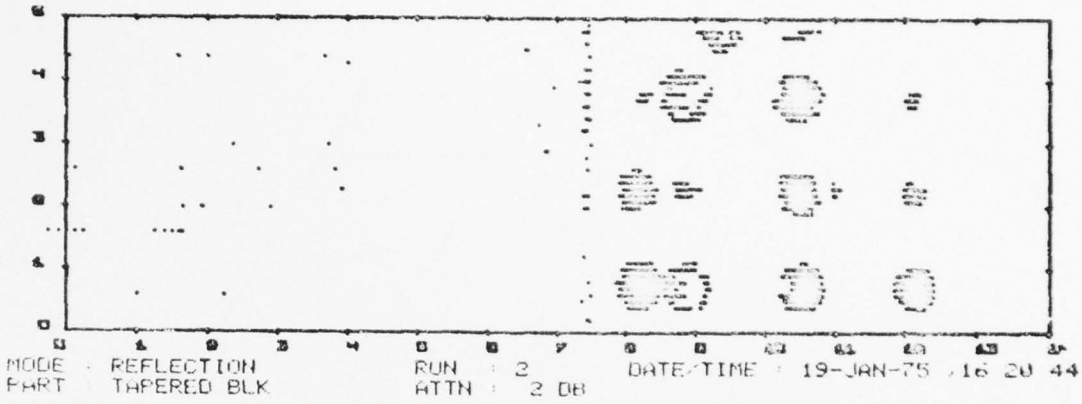


Figure 33 Near-Real-Time Inspection Record of AFML TB # 3 with Speed Control and Coordinate Transformation

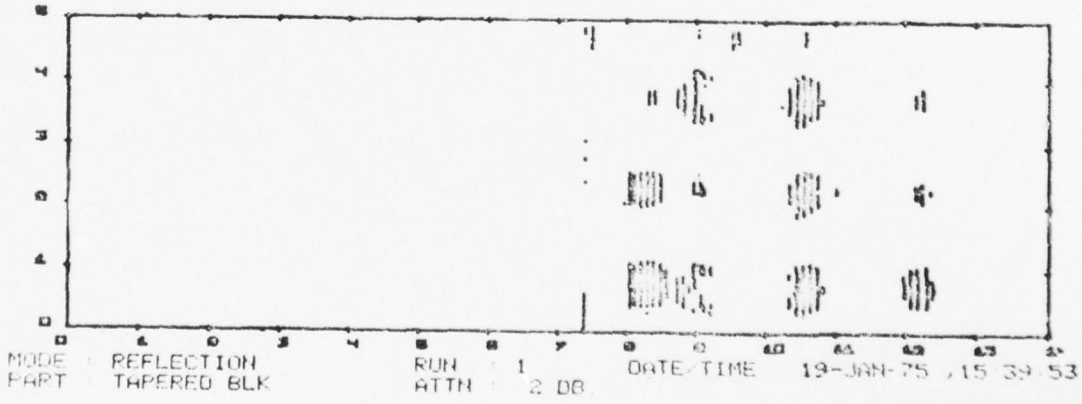


Figure 34 Near-Real-Time Inspection Record of AFML TB # 3

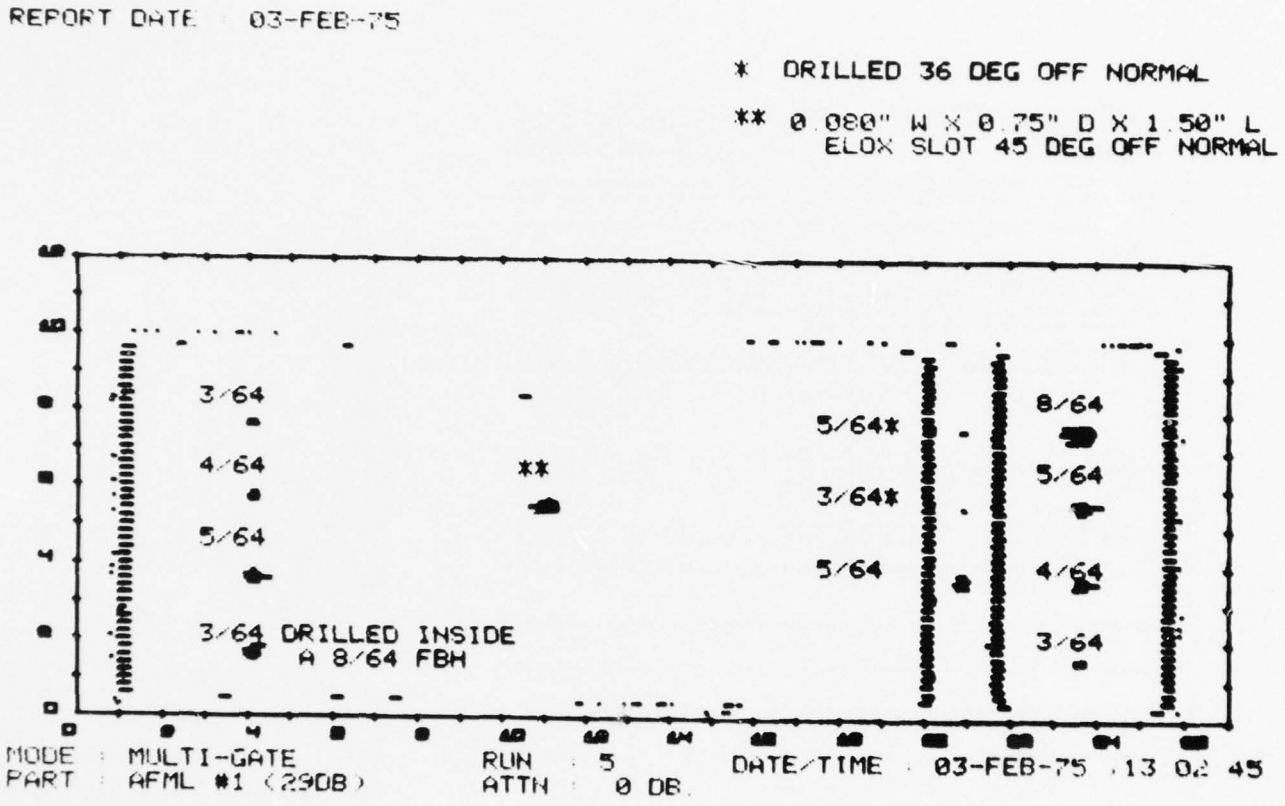


Figure 35 Near-Real-Time Inspection Record of Multi-Gate Inspection of AFML TB # 1

MULTI-GATE MODE DATA REPORT 03-FEB-75 15:23:14 PAGE 3

X	Y	BS	G	D1	A1	D2	A2	D3	A1
1.60	4.09	1	3	2.61	951	2.99	1283	3.47	4095
1.60	4.10	1	3	2.62	925	2.99	1236	3.47	4095
1.60	4.11	1	3	2.62	935	2.99	1194	3.47	4095
1.60	4.13	1	3	2.61	929	2.99	1157	3.47	4095
1.60	4.14	1	3	2.62	937	2.99	1090	3.49	4095
1.60	4.15	1	3	2.62	953	3.01	1029	3.49	4095
1.60	4.16	1	2	2.62	974	3.47	4095	0.00	0
1.60	4.17	1	2	2.99	852	3.47	4095	0.00	0
1.60	4.19	1	2	3.01	817	3.47	4095	0.00	0
1.60	4.20	1	2	3.01	816	3.47	4095	0.00	0
1.60	4.21	1	2	3.01	808	3.47	4095	0.00	0
1.60	4.22	1	2	3.01	804	3.47	4095	0.00	0
1.60	4.23	1	2	3.02	816	3.47	4095	0.00	0
1.60	4.25	1	2	3.02	807	3.47	4095	0.00	0
1.60	4.26	1	2	3.03	810	3.47	4095	0.00	0
1.70	4.22	1	2	2.62	847	3.47	4095	0.00	0
1.70	4.20	1	2	2.61	824	3.47	4095	0.00	0
1.70	4.19	1	3	2.61	779	3.02	226	3.49	4095
1.70	4.18	1	3	2.61	914	3.01	545	3.47	4095
1.70	4.17	1	3	2.61	915	2.99	548	3.47	4095
1.70	4.16	1	3	2.61	918	3.01	602	3.47	4095
1.70	4.15	1	3	2.61	917	2.99	644	3.49	4095
1.70	4.13	1	3	2.61	823	2.99	703	3.49	4095
1.70	4.12	1	3	2.60	838	2.99	736	3.47	4095
1.70	4.11	1	3	2.61	829	2.99	786	3.49	4095
1.70	4.10	1	3	2.61	801	3.01	821	3.49	4095
1.70	4.09	1	3	2.61	849	2.99	877	3.49	4095
1.70	4.07	1	3	2.61	904	3.01	899	3.49	4095
1.70	4.06	1	3	2.61	946	2.99	928	3.49	4095
1.70	4.05	1	3	2.61	934	2.99	925	3.49	4095
1.70	4.04	1	3	2.60	932	2.99	933	3.47	4095

X = X Position of Flaw Indication
Y = Y Position of Flaw Indication
BS = 0: No Back Surface
1: Back Surface
G = Gate Which has Back Surface
D1 = Depth of 1st Flaw or BSR
A1 = Amplitude of 1st Flaw or BSR
D2 = Depth of 2nd Flaw or BSR
A2 = Amplitude of 2nd Flaw or BSR
D3 = Depth of 3rd Flaw or BSR
A3 = Amplitude of 3rd Flaw or BSR

Figure 36 Post-Inspection Report Record of the Areas of the Two Inclined Flaws

surface. If so, it will be disregarded. The flow chart for this routine is described in Paragraph D.4.6.

4.3.1 Multi-Gate Over a Step Function Change in Thickness

The multiple flaw gate system can also be used to reduce the shadow zone due to an abrupt change in the thickness on the far side of a test specimen. Defects located in this shadow zone can go undetected. Figure 37 is a layout of test specimen AFML Test Block No. 5. Figure 38 is an inspection display of this specimen obtained with the use of the multiple gate system. A FBH located very near a step function change in the thickness on the back surface can be detected with the use of the multiple gate system. Figure 39 is a display of this specimen obtained with the use of only a single computer controlled gate. The same FBH that was found using the multiple gate system was not found using the single gate system.

4.4 INSPECTION RESULTS FROM ENGINE DISKS

Engine disk forging can be inspected with either a rectangular or a circular scan mode. The circular scan provides a more complete inspection of the total volume of the disk over the rectangular scan due to the forging symmetry.

4.4.1 GE Top-Hat Disk

The engine disk forging shown in Figure 40 was inspected using both rectangular and circular scan modes. Scanning the part with the step function on the back side produced the display shown in Figure 41. Spatial filtering to remove the data from the step function produced the display shown in Figure 42. The data in the upper right-hand corner is flaw information. This data was taken before the reference holes were drilled.

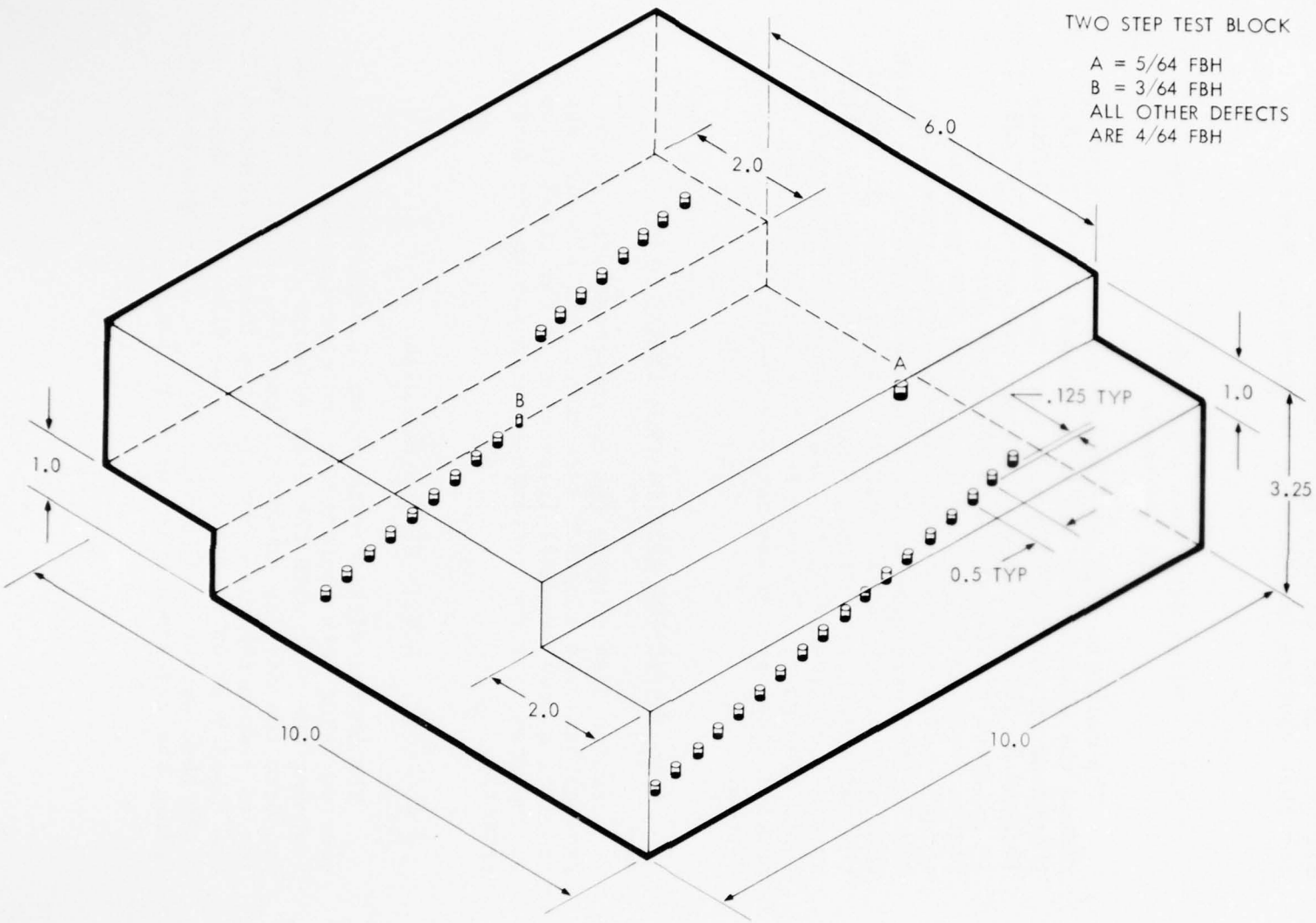


Figure 37 AFML Test Block #5

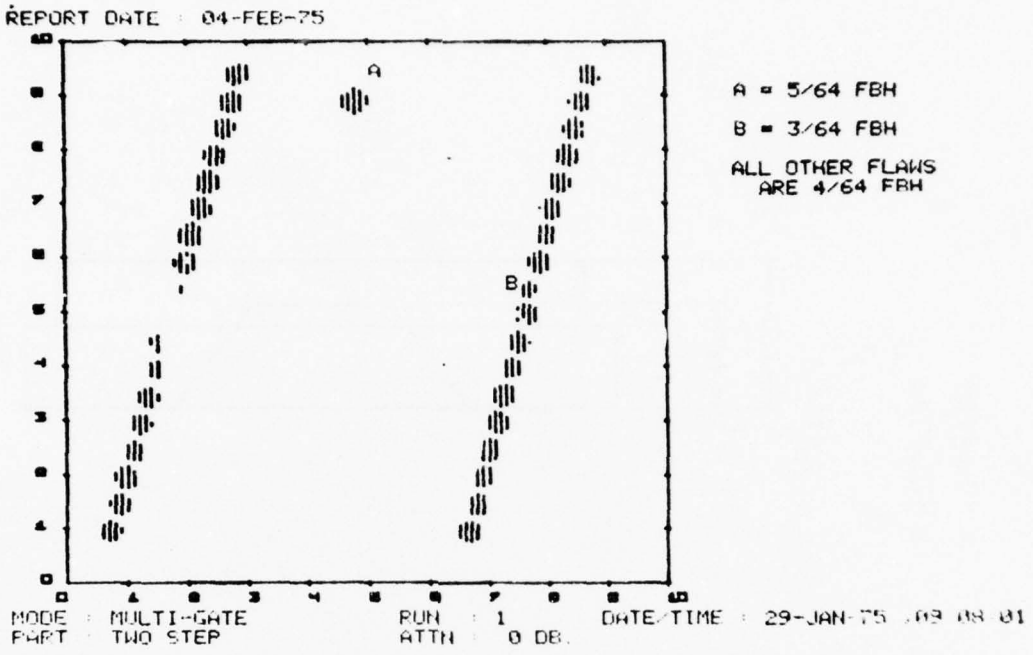


Figure 38 Near-Real-Time Inspection Record Using Multi-Gate Inspection of AFML TB # 5

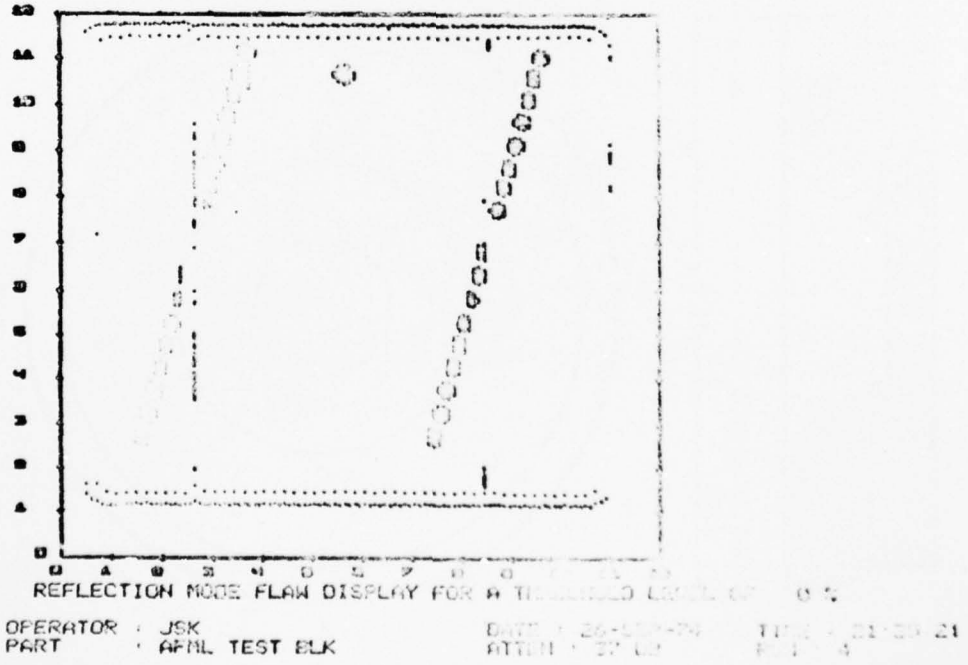
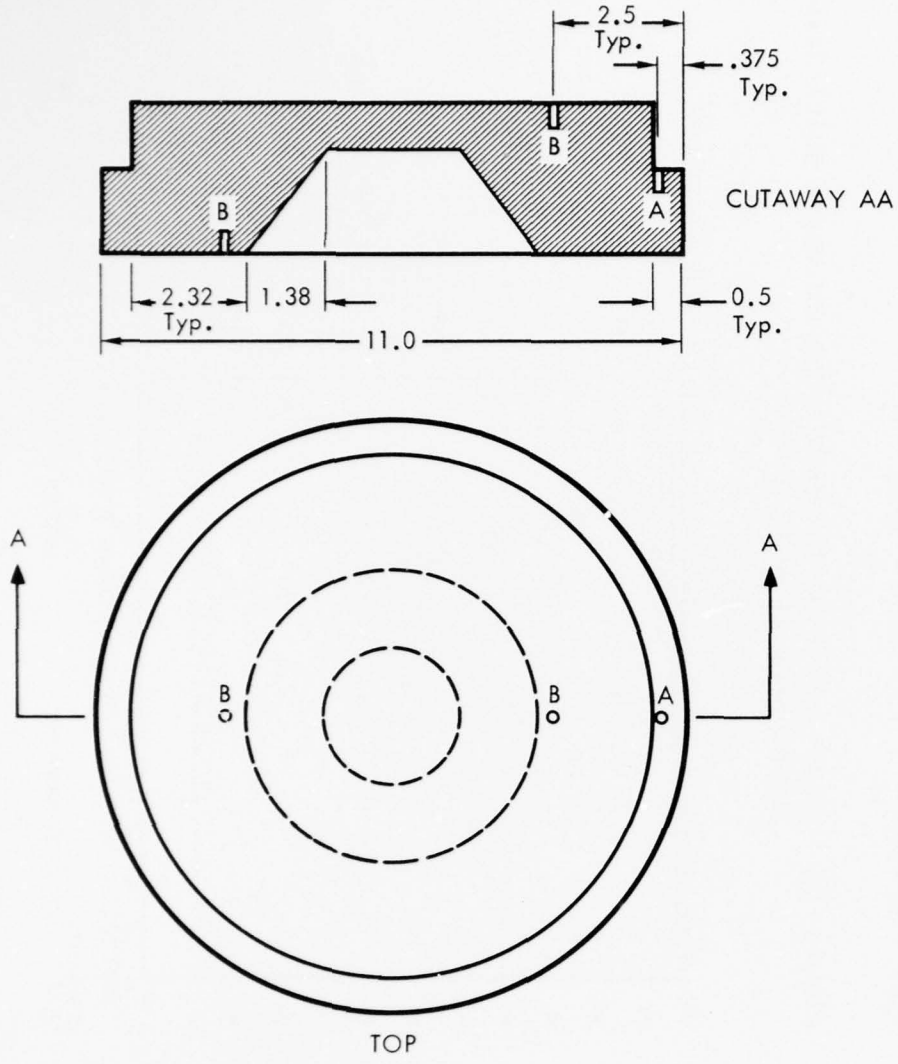


Figure 39 Near-Real-Time Inspection Record Using Computer Control Flaw Gate Inspection of AFML TB # 5



A = 3/64 FBH

B = 5/64 FBH

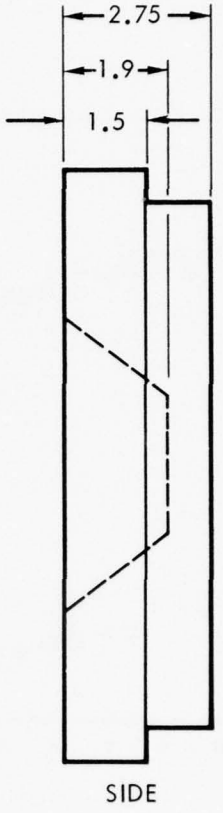


Figure 40 G.E. Top-Hat Disk

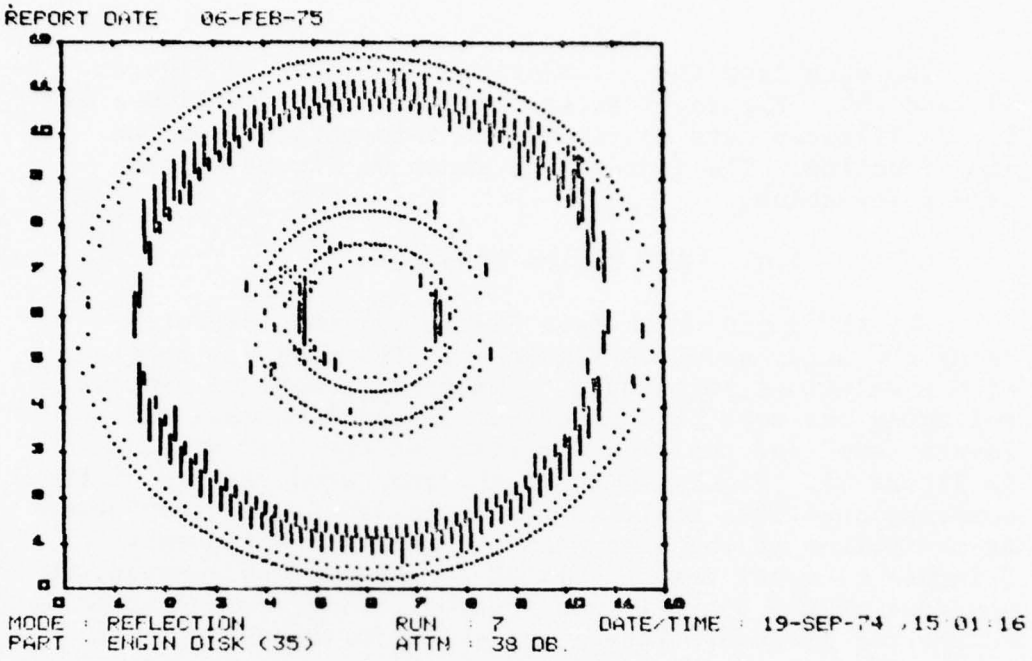


Figure 41 Near-Real-Time Inspection Record of Top-Hat Disk Using Rectangular Scan

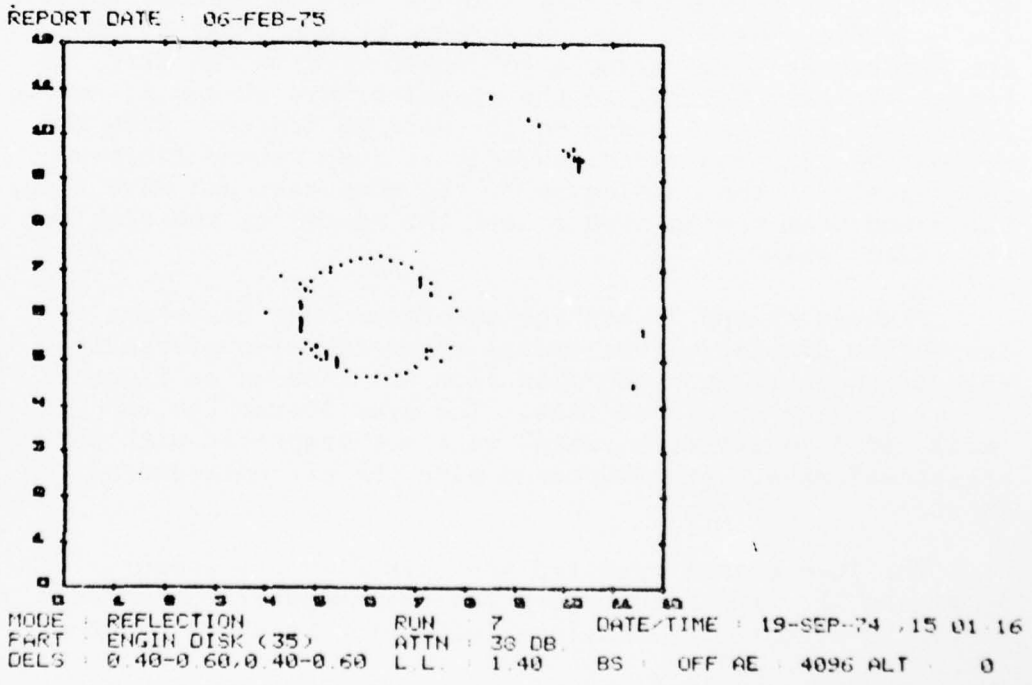


Figure 42 Post-Inspection Record of Top-Hat Disk Using Spatial Filter

The data from the circular scan is shown in Figures 43 and 44. Figure 43 is the original data and Figure 44 is the filtered data to remove the information from the step function. The indications shown on Figure 44 are flaw information.

4.4.2 AFT Engine Disk Data

The AFT engine disk (see Figure 45) was inspected using the setup shown in Figure 46. The disk was rotated at 9 revolutions per minute. The peaking mode of contour following was used to inspect the 3/4 inch concave and connex radii and the sloped section of the disk as shown in Figure 47. Figure 48 shows the annotated results of the compressional wave scan. The compressional wave scan began at the bottom of the edge with the gate width set only for 3 inches of metal travel. After the transducer reached the top edge of the disk, it was rotated 90 degrees and normalized to the top surface. Then, inspection commenced from the outer edge toward the center of the disk. The transducer could not follow the first two small radii, which were smaller than $\frac{1}{4}$ inch. These areas were skipped over and not inspected with compressional wave. The compressional wave inspection was completed when the transducer reached the inner edge of the disk. At this point, the computer was programmed to move the transducer back to the outer edge of the disk, to tilt the transducer to generate a 45° shear wave in the disk, to change the gain setting to the precalibrated dB level, and to change the flaw gate width to the desired length. Both the circumferential and radial shear wave scan were performed immediately at the completion of the compressional wave scan. The sound beam was pointed toward the center of the disk for the radial shear.

Figures 49 and 50 are the annotated near real-time inspection display of the radial shear and circumferential shear, respectively. The elox slot No. E shown on Figure 45 was used as reference flaw. The area around the two small radii on the disk, which were not inspected with compressional wave, were inspected with the circumferential shear.

The inspections required for this disk are shown in Figure 51. The time needed for the computer-automated system to perform the complete inspection is about one hour,

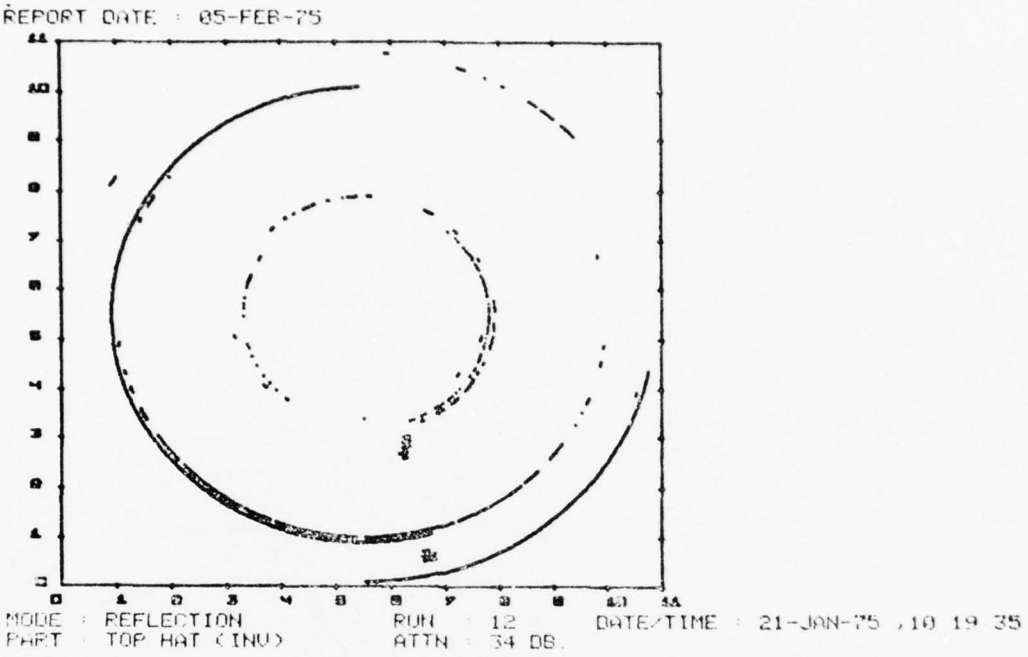


Figure 43 Near-Real-Time Inspection Record of Top-Hat Disk Using Circular Scan

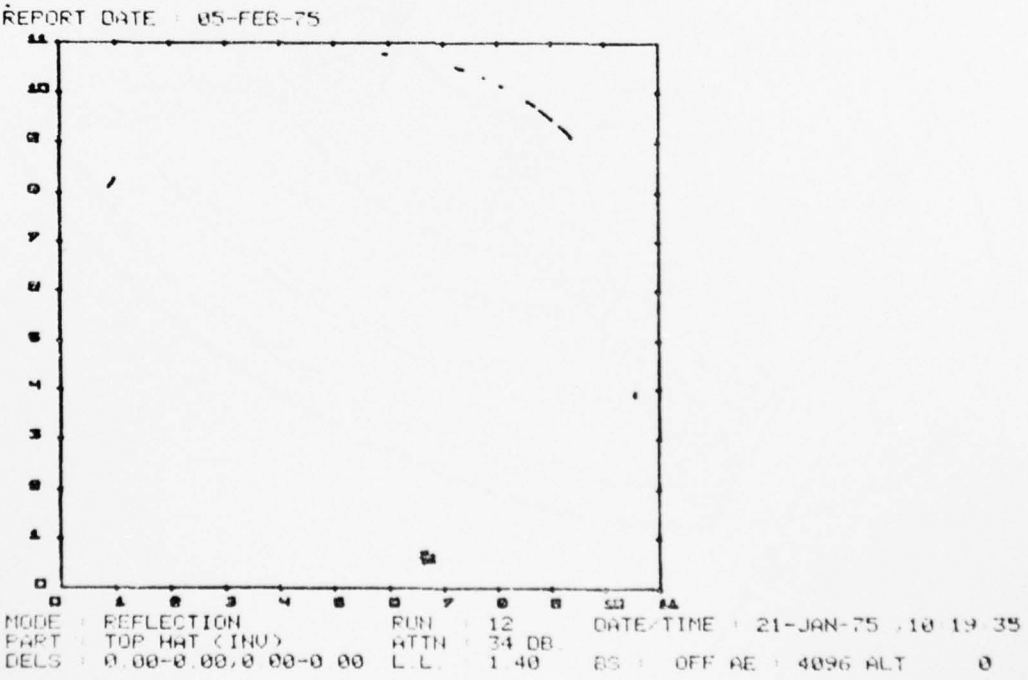


Figure 44 Post Inspection Record of Top-Hat Disk Using Spatial Filtering

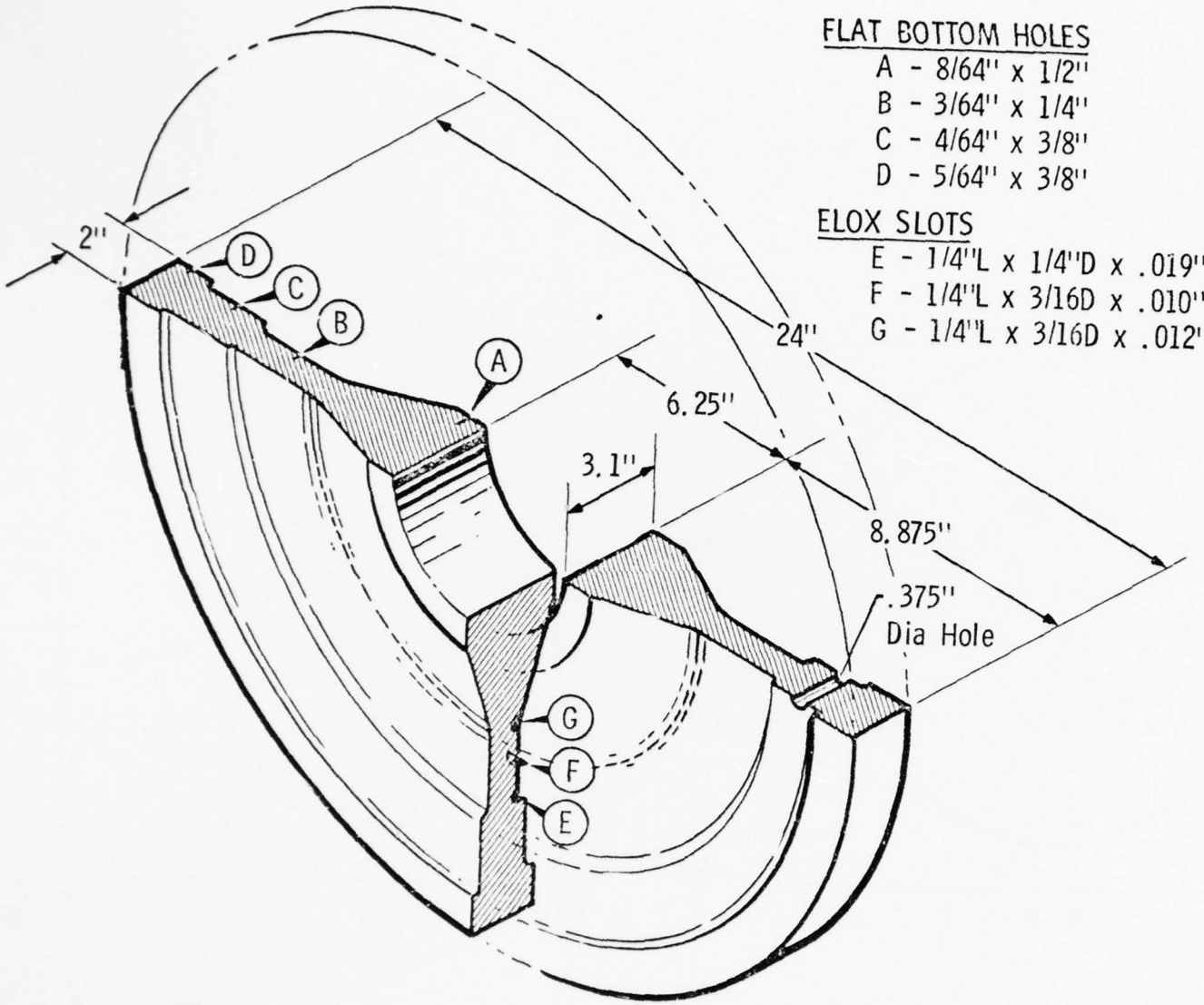


Figure 45 AFT Engine Disk

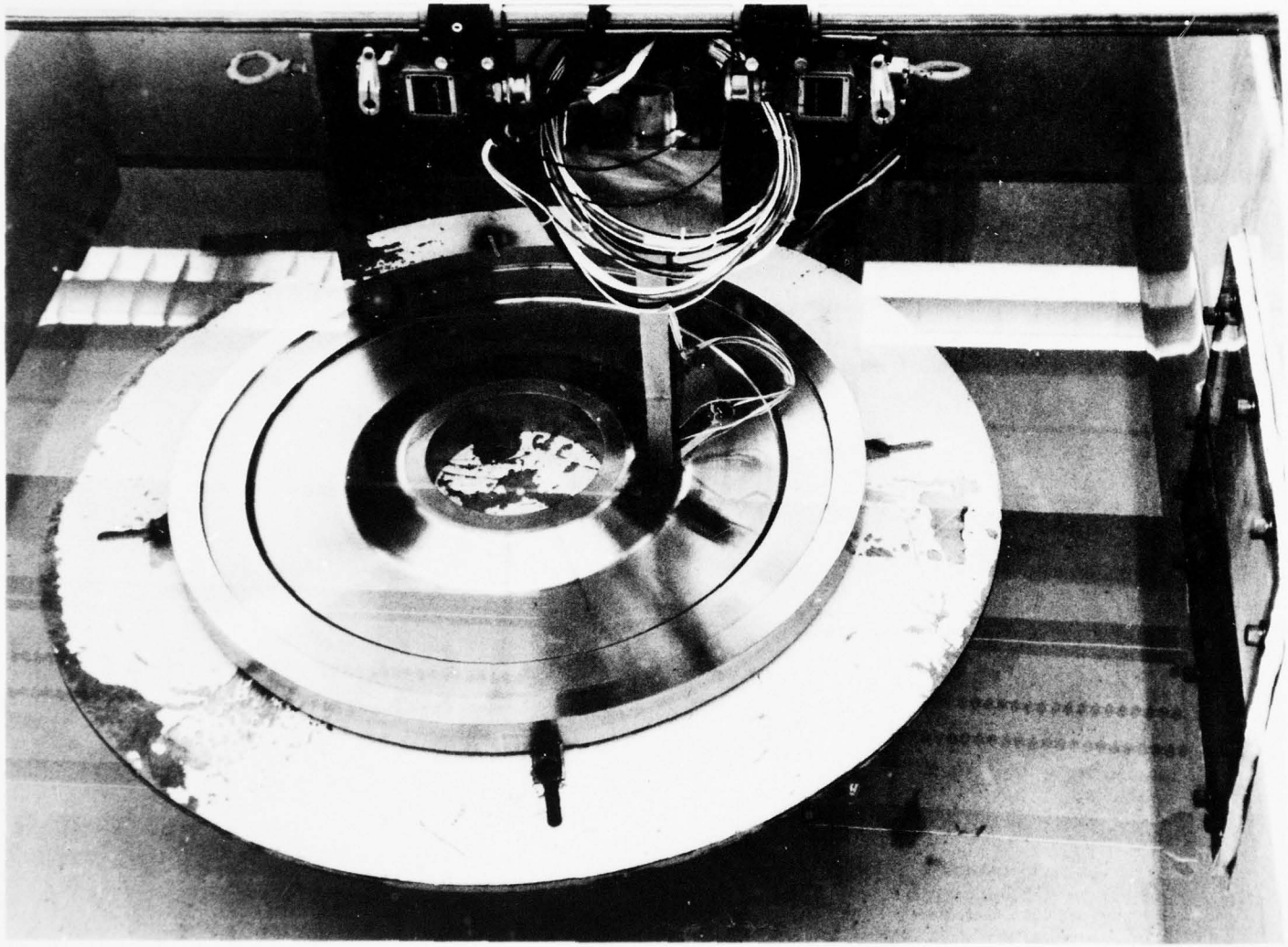


Figure 46 Photograph of Engine Disk Under Inspection

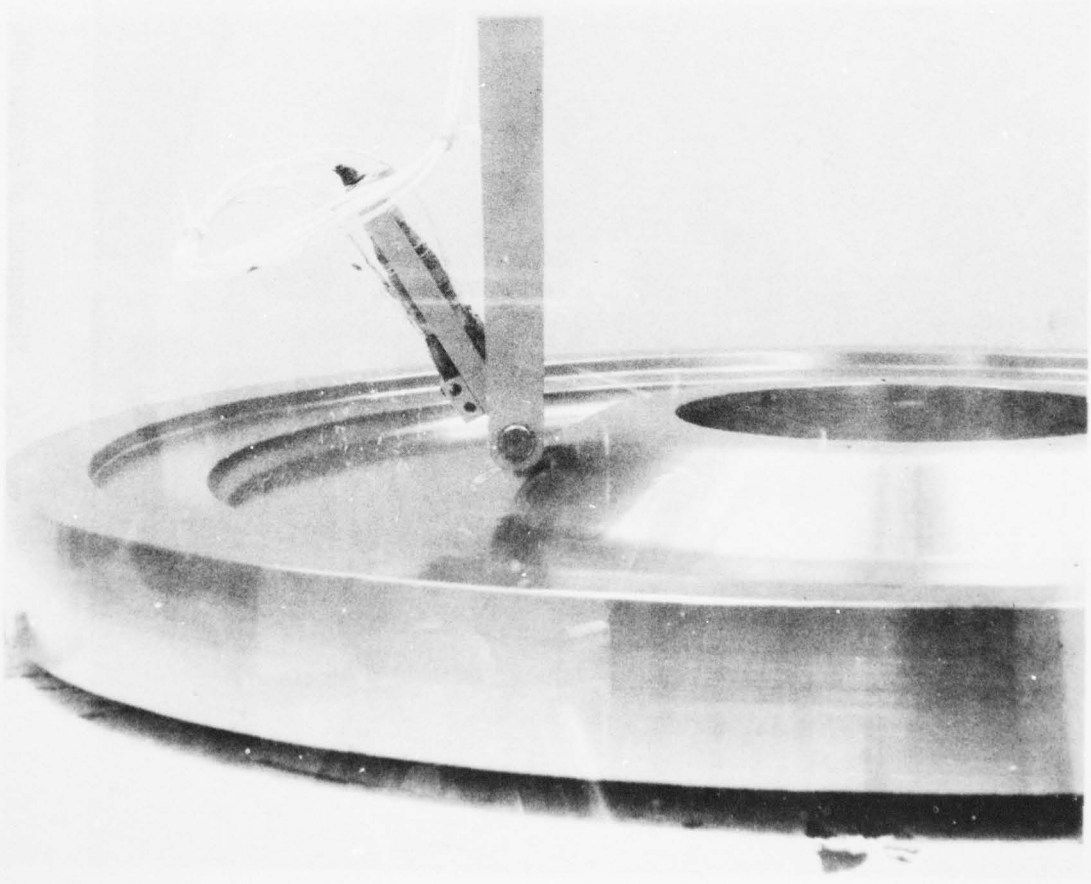


Figure 47 Photograph of Transducer Scanning Engine Disk

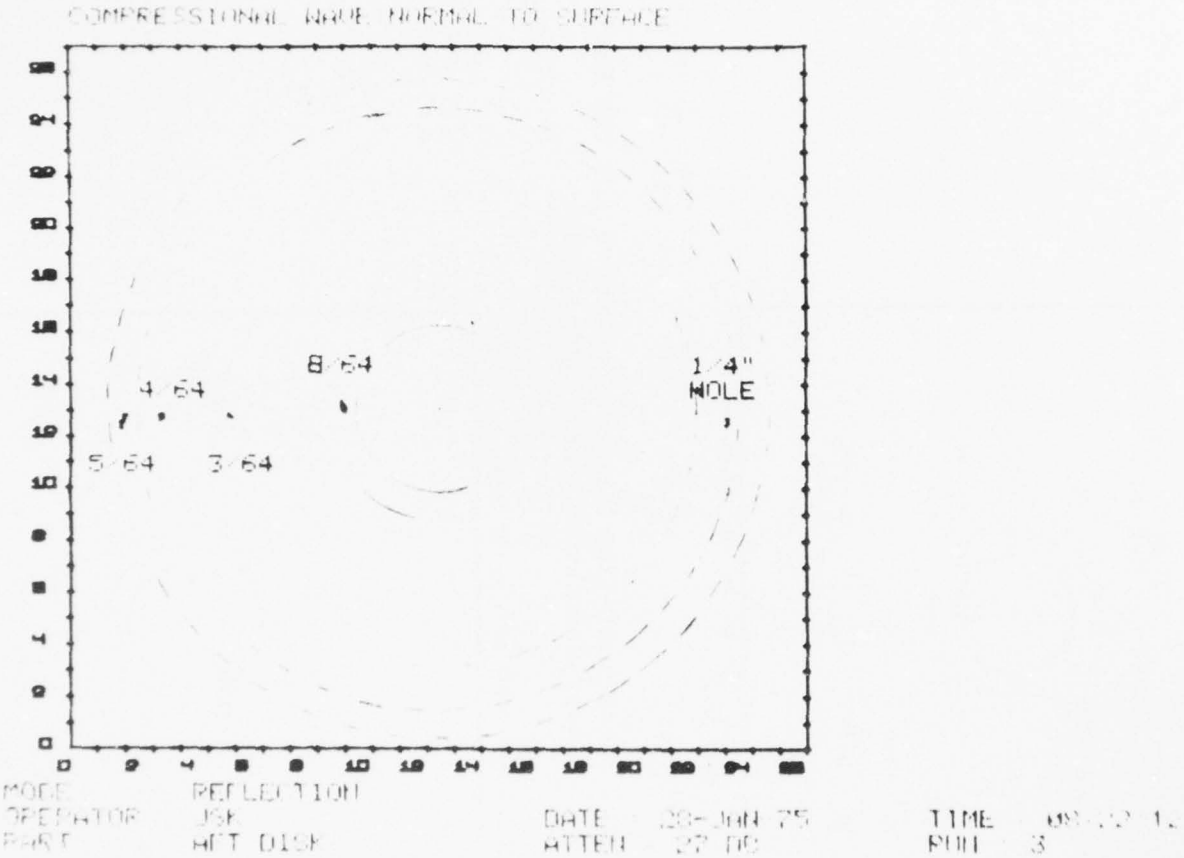
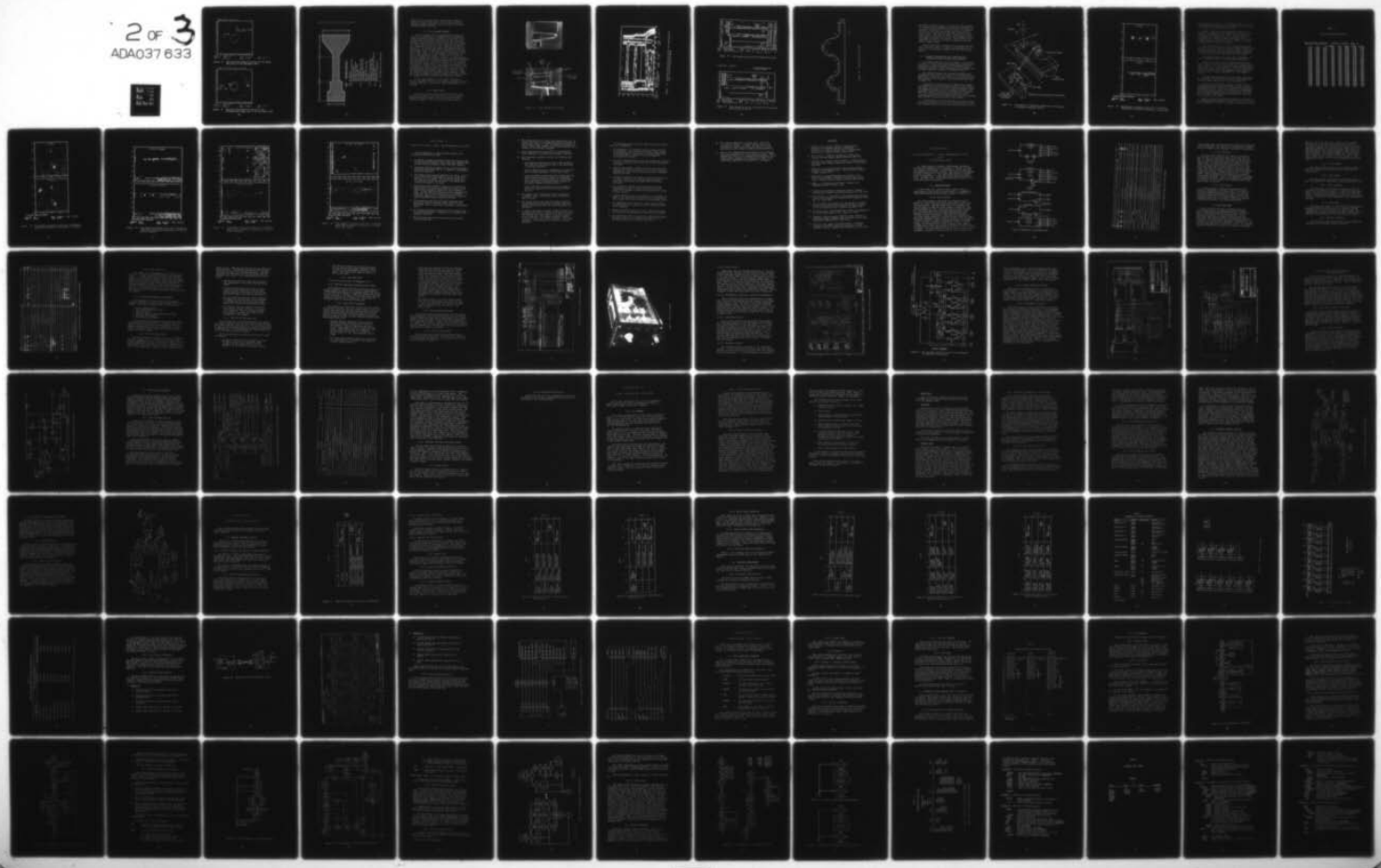


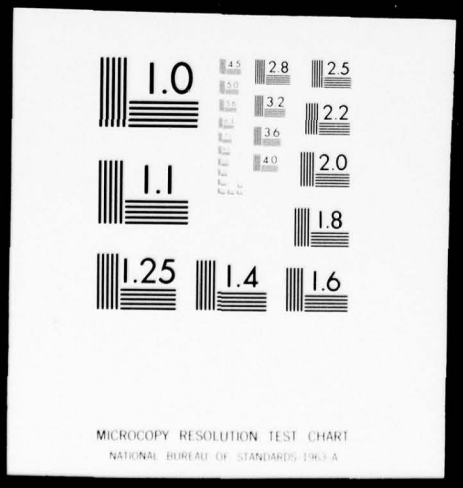
Figure 48 Near-Real-Time Inspection Record for the Compressional Scan of AFT Engine Disk

AD-A037 633 GENERAL DYNAMICS/FORT WORTH TEX FORT WORTH DIV F/G 13/8
COMPUTER-AUTOMATED ULTRASONIC INSPECTION SYSTEM FOR AIRCRAFT FO--ETC(U)
MAY 75 B G YEE, J S KUNSELMAN, T C WALKER F33615-72-C-1828
UNCLASSIFIED AFML-TR-75-82 NL

2 OF 3
ADA037 633



2 OF 3
ADA037 633



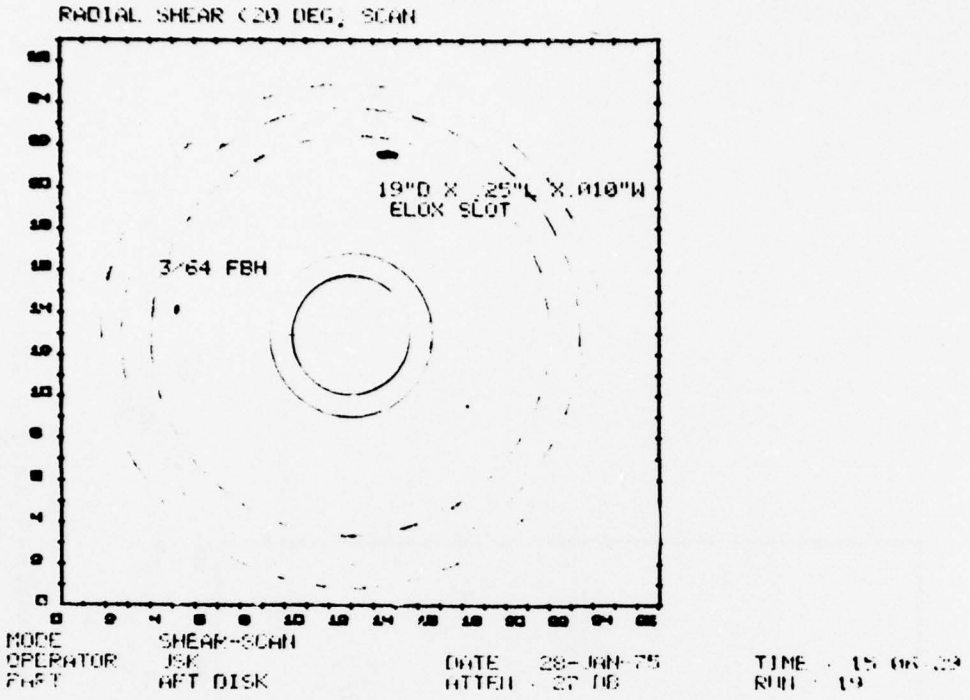


Figure 49 Near-Real-Time Inspection Record for the Radial Shear Scan of the AFT Engine Disk

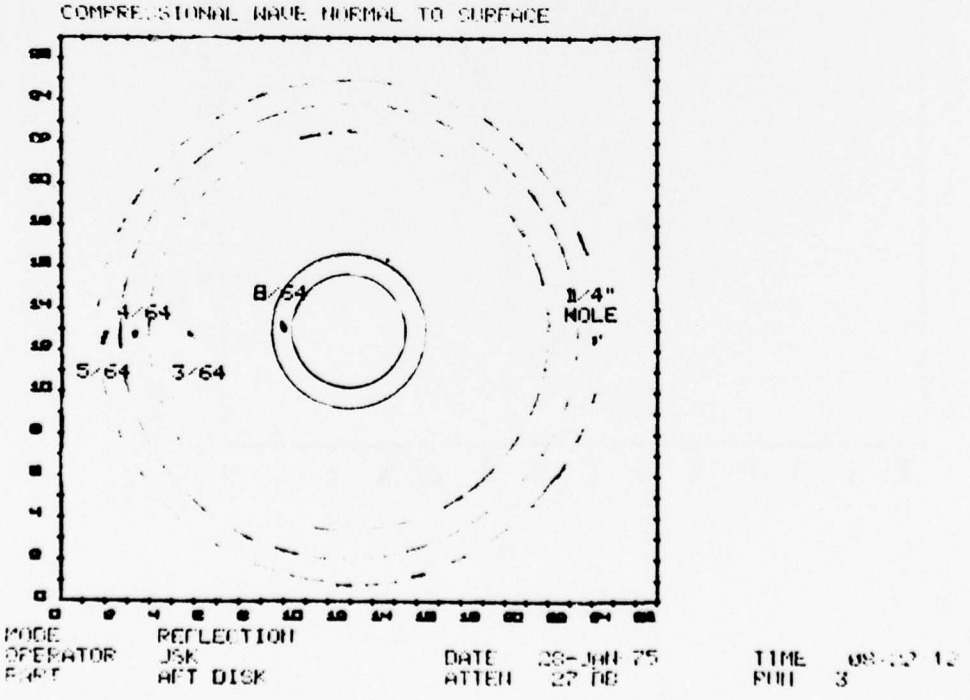
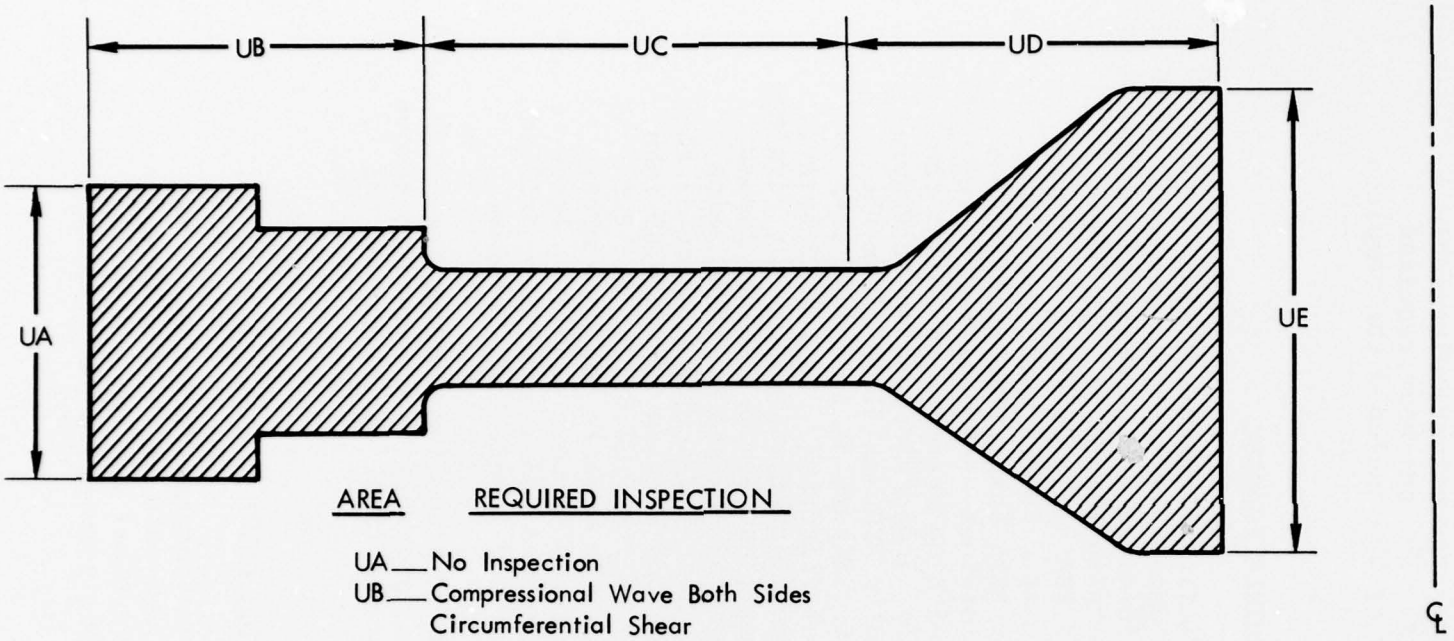


Figure 50 Near-Real-Time Inspection Record for the Circumferential Shear Scan of the AFT Engine Disk



AREA — REQUIRED INSPECTION

UA — No Inspection

UB — Compressional Wave Both Sides
Circumferential Shear
Both Sides (One Direction)
Radial Shear Both Sides
(One Direction)

UC — Compressional Wave One Side
Circumferential Shear One Side
(One Direction)
Radial Shear One Side (One
Direction)

UD — Compressional Wave Both Sides
Circumferential Shear Both Sides
Radial Shear Both Sides (One Direction)

UE — Compressional Wave
Radial Shear (One Direction)

Figure 51 AFT Engine Disk Scan Requirements

while the time required using conventional ultrasonic equipment is over four hours. The one hour required with the computer-automated system included the complete calibration and setup time.

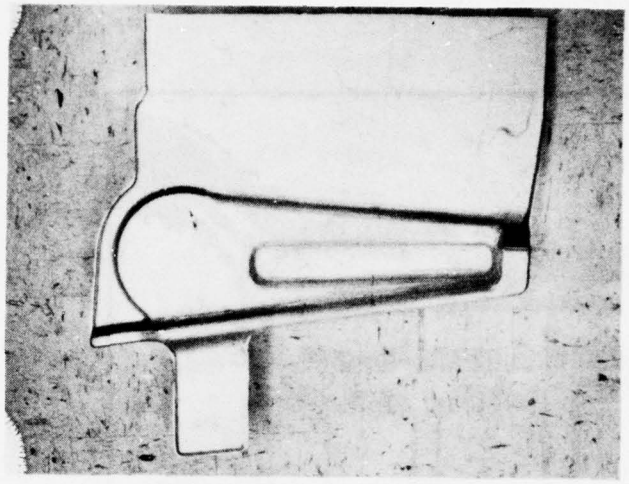
4.5 F-111 ALUMINUM FORGING

A F-111 landing gear fitting aluminum forging was selected to demonstrate the capability of the system to inspect moderately complex forgings. The portion of the forging that was used is shown in Figure 52. The size, location, and orientation of FBH are also shown in Figure 52. The forging was scanned at 6 inches per second and the display of the near real-time inspection is shown in Figure 53. The result was obtained by scanning from the top surface of the forging with no attempts to follow the small radii. Most of the flaw indications shown in Figure 53 are the results of recording BSRs as flaws after the loss of BSR around the radii. Figure 54 is a post inspection display with spatial filtering. In this display, all flaw indications or signals originating from the forging that is between 1 to 1.20 inch, between 2.1 to 2.3 inches, and below 2.4 inches from the top surface of the forging are removed. Figure 55 is a post inspection display of the forging with all flaw indications between 0.7 to 0.85 inch and below 1.45 inch from the top surface filtered. But all indications containing a BSR, even if they are within the filtered region, are included in this display. These two filtering schemes detected all FBHs, even those drilled at an angle of 30^{o} off normal and located in a radius.

If the final dimensions of a complex forging are known, a filtering scheme can probably be designed to remove all flaw indications outside the final dimensions of the forging.

4.6 VECTOR DRIVE

A contour following scheme called Vector Drive was developed to inspect a specimen such as the one shown in Figure 56 which contains a vertical section and still maintains normalcy. The other schemes cannot scan up



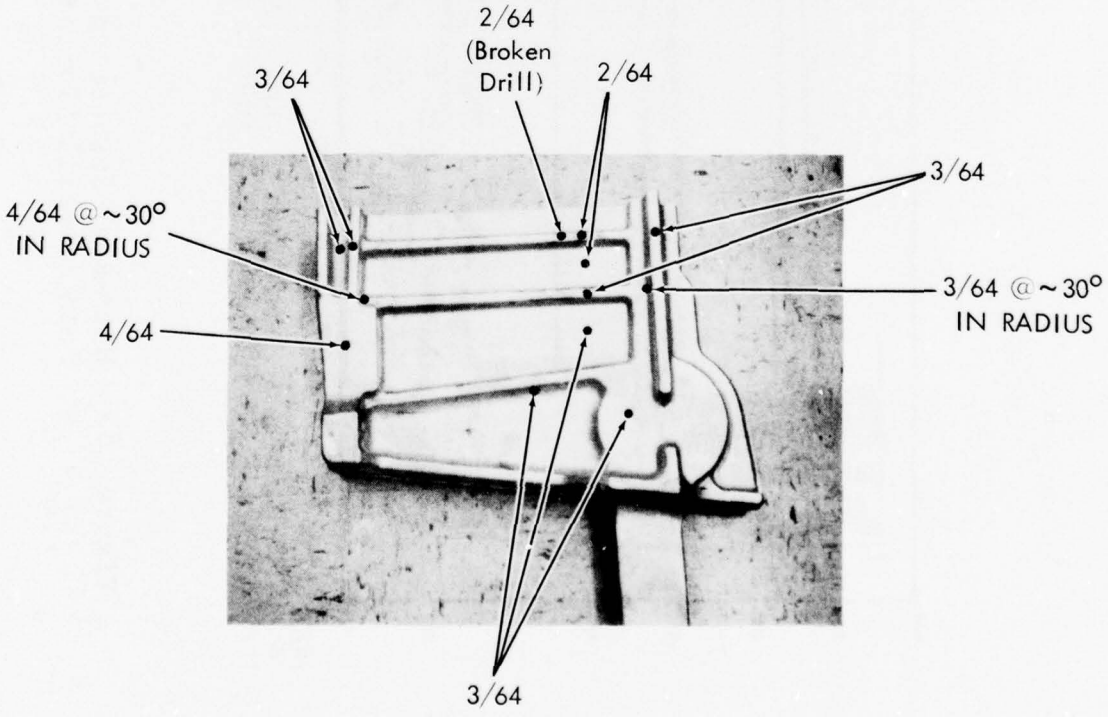


Figure 52 F-111 Landing Gear Forging

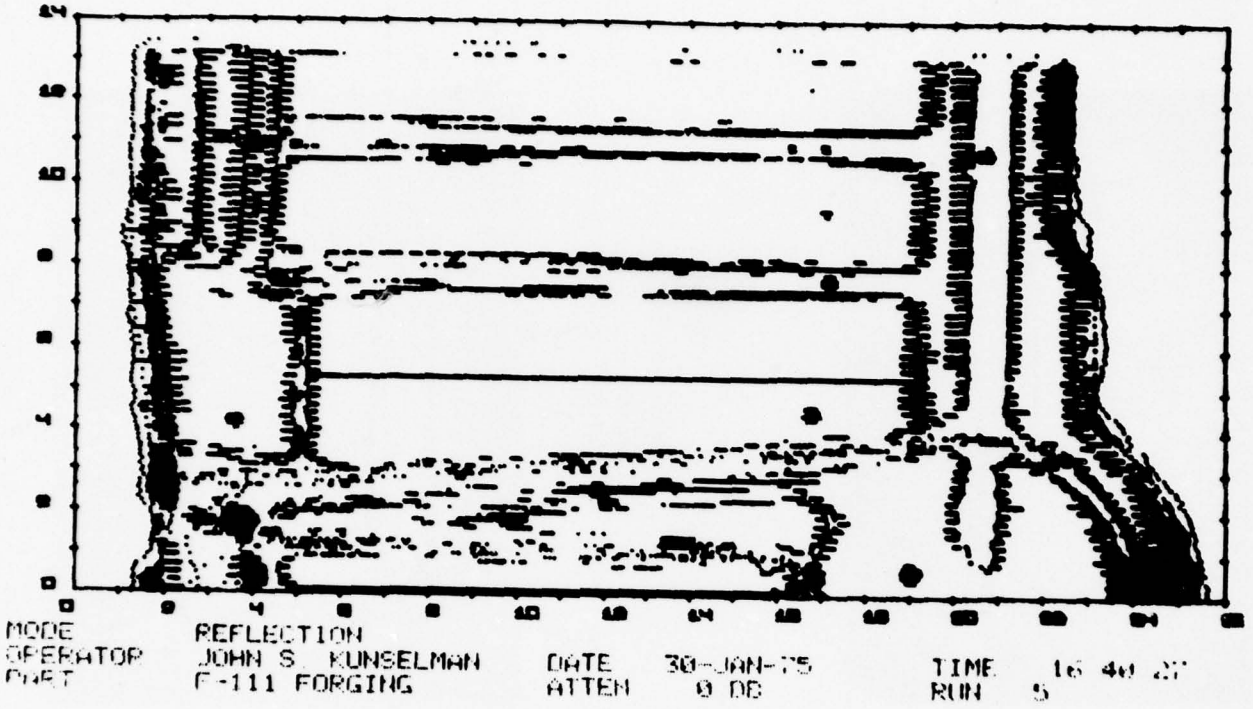


Figure 53 Near-Real Inspection Record for the Compressional Scan of F-111 Aluminum Forging

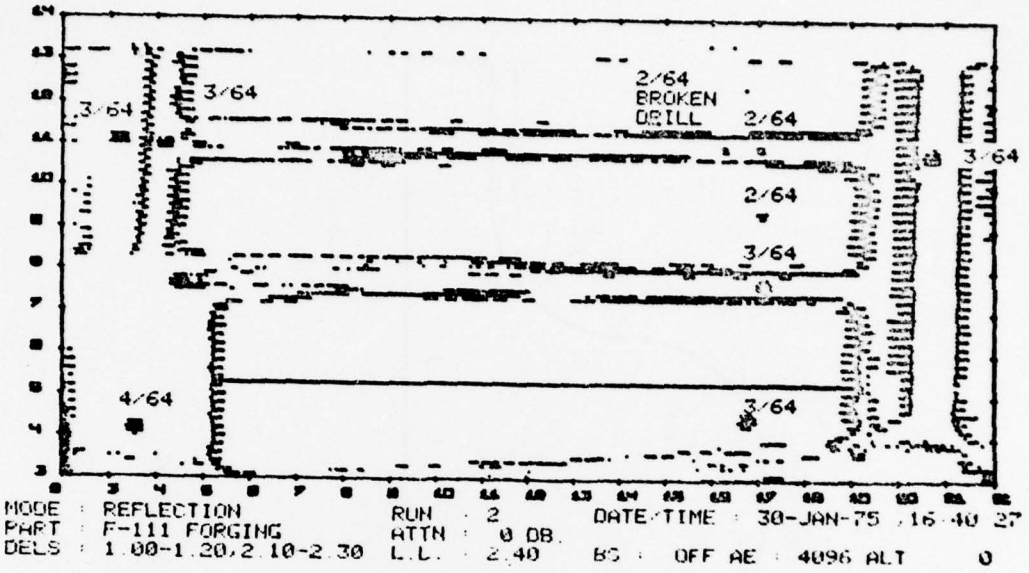


Figure 54 Post-Inspection Record with Spatial Filtering

REPORT DATE : 03-FEB-75

* FBH DRILLED 30 DEG OFF NORMAL IN RADIUS

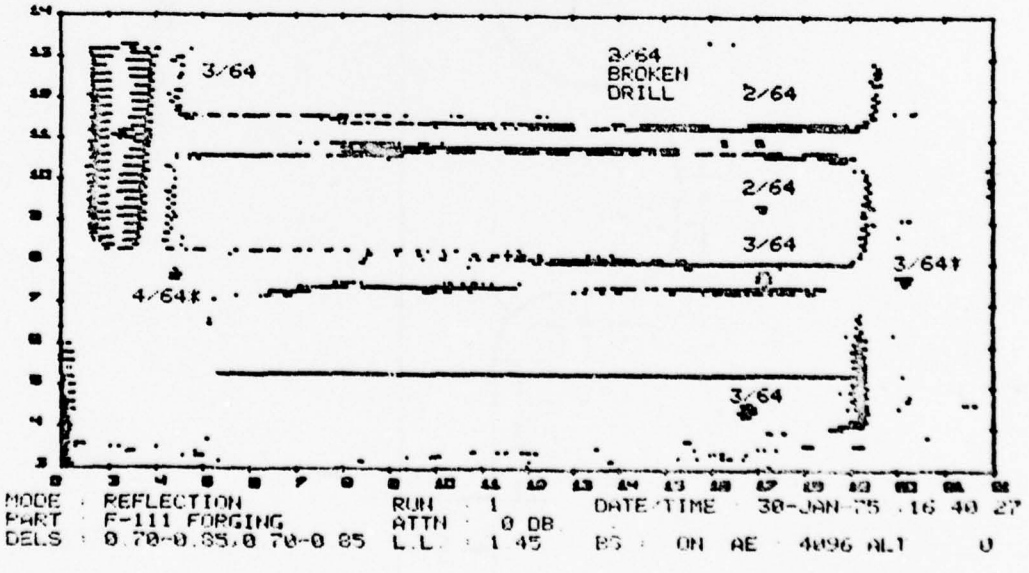


Figure 55 Post-Inspection Record with Spatial Filtering and Back Surface Switch ON

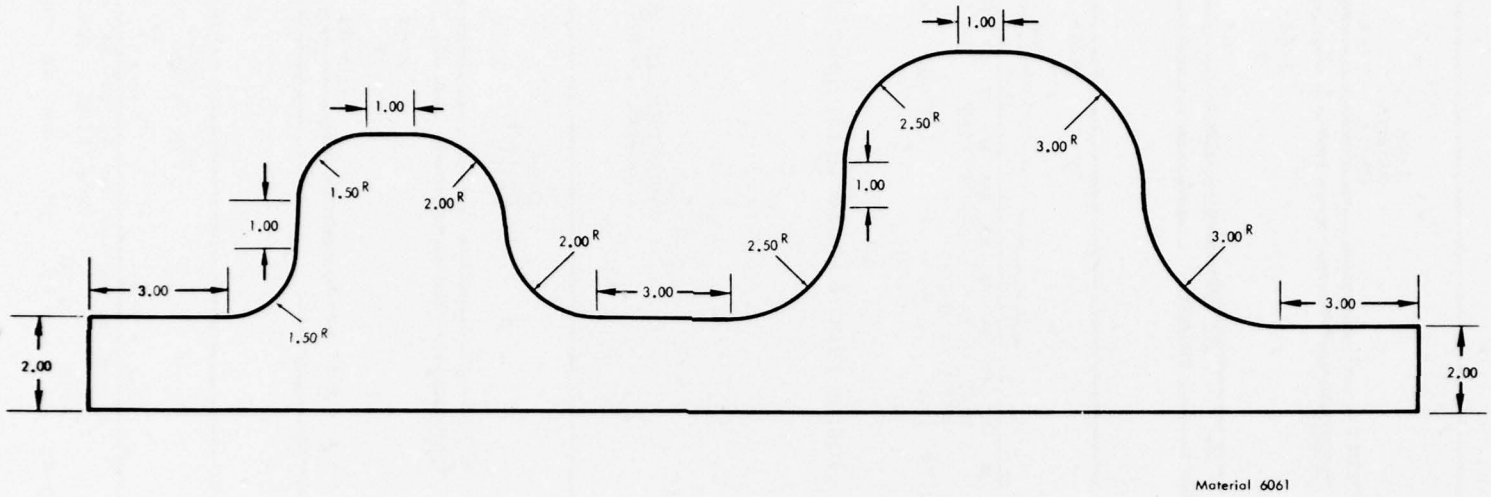


Figure 56 Camel-Back Test Specimen

the (90°) vertical section. In the Vector Drive scheme, the computer is preprogrammed to drive the transducer by a selected distance (0.1, 0.25 inch, etc.) in a selected direction. Then, the top surface reflection at this vector point is maximized and the DOS corrected to the preset value. Data will be taken at each vector point and between vector points as well, even though the sound beam might be slightly off normal. Theoretically, the sound beam will not be very far off normal if the step taken is small enough.

The specimen shown in Figure 57 was scanned successfully with this scheme. The speed in scanning this or any other test specimen depends on the size of the step taken.

4.7 VARIABLE TILT-MULTIPLE SCAN INSPECTION OF A DIFFUSION BONDED TITANIUM ALLOY STRUCTURE

The CAUIS system was used to evaluate a rib-stiffened section of a large diffusion bonded structure during the performance of Contract F33615-72-1705 "Nondestructive Testing of Diffusion Bonded Titanium Alloys for Engine and Airframe Components, reported in AFML-TR-74-215.[11]

The diffusion bonded part contained displaced and angularized bond planes as a result of the bonding process. Orientation of the part with respect to the scan axis and the position of the reference flat bottom holes are shown in Figure 58.

Inspection was carried out at 10 MHz using a Panametrics Model A311, 10/0.5I S/N 998 transducer (flat-faced). The signal level was set at 30% of screen saturation using the maximized response from the inclined 5/64 FBH. This maximized response occurred at a transducer tilt angle of -8°. This value agrees with Snell's Law for a water-titanium system and a reflecting surface within the titanium whose normal is inclined at 30° to the vertical.

A preliminary set of scans was made over the reference holes at tilt angles of -8° to +8° in 2° increments. The hole indications were distinct and separate at $\theta = -8°$, but

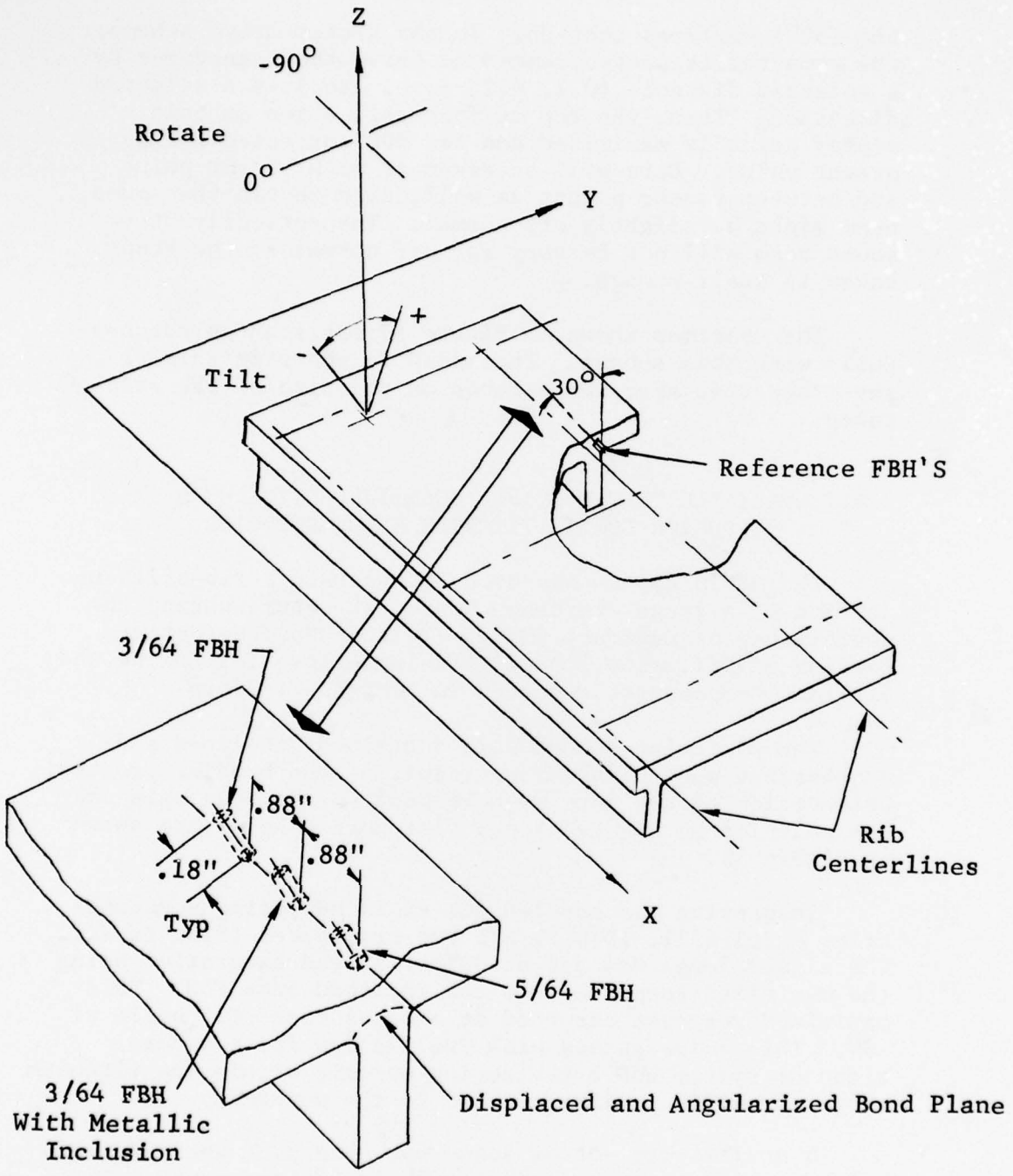


Figure 57 Orientation of Diffusion Bonded Part with Respect to Scanner Coordinate System

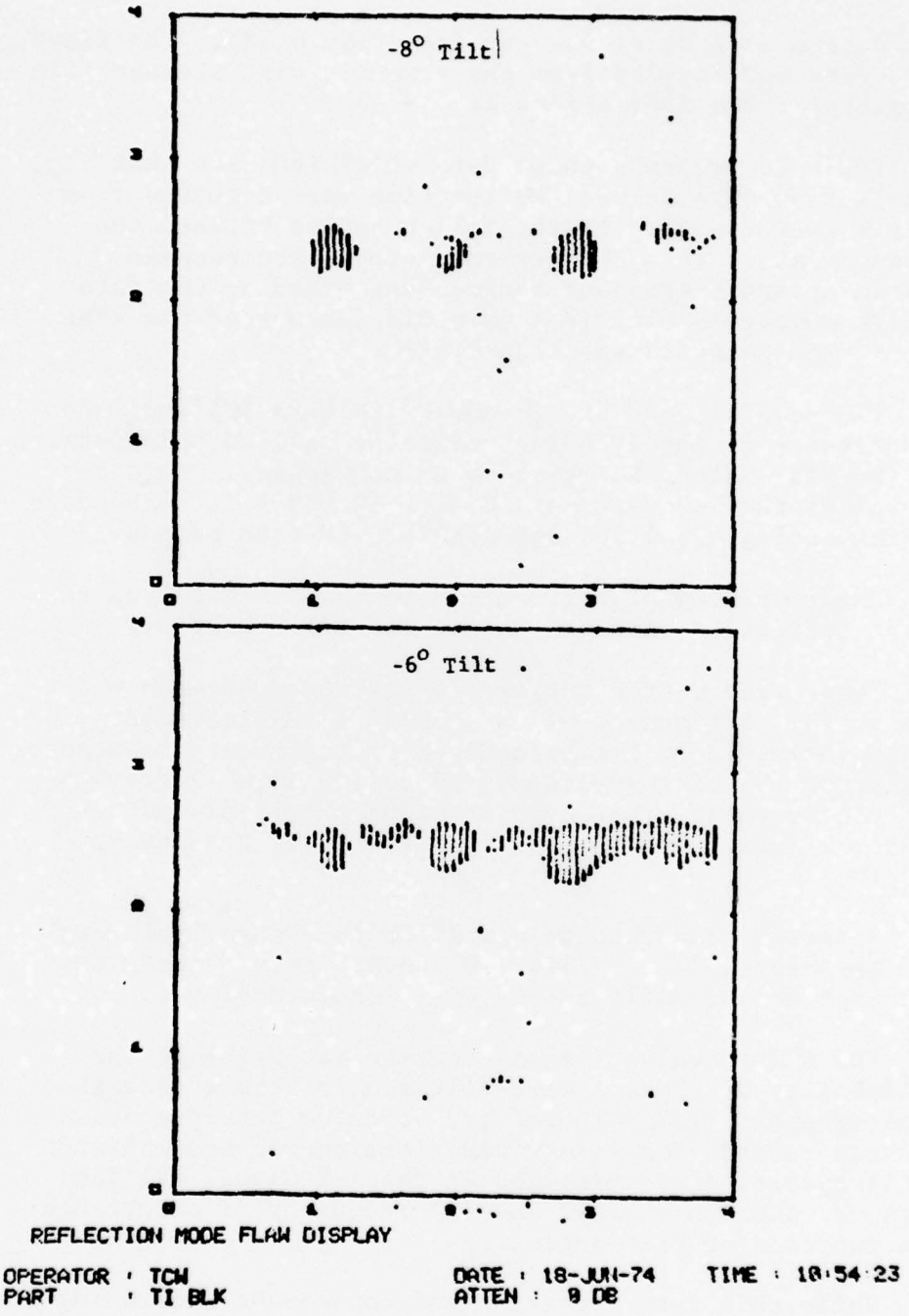


Figure 58 Flaw Display in Reference Hole Area of Diffusion Bonded Part (Transducer Inclination, -8° and -6°)

they became less so at $\theta = -6^{o}$ (see Figure 58). The flaw depth data were called from the computer disc storage file to interpret the indications at $\theta = -6^{o}$.

Table 2 presents these data which indicate that signals from outside the FBH location were returned from a depth corresponding to the fillet radius between the rib and plate. This ability to discriminate between legitimate and extraneous indications based on the data in disk memory is clearly a valuable feature of the AFML Computer-Automated Inspection System.

The scan records at -2^{o} and 0^{o} (Figure 59) indicate the presence of the 3/64-inch diameter drilled hole between the two flat-bottom holes which do not appear. This re-emphasizes that conventional C-scan ($\theta = 0^{o}$) is inadequate for inspecting displaced and angularized bond planes.

The remaining scans from $+2^{o}$ to $+8^{o}$ contained no relevant indications and are not included for brevity.

Inspection of the entire rib-stiffened section was done at (a) tilt angles of -8^{o} to $+8^{o}$ in 2^{o} increments, 0^{o} rotate angle, i.e., the transducer tilted about the scanner X-axis and (b) tilt angles of -8^{o} to $+8^{o}$ in 2^{o} increments, -90^{o} rotate angle, i.e., the transducer tilted about the scanner Y-axis. This is equivalent to a 17-transducer array.

Selected scan records are given in Figure 58 through 62. As before, the -8^{o} tilt, 0^{o} rotate record shows the reference holes, while the 0^{o} tilt record does not.

The above evaluation was carried out prior to the availability of the software filtering routines described in paragraph 3.10.4. Therefore, operator interpretation of the scan records for defect verification was accomplished by (1) spatial discrimination in the X-Y plane, (2) flaw depth vs. part thickness, and (3) frequency of occurrence as a function of tilt angle.

While this interpretation and consequent sectioning of the diffusion bonded component resulted in the verification of two anomalies, the value of software filtering is obvious.

TABLE 2

Reflection Mode Data Report

REFLECTION MODE DATA REPORT 18-JUN-74 10:29:57 PAGE 3

X	Y	Z	ROTATE	TILT	THICK	FLW DP	FLW AM
2.89	2.50	0.00	0.0	-5.8	19.54	0.44	4035
2.89	2.50	0.00	0.0	-5.8	19.51	0.43	4005
2.89	2.50	0.00	0.0	-5.8	19.53	0.43	4005
2.89	2.51	0.00	0.0	-5.8	19.51	0.43	4005
2.89	2.51	0.00	0.0	-5.8	19.50	0.43	4008
2.89	2.51	0.00	0.0	-5.8	19.93	0.43	4002
2.89	2.51	0.00	0.0	-5.8	19.51	0.43	4009
2.89	2.51	0.00	0.0	-5.8	19.93	0.43	4004
2.89	2.52	0.00	0.0	-5.8	19.53	0.43	4006
2.89	2.52	0.00	0.0	-5.8	19.68	0.43	4014
2.89	2.52	0.00	0.0	-5.8	19.93	0.42	3997
2.89	2.52	0.00	0.0	-5.8	19.53	0.42	3938
2.89	2.52	0.00	0.0	-5.8	19.53	0.43	3917
2.89	2.53	0.00	0.0	-5.8	19.91	0.43	3858
2.89	2.53	0.00	0.0	-5.8	19.51	0.42	3880
2.89	2.53	0.00	0.0	-5.8	19.51	0.41	3776
2.89	2.53	0.00	0.0	-5.8	19.92	0.41	3731
3.29	2.49	0.00	0.0	-5.8	19.51	0.59	3695
3.29	2.49	0.00	0.0	-5.8	19.70	0.59	3730
3.29	2.49	0.00	0.0	-5.8	19.50	0.59	3746
3.29	2.49	0.00	0.0	-5.8	19.52	0.59	3760
3.29	2.50	0.00	0.0	-5.8	19.52	0.59	3778
3.29	2.50	0.00	0.0	-5.8	19.66	0.60	3791
3.29	2.50	0.00	0.0	-5.8	19.93	0.60	3796
3.29	2.50	0.00	0.0	-5.8	19.51	0.59	3808
3.29	2.50	0.00	0.0	-5.8	19.52	0.59	3827
3.29	2.51	0.00	0.0	-5.8	19.53	0.59	3820
3.29	2.51	0.00	0.0	-5.8	19.66	0.59	3826
3.29	2.51	0.00	0.0	-5.8	19.95	0.59	3823

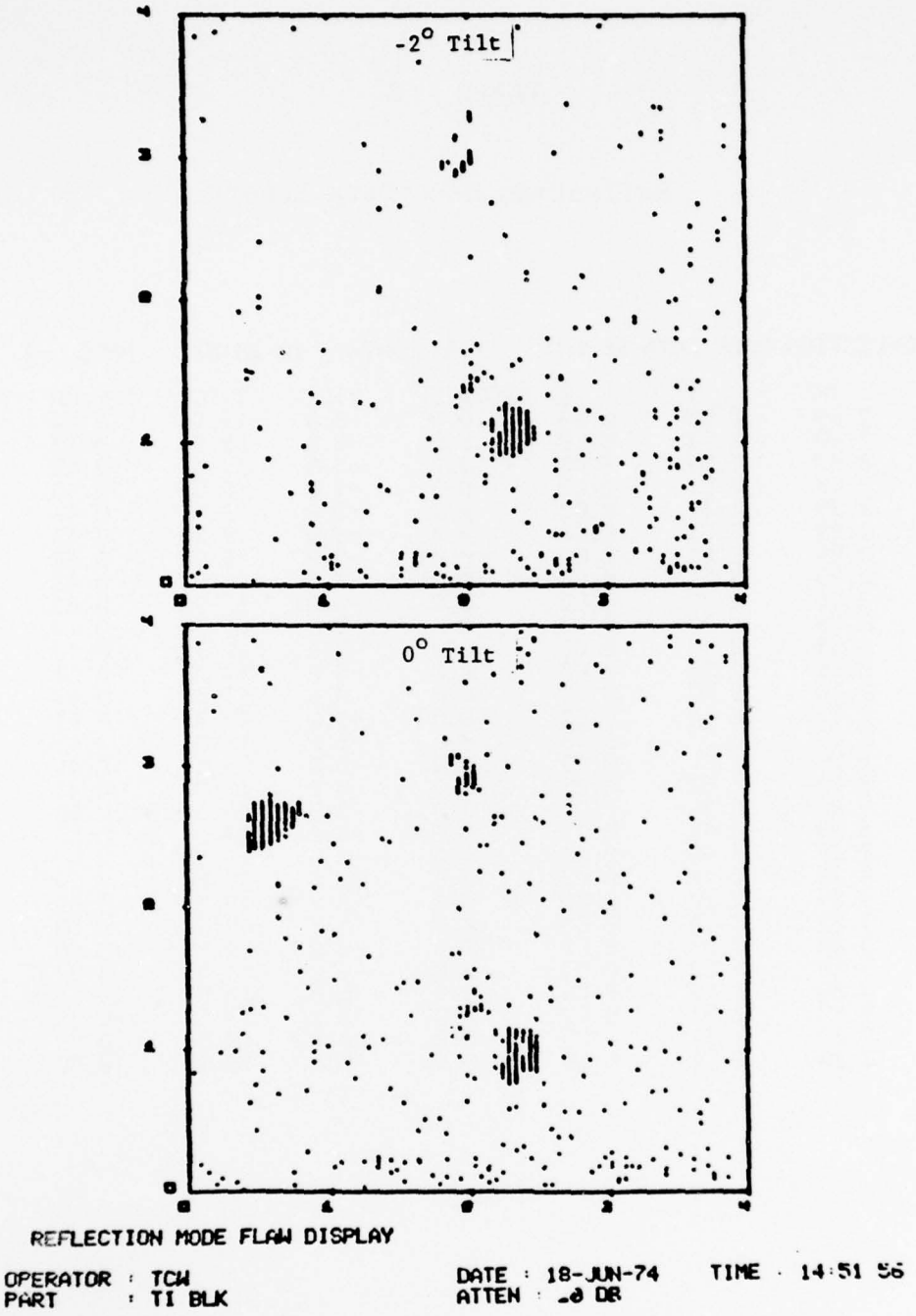


Figure 59 Flaw Display in Reference Hole Area of Diffusion Bonded Part (Transducer Inclination, -2° and 0°)

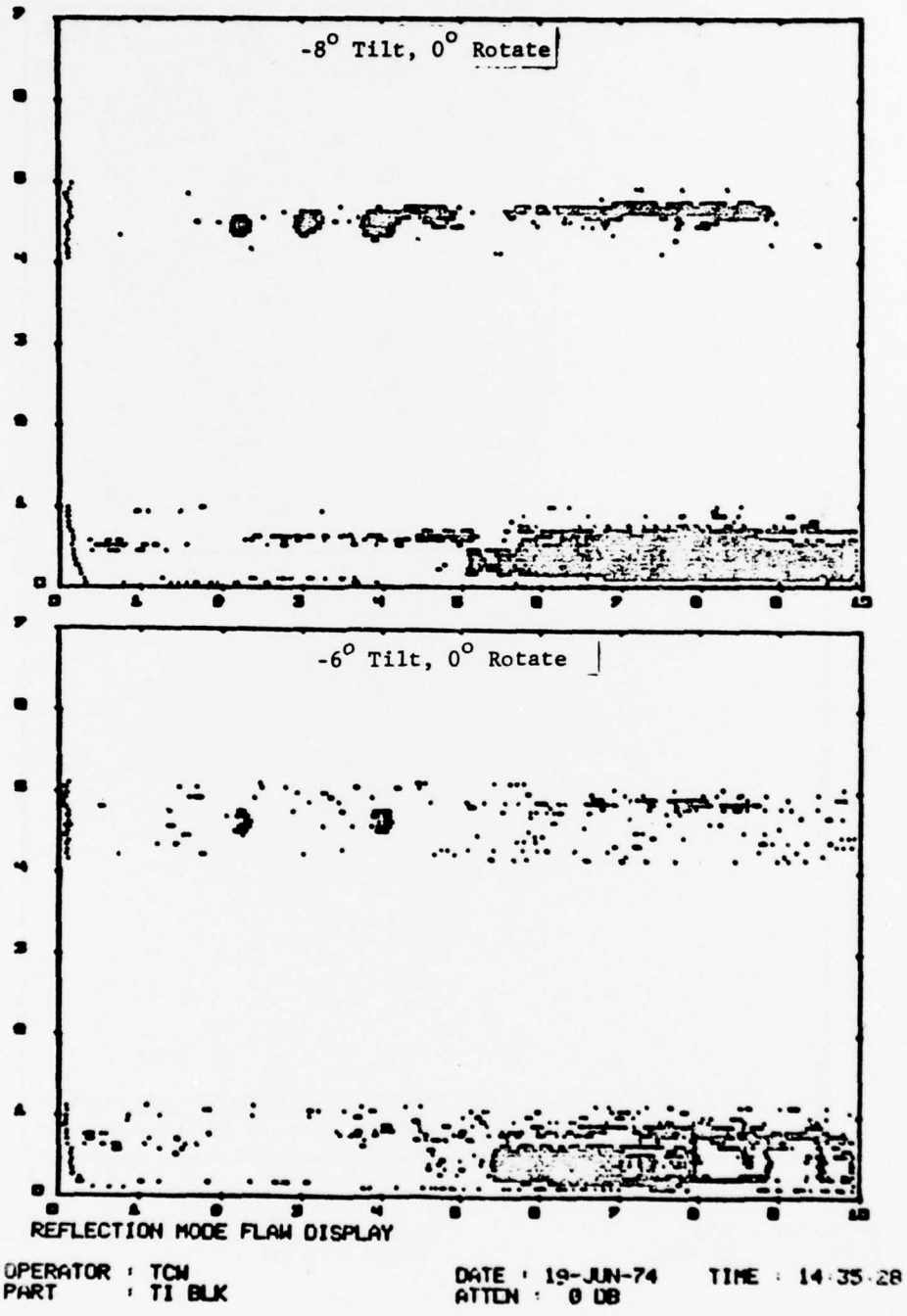


Figure 60 Flaw Display in Reference Hole Area of Diffusion Bonded Part (Transducer Inclination, -8° and -6° Tilt; 0° Rotate)

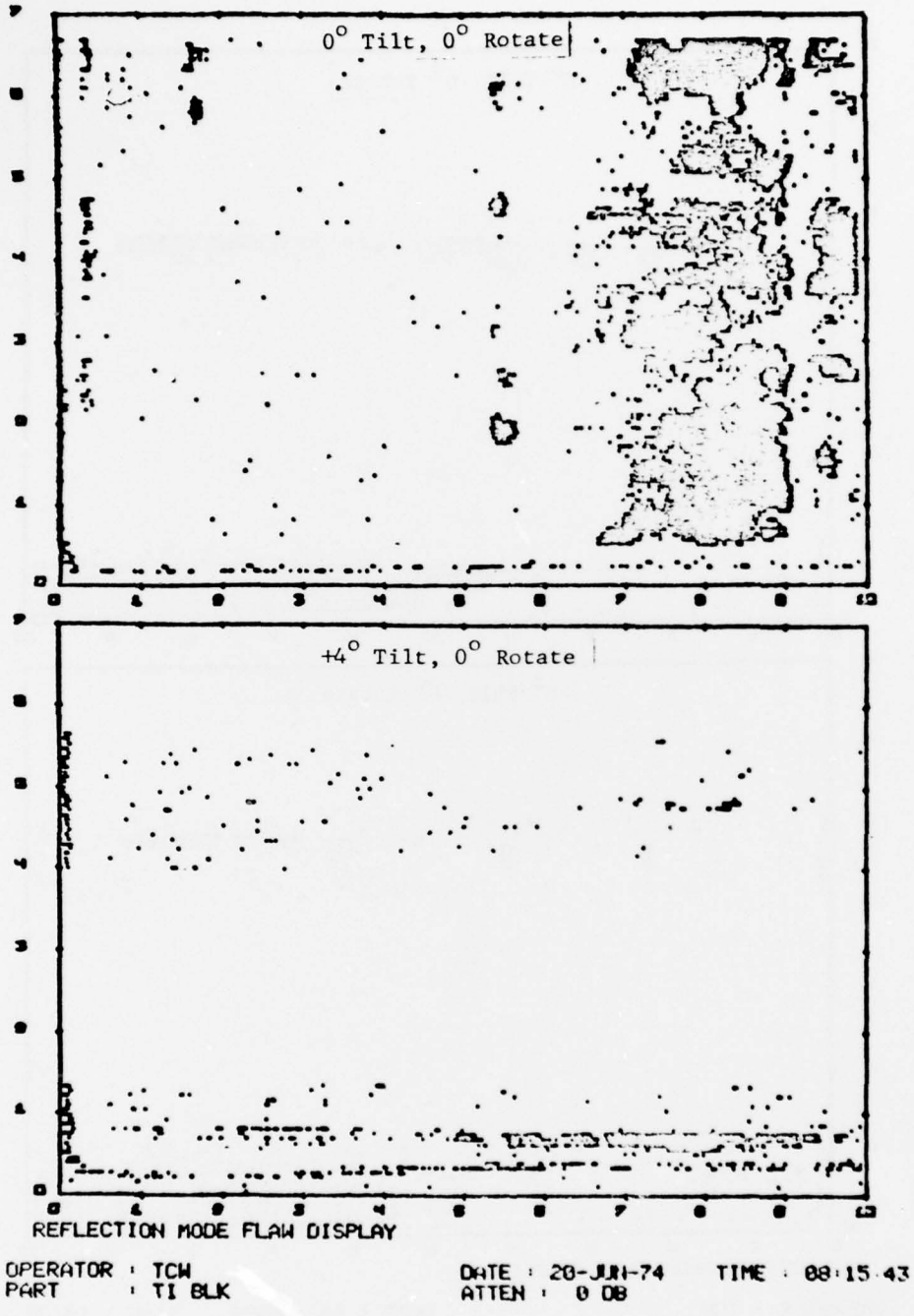


Figure 61 Flaw Display in Reference Hole Area of Diffusion Bonded Part (Transducer Inclination, 0° and +4° Tilt; 0° Rotate)

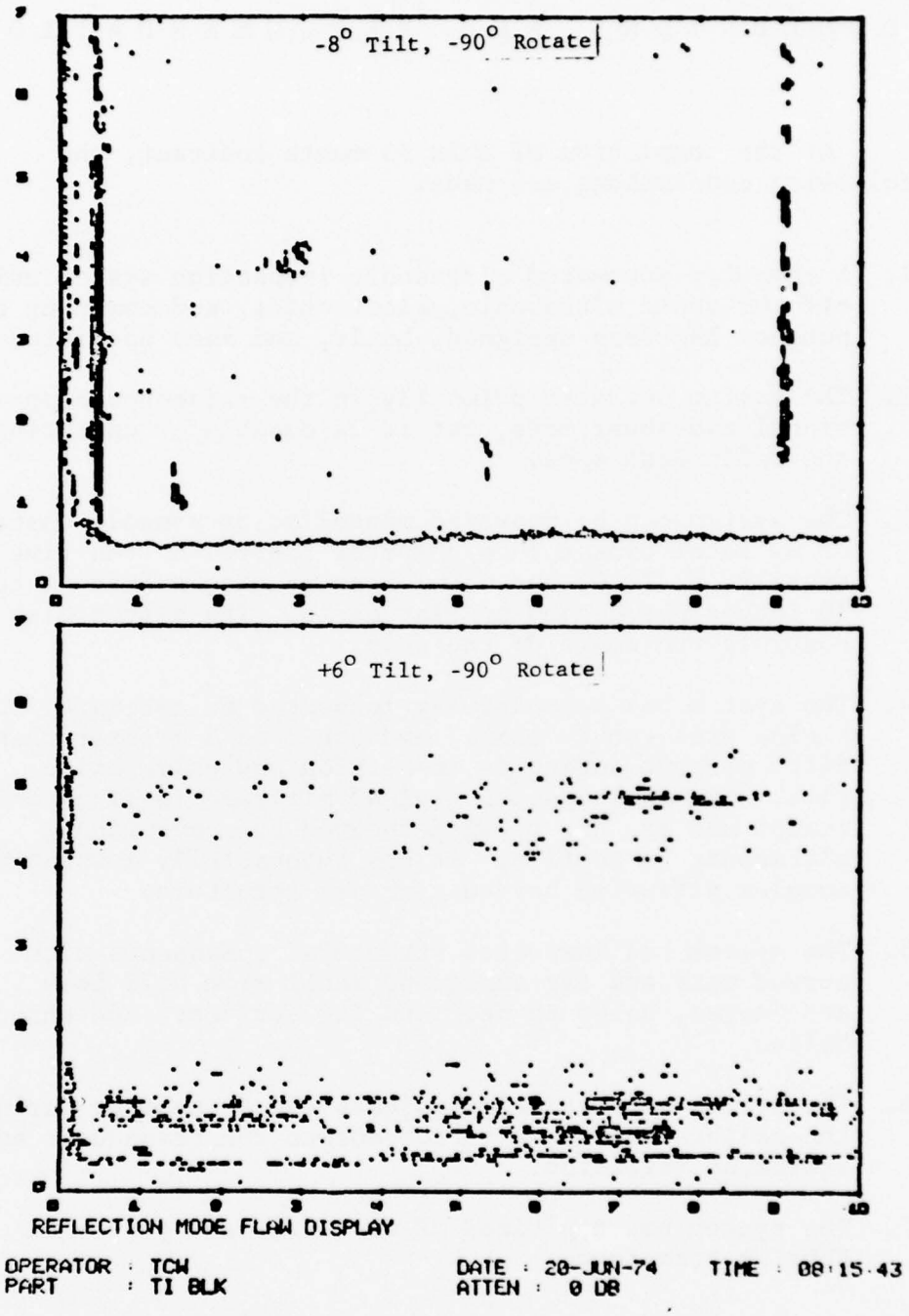


Figure 62 Flaw Display in Reference Hole Area of Diffusion Bonded Part (Transducer Inclination, -8° and+6° Tilt; -90° Rotate)

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

At the completion of this 33 month contract, the following conclusions are made:

1. A computer automated ultrasonic inspection system using off the shelf ultrasonic, electronics, and computer components has been designed, built, and made operable.

2. The system operates primarily in the reflected compressional and shear mode, but it is capable of operating in the Delta Scan mode.

3. The system can be operated manually, by console control, or by total closed loop computer control of the five axes: X, Y, Z, θ, and $\emptyset$. It can scan at speeds up to 10 inches per second on flat parts. The system also controls the speed of the scan.

4. The system has successfully inspected an aircraft jet engine disk (sonic shape) and achieved a greater than fifty percent saving in inspection and calibration time. It has inspected typical airframe forgings which cannot and are not being inspected by conventional ultrasonic inspection. It has successfully inspected a complex diffusion bonded aircraft structure.

5. The system has inspected structural components with curved near and far surfaces, radii from 0.75 inch and larger, holes in near and far surfaces, and through holes.

6. The system automatically adjusts the db setting during the calibration phase to compensate for transducer and equipment variation.

7. The system has digitized RF waveforms and performed Fourier transforms.

8. The system has and can remove flaw indications from outside of the final or net shaped structural component by performing a series of logic and spatial filtering routines. Blind zones caused by step discontinuities can be reduced by the multiple flaw gate.

9. Defect indications are presented in a conventional C-scan display on a storage scope (Graphic Terminal).

10. Post inspection analysis include the following capabilities.

    . Amplitude discrimination of defect data provides a very effective and expedient aid in the acceptance or rejection decision.

    . Defect indications can be displayed as an isometric plot of defect amplitude on the X and Y axes.

    . Areas with defect indications are searched with the defect homing routine to obtain the coordinates (X, Y, Z, θ, and $\emptyset$) which yield the largest ultrasonic amplitude to determine defect orientation and detect randomly oriented defects.

    . Areas with defect indications can be expanded to give a more detailed view of the defect cross-section.

11. The system records inspection results permanently on magnetic disk. The results can be recalled in near real time.

12. The system reduces, but does not remove, operator interpretation on potentially rejectable flaws and operator involvement with the overall inspection requirements.

13. A computer automated ultrasonic inspection system is feasible and reliable. During the 19 months in which the computer was in operation, it failed to operate on six occasions. The computer required outside services on only two of these occasions. The other occasions, it was repaired by in-house electronic personnel.

The following areas of further improvements and developments are recommended.

1. A large amount of ultrasonic data are being collected and available. More and better software logic, signal processing schemes, and spatial filtering schemes need to be developed to produce a clear and ambiguous presentation of results.

2. A contour following scheme which can rapidly and reliably, follow and inspect radii between 1/8 to 3/4 inch must be developed.

3. Software and hardware schemes need to be developed and made operable with conventional off-the-shelf ultrasonic equipment to reduce the top surface envelope to approximately 0.05 inch.

4. A scheme to identify the radius of curvatures and correct for their effects on the focusing and defocusing of ultrasonic sound beams and energy density should be developed.

5. The ultrasonic transducer housing assembly must be miniaturized so that it can be inserted into small pockets (2-3 inches in diameter) and inspect for defects in these pockets.

6. Software schemes need to be developed to reconstruct the image of the defect when the defect can be illuminated from several directions, such as the flaw homing routine.

7. The capability of the system to inspect actual complex aircraft structures reliably and cost effectively needs to be evaluated.

8. Signal processing schemes for defect dimension determination need to be implemented as they become available.

9. The calibration and set up procedure and operator-system interface need to be streamlined and simplified for potential reduction to production practice.

10. For a given inspection, a great deal of data are recorded and stored. Software schemes need to be developed to compact or reduce the amount of data necessary to have complete inspection documentation.

11. Many of the capabilities described in the conclusion have been demonstrated on an individual basis. These capabilities need to be combined and integrated into a single master program that possesses as many of the individual capabilities as possible or necessary.

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APPENDIX A

ULTRASONICS INSTRUMENTATION AND INTERFACING

A certain amount of signal conditioning, synchronization, and chronometry are necessary to prepare the data for computer interfacing. A description of the interface and associated circuitry follows. The system block diagram is shown in Figure 2. The system will operate in three modes of inspection: reflection, Delta-Scan, and shear-wave. However, most of the effort has been devoted to the reflection mode of operation.

A.1 REFLECTION MODE

In this mode, the receiver video output is fed to linear gates A and B, and to logic gate C. A diagram for identifying signal abbreviations is shown in Figure 63.

A.1.1 Front Surface

The front surface reflection is isolated by gate A which is a fast linear gate with front panel controls for delay and width. During calibration, the operator will set this gate to span the front surface reflection. The timing diagram for the reflection mode is shown in Figure 64. This gate generates a synchronization pulse (IF) whenever the first echo after the transmission pulse exceeds a preset threshold. This pulse corresponds to the front surface and will be used to start both the flaw-depth and thickness timers, each of which, in turn, enables a binary counter to start counting the pulses of 10-MHz clock. The gate contains a peak detector whose output remains at the peak level of the previous cycle until it is updated at a time approximately 30 microseconds following the gate. The peak detector output is used to monitor the transducer coupling efficiency, and if the peak detector

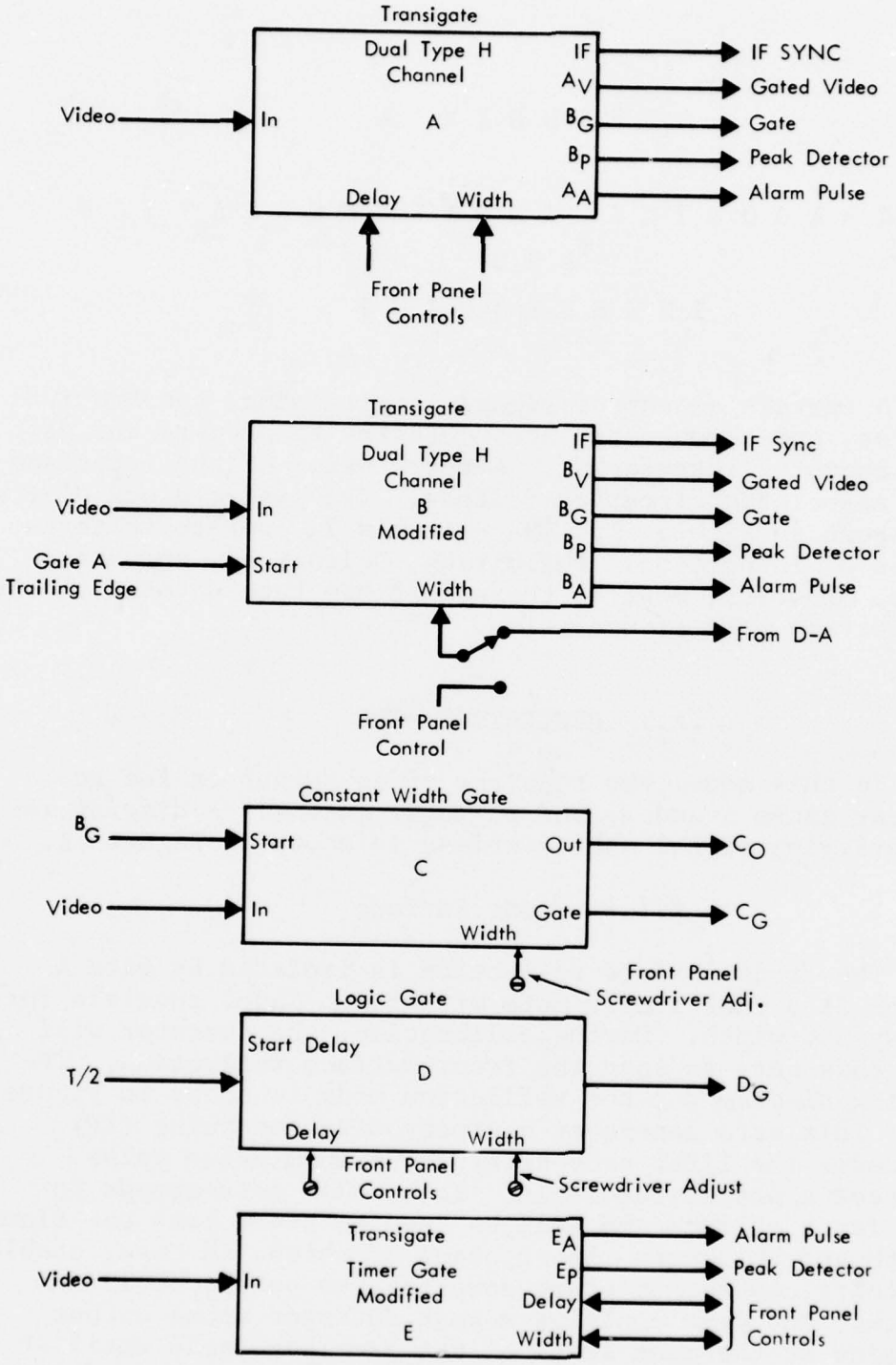


Figure 63 Identification of Signal Abbreviations

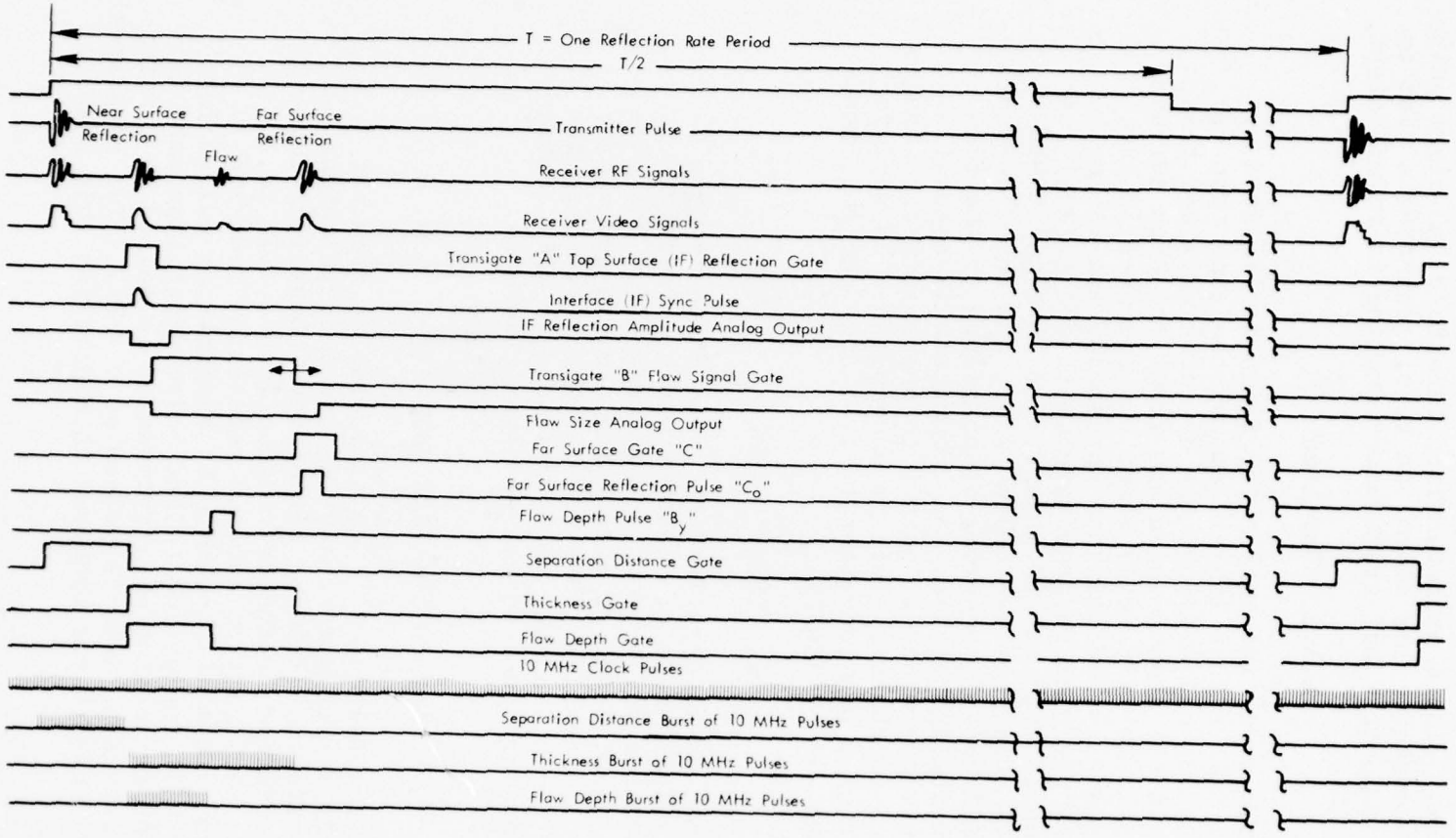


Figure 64 Reflection Mode Signal Timing Diagram

output drops below a predetermined threshold, an alarm pulse will be generated. The alarm, in turn, generates a flag to alert the computer that transducer coupling is insufficient.

A.1.2 Flaw Area

The area under inspection for flaws is isolated by gate B which is a fast linear gate of the same type as gate A. During calibration, the operator will set this gate to span the area between the front and back surface reflections. An alarm will alert the computer if any signal exceeds a predetermined threshold, and the peak detector output will be proportional to the size of the flaw. When this threshold is exceeded, the gated video output will stop the flaw-depth timer, and the flaw-depth counter will contain a number proportional to the flaw depth. During inspection, the computer will automatically adjust the width of gate B to compensate for changes in specimen thickness. This is accomplished by applying the output of a D/A converter to a voltage control, monostable timer in the gate.

A.1.3 Back Surface

The back surface reflection is isolated by gate C which is a logic gate of constant width. This gate is started automatically when gate B turns off. The gate will have a pulse output when the video exceeds a predetermined threshold. This video signal will stop the thickness timer, and the thickness counter will contain a number proportional to the specimen thickness.

A.2 DELTA-SCAN MODE

Since the Delta-Scan mode of operation does not lend itself directly to measuring specimen thickness nor to monitoring coupling efficiency, these functions must be performed by the reflection method. It is, therefore, necessary to conduct reflection mode and Delta-Scan mode simultaneously by alternating pulses for each mode. If the period of the pulse repetition rate is T, then the reflection mode transducer is pulsed at $t = T_o$, and the Delta-Scan mode is pulsed at $t = T/2$. Two separate ultrasonic pulsers are required to accomplish this means.

However, the reflection mode returns a much stronger echo than does the Delta-Scan mode, and it will be necessary to pulse the reflection mode with less energy since both signals are processed by a common receiver. Experimentation will yield an optimum energy ratio of the two pulses. The timing diagram for the Delta-Scan mode of operation is shown in Figure 65. The receiver video output is fed to gates A, B, C, D, and E. The received RF output is fed to the RF amplifier and rectifier.

A.2.1 Front Surface

The front surface reflection is isolated by gate A and its operation is identical to that described in Section A.1.1.

A.2.2 Back Surface

The back surface reflection is isolated by gate C and its operation is identical to that outlined in A.1.3.

A.2.3 Mode Separation

The Delta-Scan echo pattern is separated from the reflection echo pattern by gate D. This is a logic gate which is preset by the operator to span all Delta-Scan echoes. Screwdriver adjustments on the front panel allow control of delay time from transmitter pulse and width of the gate.

A.2.4 Shear Wave

The shear wave signal in the Delta-Scan operation is isolated by gate E and is set by the operator during calibration. The alarm generates a flag to alert the computer that a flaw is present, and the relative size of the flaw is proportional to the peak detector output.

A.2.5 Specimen Thickness

The thickness timer functions in the same manner as outlined in the reflection mode discussion.

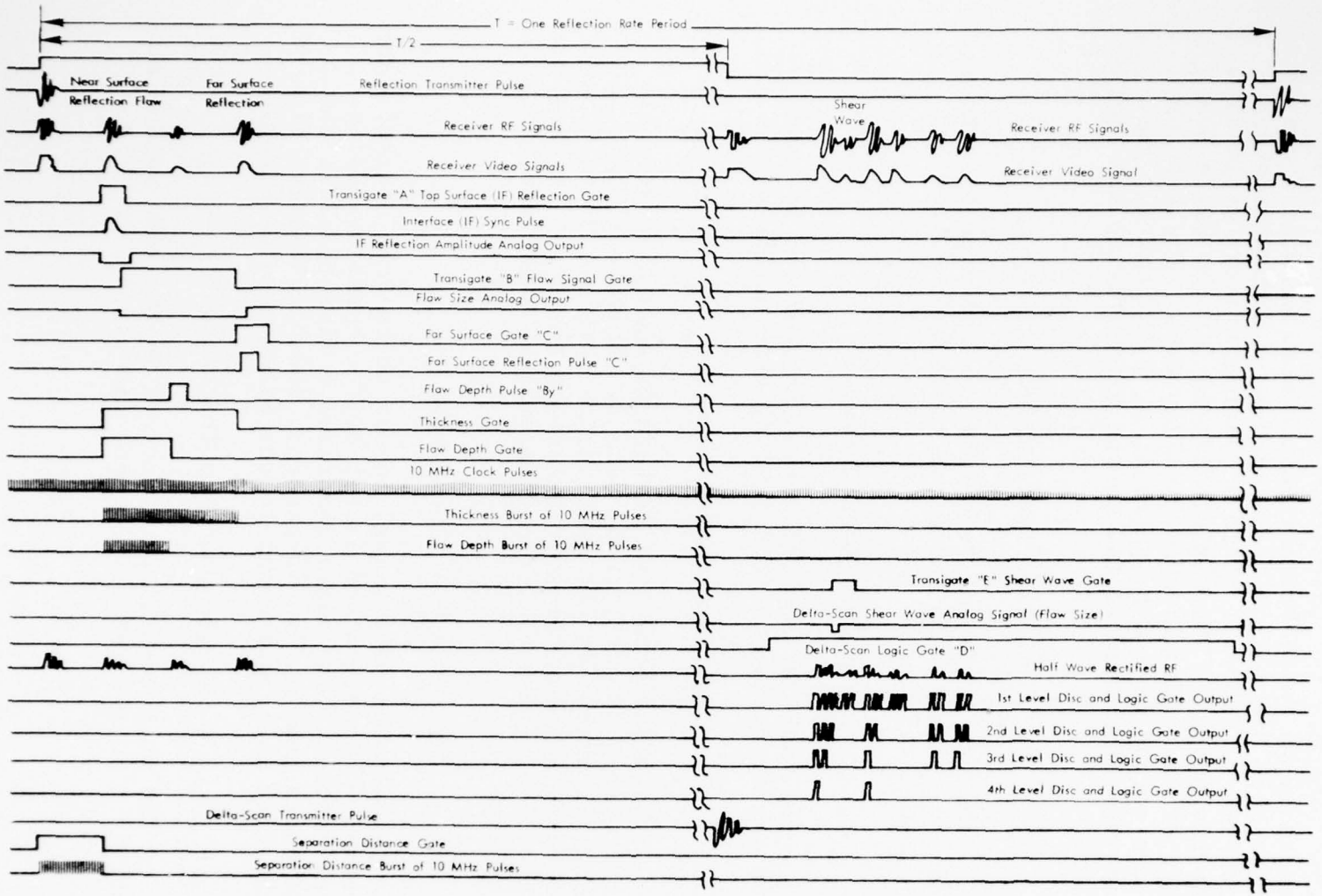


Figure 65 Simultaneous Delta-Scan - Reflection Mode Signal Timing Diagram

A.2.6 Pulse Counters

The output of the RF amplifier and rectifier is a train of half-wave rectified RF pulses of various amplitudes. This pulse train is fed to four level discriminators, each of which is biased to pass only those pulses which exceed its input threshold. These input thresholds will be four discrete values which will be optimized during the system test phase. Each discriminator output is a train of logic pulses which are fed to a binary counter. These binary counters are gated on and off by the output of gate D; therefore, only the Delta-Scan echoes are counted.

A.3 ULTRASONIC EQUIPMENT AND COMPONENTS

The ultrasonic test unit which is an Automation Industries Type UM 771 Reflectoscope will be used for this program. The system consists of the following units:

- o UM 771 Display Chassis
- o 10S db Pulser/Receiver (two)
- o Type AGIF Timer
- o Distance-Amplitude-Compensation Unit (DAC)
- o Dual Type H Transigate
- o Special-Function Chassis

General Dynamics purchased and received the system outlined above in Febriary 1973. A detailed check of the system circuits was performed and the system found to operate satisfactorily after some modification. A photograph of the UM 771 Reflectoscope and special-function chassis is shown in Figure .

A.3.1 UM 771 Display Chassis

This unit contains the cathode ray tube for display, all power supplies for the unit, the timer module, and plug-in compartments for the reflection mode pulser/receiver and the dual type H transigate. All these components are essentially solid state. The timer module includes a gate unit for converting video signals to analog signals and an

alarm circuit. This gate will be used for the Delta-Scan shear wave gate. The display chassis has been checked and found to perform the intended functions. Some modifications have been made to it for operating with the automated test system. These modifications are listed below.

- o Q203 has been removed to make the repetition rate independent of the sweep delay and sweep length.

- o The gate display signal line from the timer module gate was disconnected from the gate display amplifier and routed to the gate display switch added to the UM 771 front panel.

- o The gate delay multivibrator will be modified to trigger at time T/2, then can be adjusted to coincide with the Delta-Scan shear wave signal that follows the second pulser signal.

- o Five switches have been added to the UM 771 front panel to permit selection of the gates to be displayed. This is necessary during system setup to prevent errors due to gate overlapping on the display.

A.3.2 Type 10S db Pulser/Receiver

Two of these units are on hand and have been tested for normal operation. One unit is used for the reflection mode pulser and the system receiver. The second unit will be used as the Delta-Scan pulser; the receiver section will be disconnected. It will plug into the right-hand module slot in the special-function chassis.

The first pulser/receiver has been modified as indicated below.

- o An emitter follower has been added to feed the RF signal at the base of transigate Q308 through a 50-ohm coaxial cable to the RF amplifier in the Delta-Scan counting circuit.

- o The present attenuator in the pulser/receiver will be removed and coaxial connectors added to connect the programmable attenuator in its place. This will permit computer control of the receiver gain.

A.3.3 Type AGIF Timer

This unit was described in Paragraph A.3.1.

A.3.4 Distance Amplitude Compensation Unit (DAC)

This plug-in module has been received and tested. It operates properly, except for a low-level approximately 25-MHz signal occurring on the blanking signal line during the time the CRT is blanket. This does not interface with normal operation of the system, but may interfere with the computer automated mode of operation. This source of oscillation will be isolated and corrected.

A.3.5 Dual Type H Transigate

This module was tested after receipt from the factory and operated properly. The unit will be used for the front surface gate which provides the coupling efficiency data, and the flaw gate which generates the flaw size analog signal and the flaw flag. Several modifications were required for proper operation in the computer automated mode. These modifications are:

- o Resistor R60 was changed to 1K ohm and diode CR13 was changed to a 1N751 zener in both A and B gates. This was required to provide a +5-volt logic signal for the coupling and flaw flags. Diodes CR5 and CR7 were jumpered. CR5 was disconnected from pin 3 of P1 and connected to pin 4 of P1. This separated the two flags.

- o The A and B gate display signals were separated to permit selection of either or both gates by the gate display switches.

- The B gate was changed to allow the flaw gate signal generated in the gate and logic module to be used for flaw data processing. This required removal of gate length multivibrator IC-4. The flaw gate from the gate and logic module was connected to pin 6 of P1, to pin 5 of P4, to pin 6 of IC-4 socket, and the input of an inverting gate. The output of the inverting gate connects to pin 1 of IC-4 socket. The B gate start and length controls on its front panel are no longer effective. The flaw gate is started by the trailing edge of the front surface gate and its length is determined by the computer analog voltage or by the manual 10-turn dial on the gate and logic module.

- The lead from pin 5 of J3 was removed to disable the I.F. (interface) sync pulse from gate A. The I.F. sync pulse for the gate and logic module is obtained only from gate B's I.F. sync circuit.

A.3.6 Special-Function Chassis

The special function chassis houses the five modular power supplies, the line drivers and line receivers, the Distance Amplitude Compensation (DAC) module, the programmable attenuator module, the Gate and Logic module, and the second pulser module. Figure 66 is a wiring diagram of the chassis. The line drivers and receivers are to insure that the signals from the ultrasonic unit are sufficient in amplitude for computer processing.

A.3.7 Gate and Logic Module

The gate and logic module contains digital logic circuits to perform functions that could not be done with the standard UM 771 equipment. A front panel view of the module is shown in Figure 67.

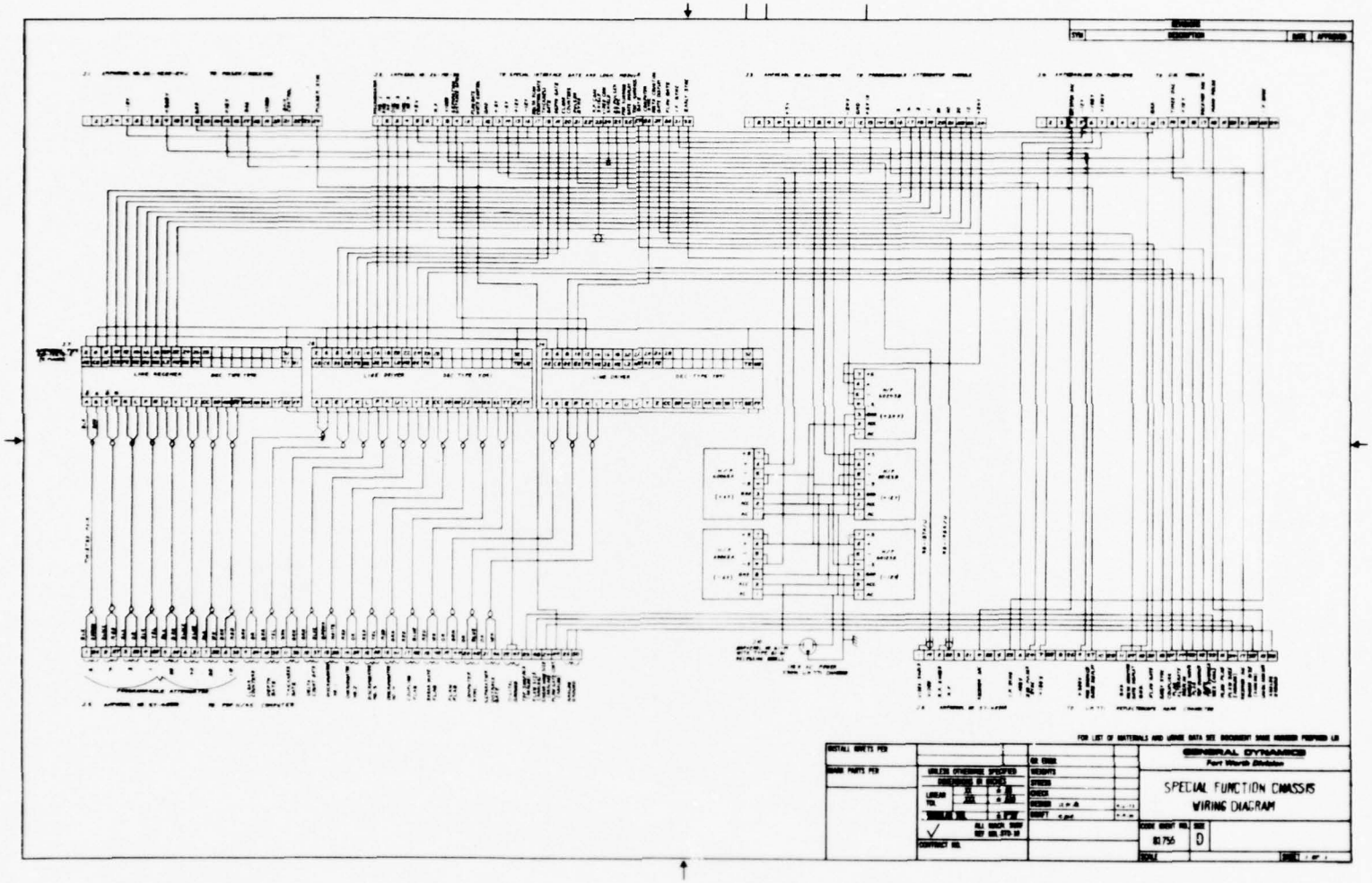


Figure 66 Special Function Chassis Wiring Diagram

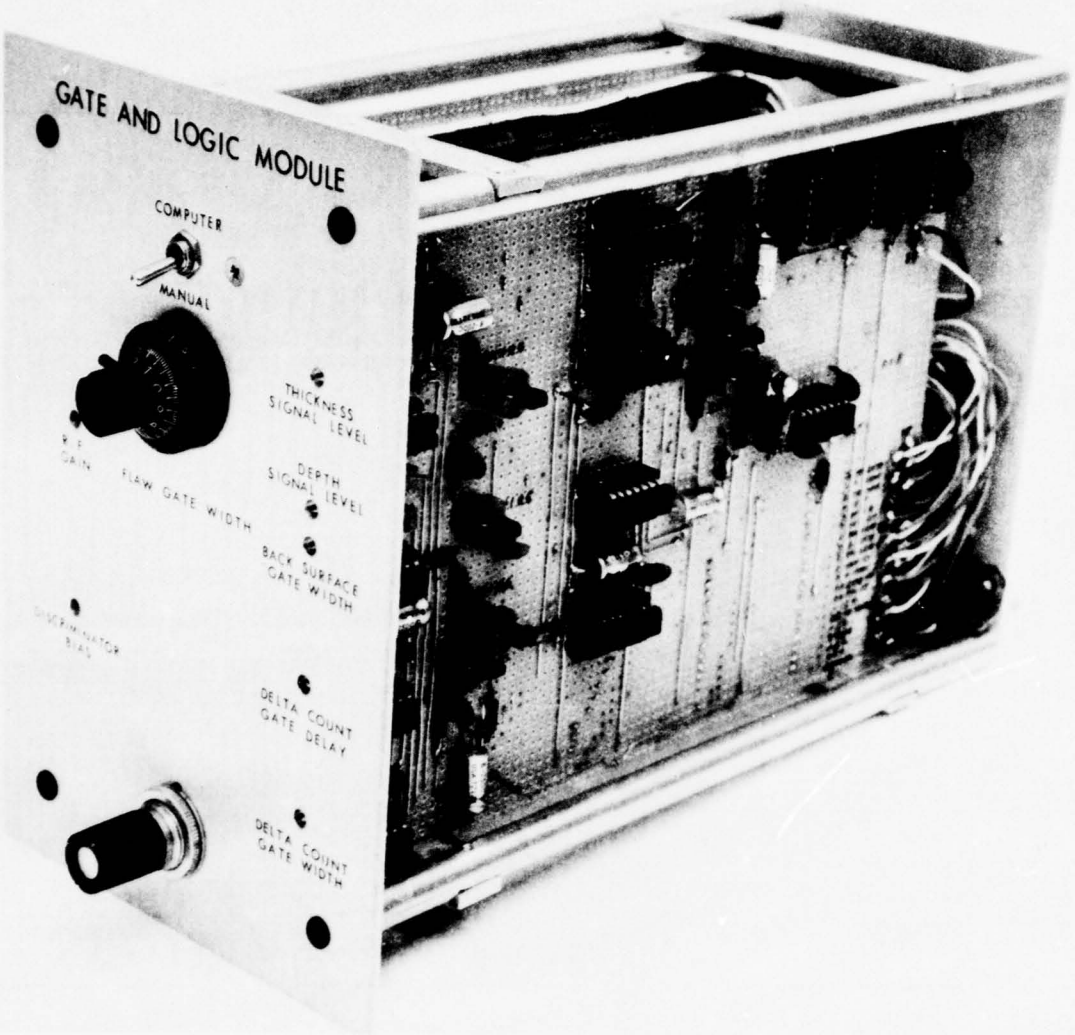


Figure 67 Gate and Logic Module

A.3.7.1 Gates C and D

These gates have been designed and built on a circuit board which also includes the flaw depth circuit, thickness circuit, and gate display drivers for gates C and D. Gate C is a logic gate which isolates the back surface reflection to generate a pulse to end the thickness counter gate. It prevents other reflections from turning off the thickness gate. Gate D is a logic gate which isolates the Delta-Scan reflections from the other reflections. This gate enables the four counters that count the Delta-Scan reflection half cycles. It prevents the other reflections and transmitted pulse from being counted by the Delta-Scan counters. Circuit schematic of gate and logic module is shown in Figure 68.

A.3.7.2 RF Amplifier, Rectifier, and Four Discriminators

These circuits provide the weighing factors on amplitude for the RF oscillations that are counted by the Delta-Scan counters, so the oscillations with higher amplitudes produce higher counts. The circuit board has been built and tested using signals from the RF emitter follower in the pulser/receiver unit and commercial digital counters. The circuit board will be mounted in the same plug-in unit as the gates C and D circuit board. Figure 69 is a schematic of this circuit.

A.3.7.3 Flaw Depth Circuit

This circuit generates the gate pulse which enables the flaw depth counter to count 10 megahertz clock pulses for a time proportional to the flaw depth. It is a flip-flop which is turned on by the interface sync pulse from the dual transigate unit and is turned off by the first reflection pulse after the flaw gate is opened. A level discriminator is included to allow adjustment of the reflection amplitude which will stop the flaw gate. The circuit, which has been wired and tested, is included on the circuit board with gates C and D, part of the gate and logic module.

A.3.7.4 Thickness Circuit

The thickness circuit is similar to the flaw depth circuit. It is started by the interface sync pulse and is turned off by the first reflection pulse that occurs during the far surface gate. A level discriminator is included to

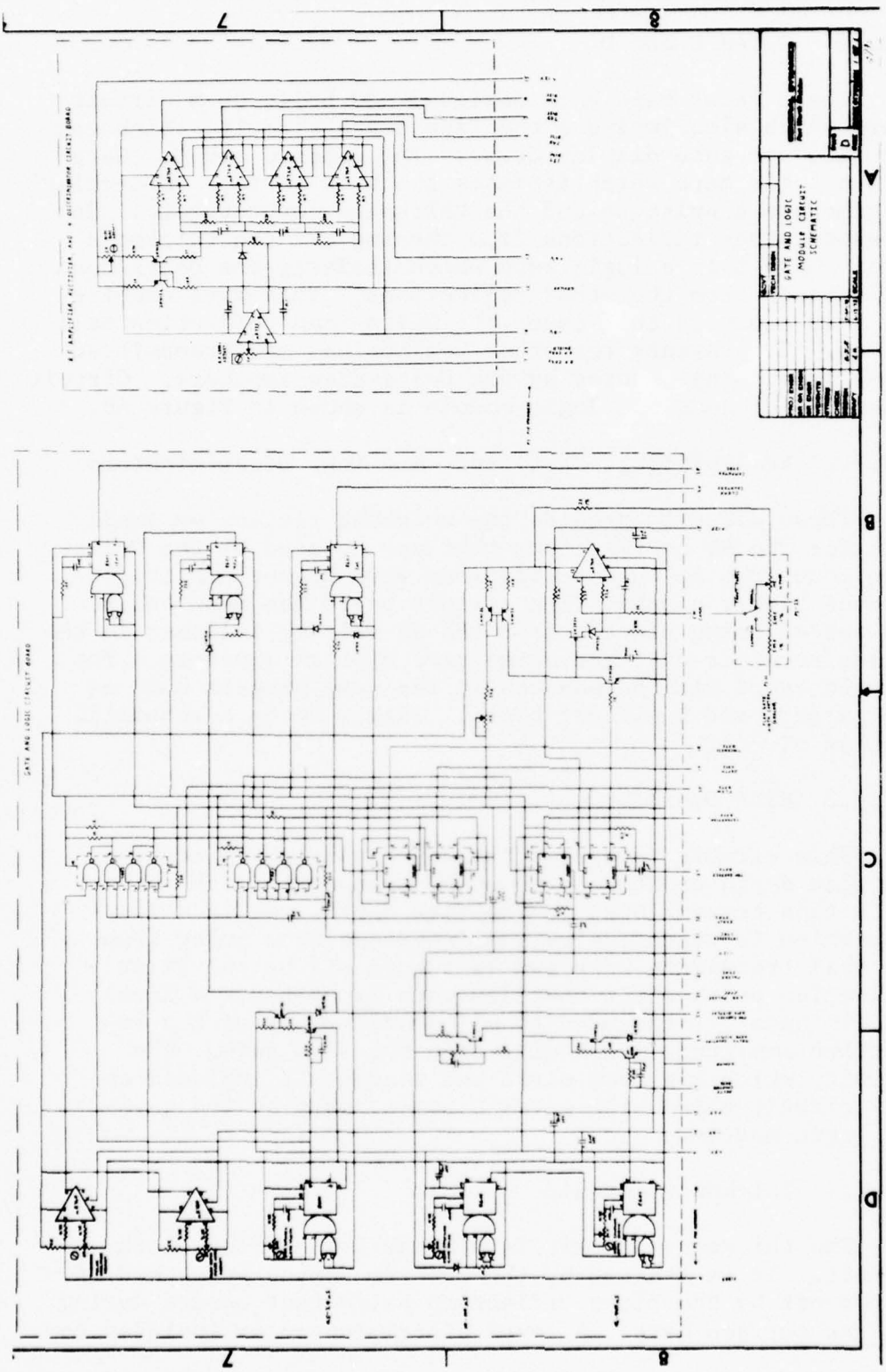
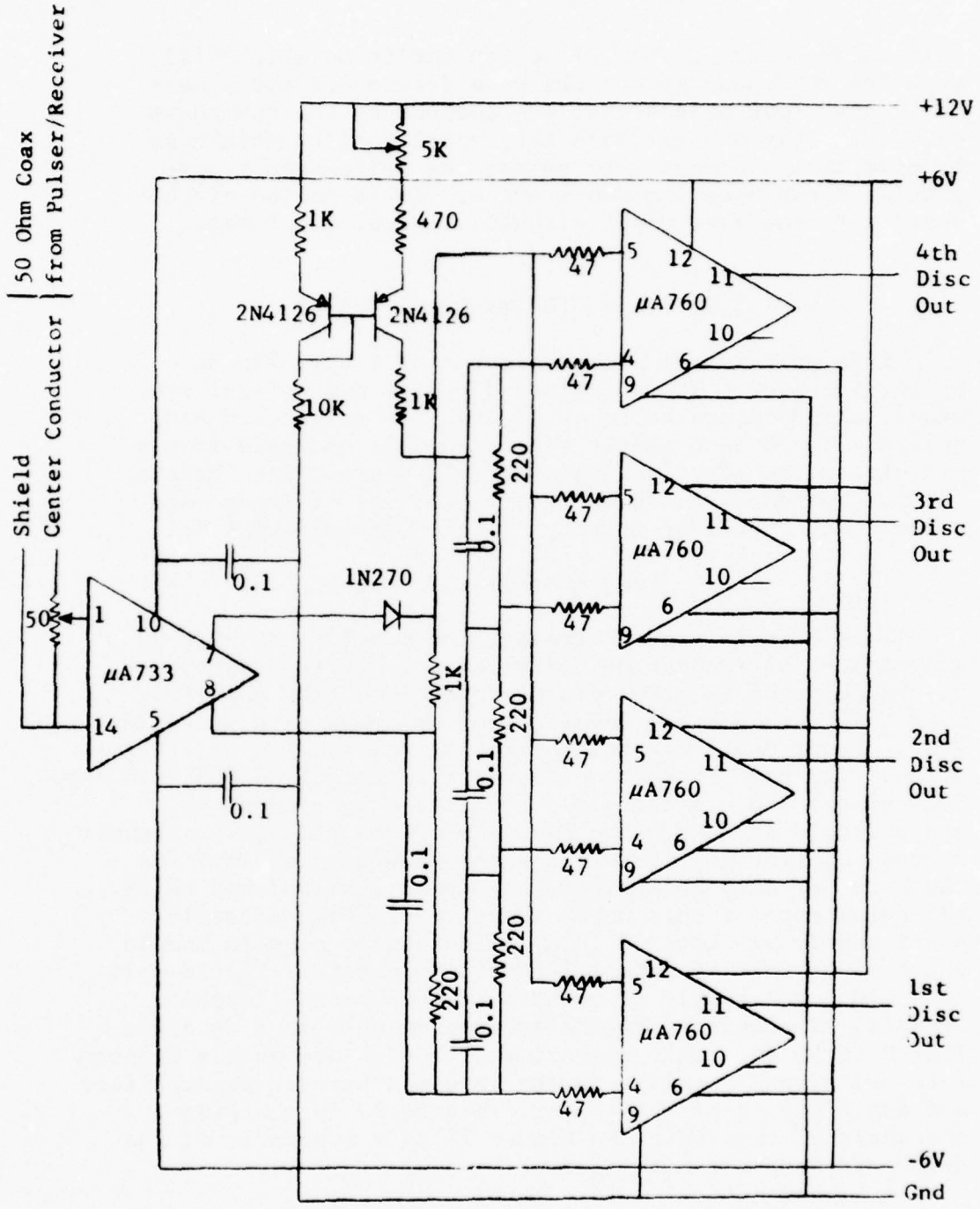


Figure 68 Circuit Schematic of Gate and Logic Module



CIRCUIT SCHEMATIC

Figure 69 R.F. Amplifier, Rectifier, and Four Discriminators for Delta-Scan Counting Mode

allow adjustment of the reflection amplitude which will stop the thickness gate. The gate determines the number of 10-MHz clock pulses that are counted by the thickness counter. This number which is proportional to thickness is used by the computer to adjust the Delta-Scan transmitting transducer incidence angle. It is on the circuit board with the flaw depth circuit, C gate, and D gate.

A.3.8 Second (Delta-Scan) Pulser

This unit is the pulser portion of a type 10S db pulser/receiver. It is triggered by a second pulser sync signal which occurs half-way between two reflection mode pulses. The second pulser sync signal is obtained from a circuit on the gate and logic circuit board which inverts the main pulser sync square wave. Removal of + and -12 volts to the receiver portion of this unit disables it.

A.3.9 Programmable Attenuator

This unit is used to replace the manual step attenuator in the ultrasonic pulser/receiver. It is programmed by the computer to produce a predetermined flaw amplitude when the transducer is located on a specimen with a standard flaw. Front panel controls permit manual setting of attenuation. The unit consists of Hewlett-Packard Type 355E and Type 355F programmable attenuators, digital code converters, and solenoid drivers. Two code converters and driver circuit boards, one for the 10-db per step attenuator and one for the 1-db per step attenuator, have been designed and built. All components of this unit except the 24-volt solenoid power supply are mounted in a reflectoscope plug-in module which plugs into the special-function chassis. The 24-volt solenoid power supply is mounted in the special-function chassis. The unit is digitally programmable in 1 db steps from 0 to 99 db. Only approximately 66 db are usable because internal signal coupling in the receiver between preamplifier and amplifier is of this order. Figure 70 is a wiring schematic of this unit and Figure 71 is a schematic of the decoder/driver circuit boards.

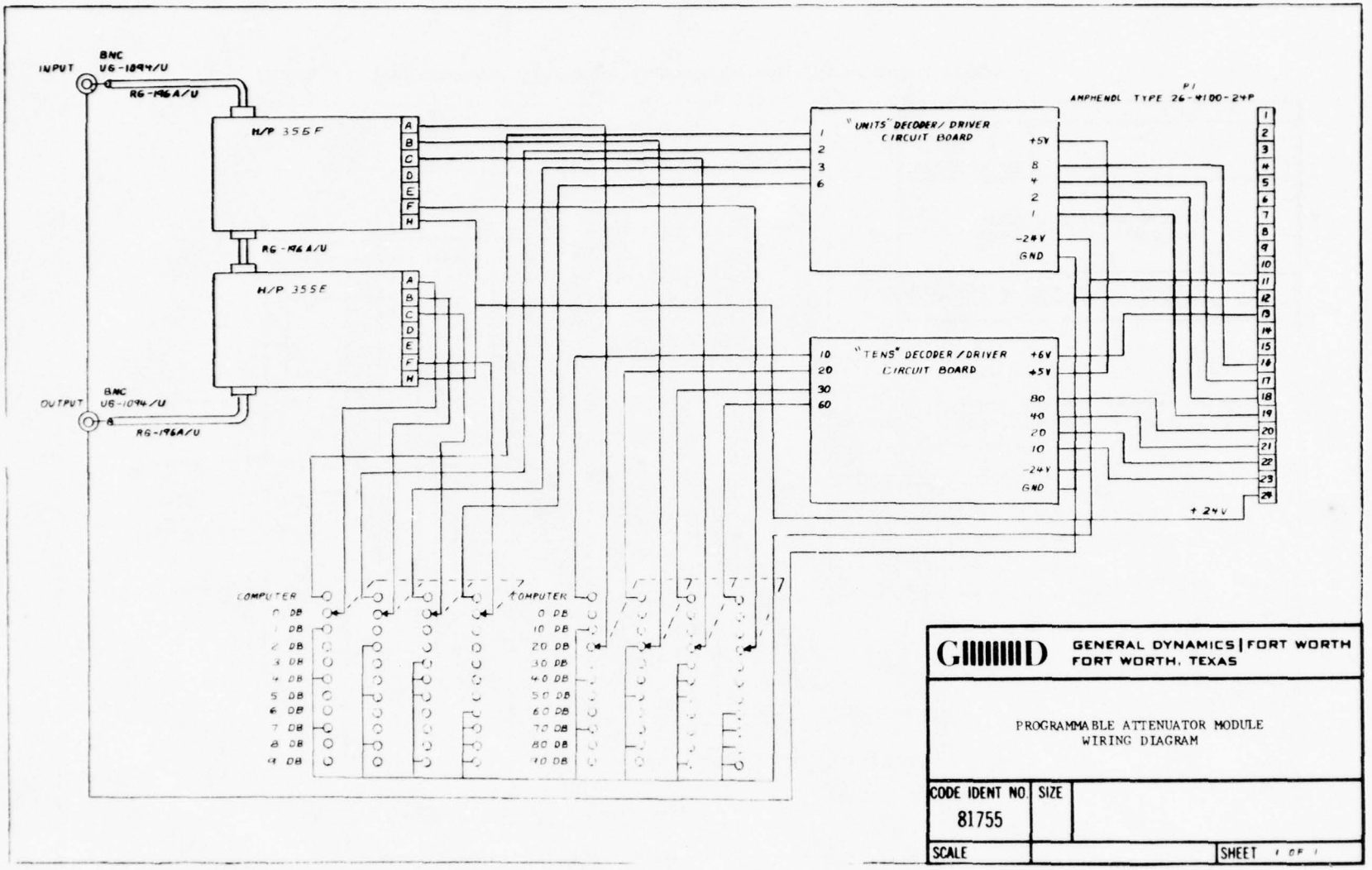


Figure 70 Wiring Diagram of a Programmable Attenuator

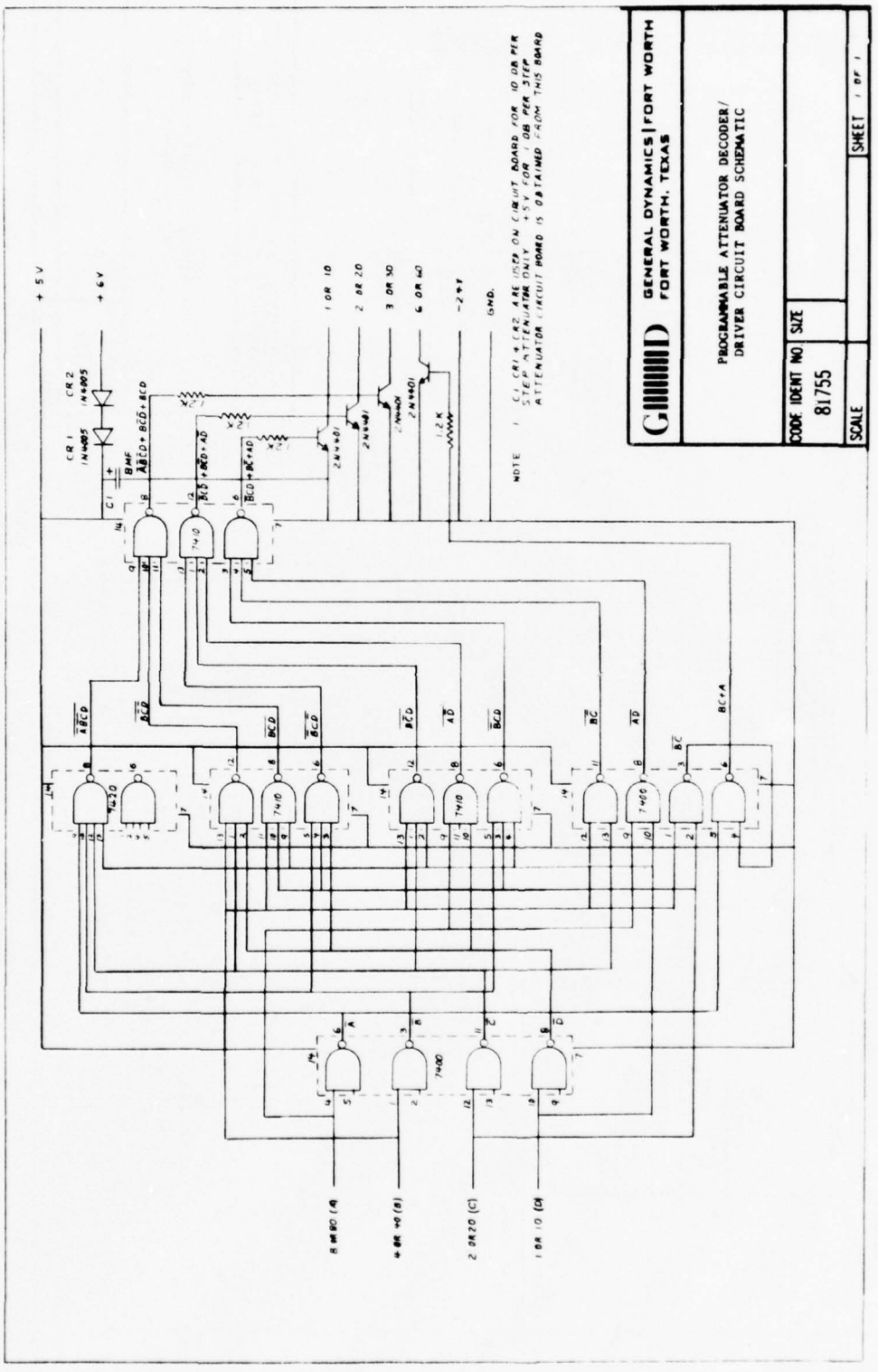


Figure 71 Programmable Attenuator Decoder/Driver Circuit Board Schematic

A.3.10 10-MHz Clock Pulse Generator and Binary Counters

The clock pulse generator is a Digital Equipment Corp. flip-flop circuit board which plugs into the computer. It supplies 10-MHz pulses to the flaw-depth counter, separation-distance counter, and thickness counter. This circuit board has been received and tested.

The special counting input/output circuits are made up of Digital Equipment Corp. flip-chip circuit boards and plug into the computer. One is used for counting flaw-depth pulses, one for thickness pulses, one for separation distance pulses, and four count the Delta-Scan RF oscillations from the four amplitude discriminators. These circuit boards have been received and will be installed when the line drivers and line receivers are installed in the computer. The line drivers and line receivers are required to transmit the fast pulses between the ultrasonic unit and the computer.

A.3.11 Line Drivers and Line Receivers

Two line-driver circuit boards with 10 line drivers on each board are mounted in the special-function chassis to transmit fast digital signals to the computer without loss of response speed. These are Digital Equipment Corporation Type Y091. One line-receiver circuit board with 10 line receivers is also included to receive eight bits of programmable attenuator digital data from the computer. This is a DEC Type Y090.

A.3.12 Stepless RF Gate

A gated RF amplifier circuit has been designed, built and added to the gate and logic module. It was designed to pass only selected portions of an ultrasonic signal with minimum "step" signals at the beginning and end of the gate. Its output is the RF envelope of the gated portion and is used for spectrum analysis for flaw pattern recognition. The circuit is presently enabled by gate A of the system. It will probably contain its own START and WIDTH controls as the technique is improved and incorporated into the automatic system. A circuit schematic of the stepless gate is shown in Figure 72.

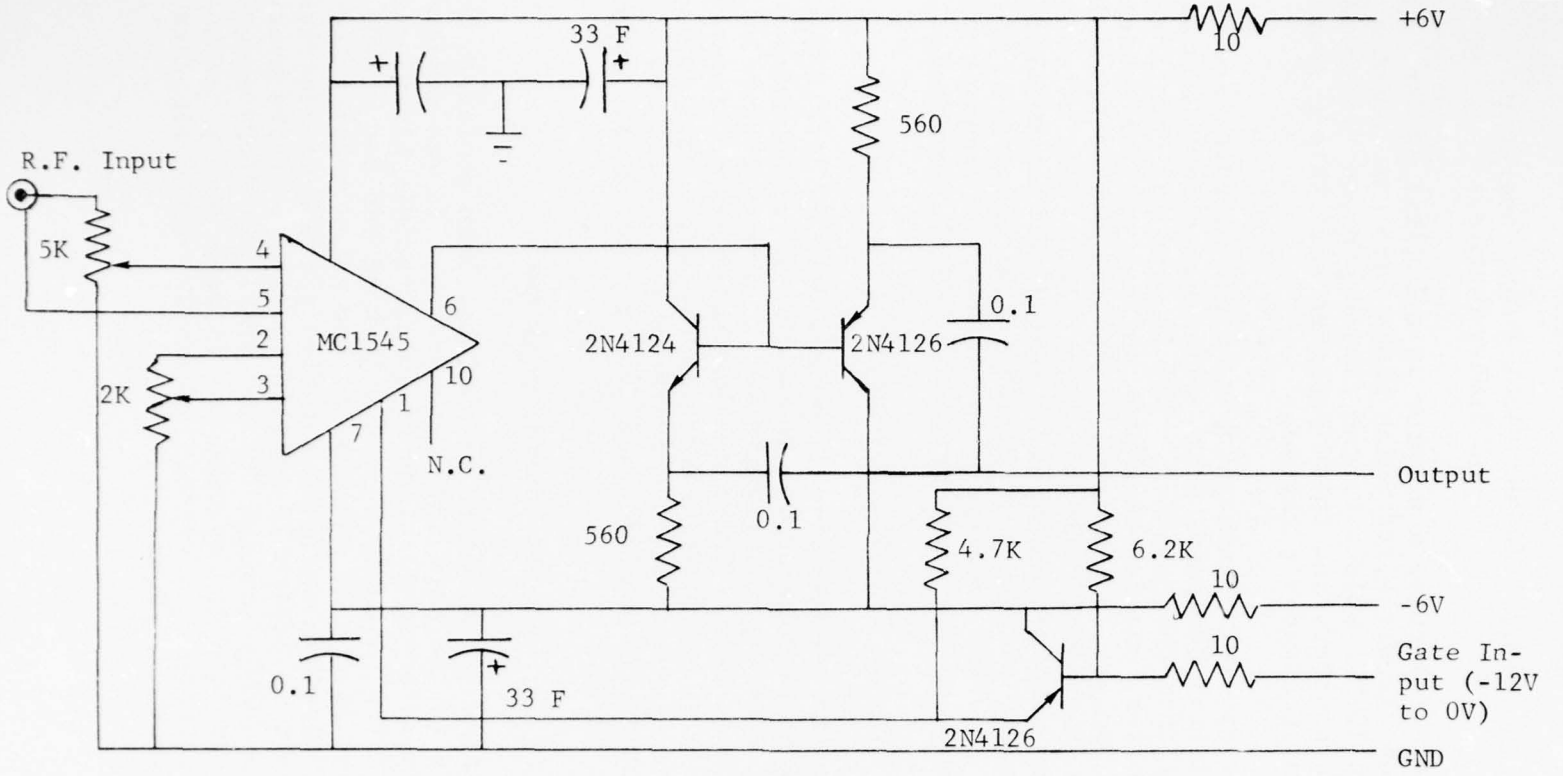


Figure 72 Stepless R.F. Gate Circuit Schematic

A.4 MULTIPLE FLAW DETECTION

A method of detecting multiple flaws at one location has been designed using the multiple flaw gate approach. Computer software is used to determine which is the back surface and which are the flaw signals. Software also determines if the signals are multiple reflections instead of additional flaws. If distance of separation is 3 inches, multiple reflection between the transducer and top surface will be further out in time than any flaw signal within 12 inches of metal and will be gated out. Figure 73 is a block diagram of the logic circuits and Figure 74 is the timing diagram for the multi-gate system.

A.4.1 Quad Transigate Type H

A quad Type H transigate on loan from AFML is being used for (a) top surface gate, (b) first flaw gate (this is the back surface if no flaws are present), (c) second flaw gate, and (3) third flaw gate. If no flaw is present, the second flaw gate will read the back surface reflection and computer logic by interrogating the states of the three binary counters will so indicate. If two flaws are present, the third flaw gate will read the back surface and computer logic will so indicate.

The above transigates have their START and LENGTH controls disabled and are timed by decoding logic circuits on the outputs of a three-stage binary counter which is triggered by the trailing-edge of the squared video pulses. The video pulses are squared by a comparator which is biased to pass all video signals above a pre-determined level.

The first gate is started after a fixed delay following T_0 (Early Sync) sufficient to miss the transmitted pulse and ringing therefrom. The first gate is termination by the trailing-edge of the top surface reflection. The second gate is started by the termination of the first gate and is terminated by the trailing-edge of the next video pulse. The third gate is started

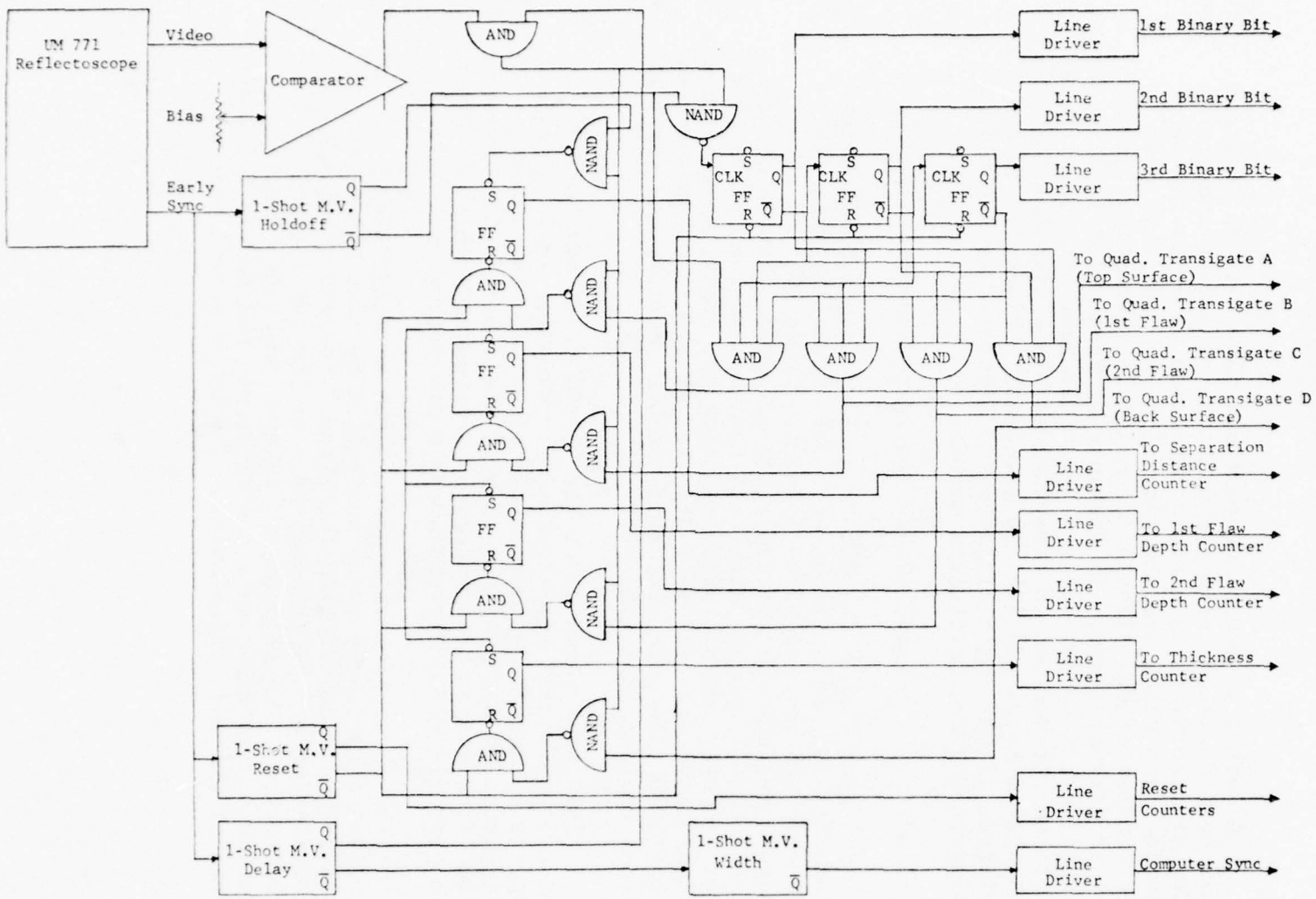


Figure 73 Multiple-Flaw Detection Logic Circuit Block Diagram

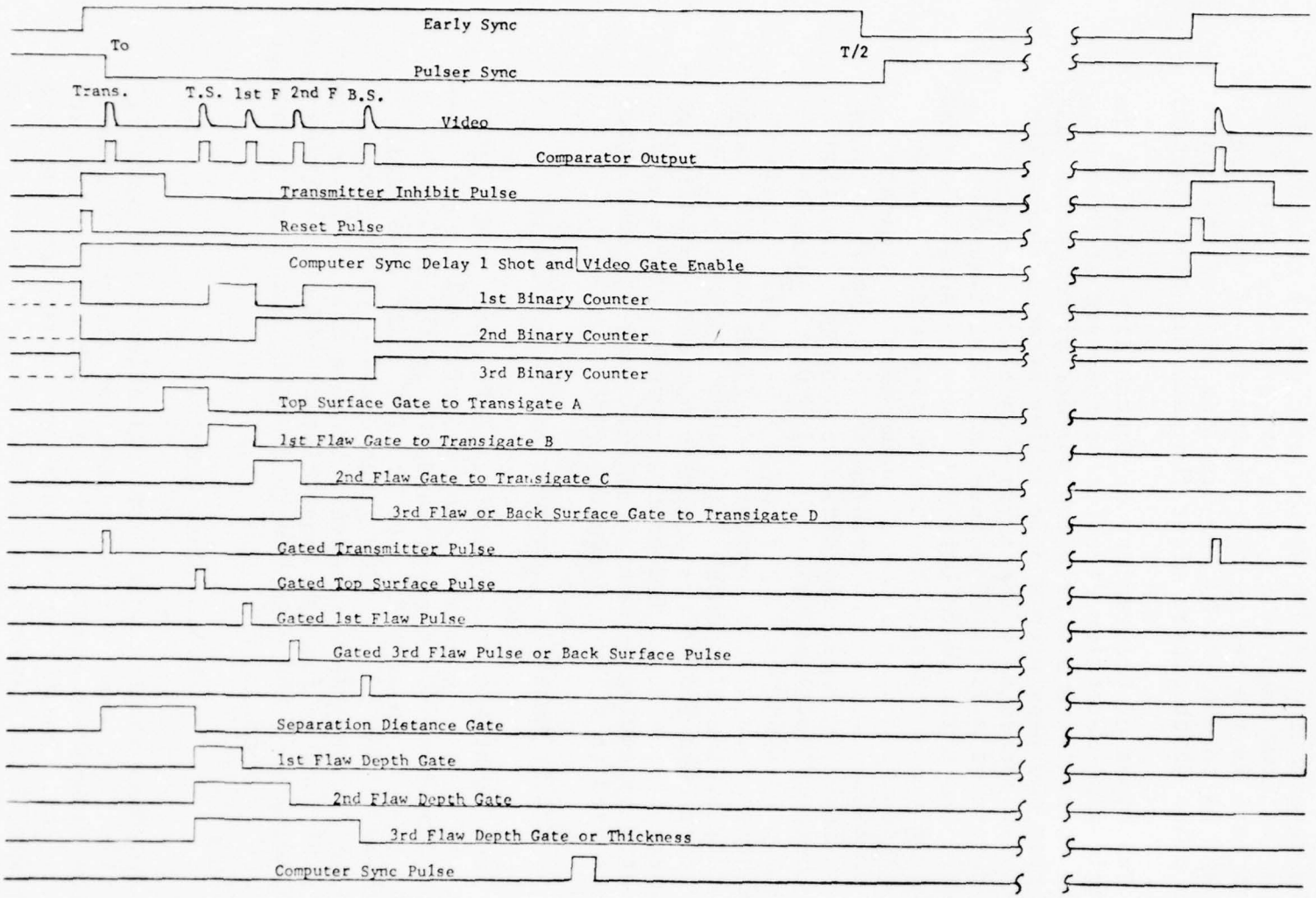


Figure 74 Multiple-Flaw Detection Timing Diagram

by the termination of the second gate and is terminated by the trailing edge of the next video pulse. The fourth gate is started by the termination of the third gate and is terminated by the trailing edge of the next video pulse which occurs after the gate has been started.

Two types of uncertainty or instability exist in the multiple flaw detection circuits as they are at present. One of these is caused by a top surface signal which has more than one peak with a deep valley between them. The first peak generates a top surface gate and the second peak generates a first flaw gate and first flaw depth signal. The solution to this will have to be elimination of the multiple peaks in the transmitted signal. Wide-band transducers with a normal pulse should eliminate this problem. The second problem is that the flaw gates are generated by logic circuits decoding the condition of the counter flip-flops while the flaw depth gates are generated by separate flip-flops. Some small signals may change the state of the counter flip-flops and not change the state of the flaw depth flip-flop. This results in flaw amplitudes fed to the computer not corresponding to the correct flaw depth fed to the computer. This will be corrected by adding a comparator following the comparator that is used as a level detector.

A.4.2 Multiple Flaw Gate and Logic Module

Four bi-stable multivibrators (FFs) are used with logic circuits to generate gates proportional to (a) separation distance, (b) first flaw depth or thickness, (c) second flaw depth or thickness and (d) third flaw depth or thickness. Each of the flaw gates are fed to the computer via line driver - line receivers to gate the 10 MHz counters that give numbers for the above distance (depth or thickness). The condition of the gate binary counter indicates the number of gates tripped.

A.4.3 Dual Counter

Two dual counter units are available in the computer for reflection mode: (a) the separation distance counter, (b) the flaw depth counter, (c) the thickness counter, and (d) a spare. These four counters can be used as described above for the multiple flaw system.

A.4.4 Analog and Flag Circuits

Analog data from the four transigates and flag data is obtained from the same transigates alarm circuitry as described for the reflection mode.

APPENDIX B

THE SCANNER SYSTEM

This section describes the X, Y, Z, θ and Ø axes scanner and control system as designed and built to scan complex shape of aircraft forgings.

B.1 X-Y SCANNER

The general configuration of the scanner is shown in Figure 5. It will scan in either the X or Y axis and index in the other axis. The unit was assembled primarily from purchased parts, but some parts were made by the Tooling Department and all assembly work was done by the Tooling Department.

The scanner frame is constructed from aluminum U channel and bolted to the top of the tank. The X-axis ways consist of 1.0 inch-diameter steel shafts and support block made by Berg Inc. Four ball bearing support brackets carry the bridge. These are to be fastened to two aluminum blocks that carry two 1.0 inch ground rods that support the Y-axis movement (platform).

Two drive motors and gearboxes are positioned on the support frame and drive the bridge and platform through three sets of POW-R-TOW cable chains. Two sets of chains, one on each side of the bridge, are driven from a common line shaft to reduce the bending movement on the bridge. One long chain is wound around in the pattern shown in Figure 5 to drive the platform. As the bridge moves, the platform stays in the same relative position with respect to Y movement.

The cable chains are constructed from cables with polyurethane rollers combined to form strong, flexible, quiet, lube-free drive. The corrosion-proof cable chain gives minimum backlash.

B.1.1 X and Y Axes Drive Motors

Separate stepping motors with 240 inch ounces of torque drive the transducer carriage in the X and Y axes. These motors are manufactured by Sigma Instruments, Inc. and are Model 6041 B with dual shafts. These motors step from 10 to 6000 steps per second and each step moves the transducer carriage 0.001 inch in the half-step mode and 0.002 inch in the full-step mode. The primary mode of motor operation is the half-step mode and an internal control switch must be moved to set the full-step mode. The half-step motor mode is used to reduce motor oscillations at less than 1 KHz stepping rate. These oscillations are standard with all stepping motors operating in the full-step mode.

Each motor drives through a 15:1 gear reducer which gives an available output torque from the reducer of (15 x 240 inch ounces) 3600 inch ounces at the slower stepping rates. The available torque decreases at the higher stepping rates.

B.1.2 X and Y Axes Motor Controls

Each motor has a separate controller which was purchased from Summit Engineering Corporation. Each controller, which is called a preset control unit Model 8151C, is designed to fill the need for an electronic control which (from a thumbwheel or computer input command) outputs the programmed number of pulses and direction command to the stepping motor drive. These output pulses are automatically accelerated and decelerated by the setting of internal potentiometers. The maximum output pulse rate (speed) is adjustable up to 6000 steps per second by an internal adjustment. Once the maximum output pulse rate is set internally, the pulse rate can be externally varied or set with a front panel control which in this case is three thumbwheel switches that can be adjusted from 10 to 6000 steps per second. The length of travel of the transducer in either axis is controlled by the number of programmed output pulses that are preset into the thumbwheel switches. Each pulse gives 0.001 inch of transducer movement. If +69.999 is preset on the "X" controller and the "initiate" button pushed, the controller outputs 69,999 pulses and a clockwise command to the "X" stepping motor.

The motor moves the transducer 69.999 inches in a clockwise or positive direction and stops. These output pulses are automatically accelerated and decelerated by internal circuitry and these "ramps" are adjustable.

The following controls are available on the front panel of each preset controller.

1. Thumbwheel speed control (3-digit), 10 to 6000 steps per second

2. Power switch

3. Preset pulse controls (limits) (5 digits and a sign) $\pm$00.000 to $\pm$99.999 inches

4. Initiate button (start pulse output to motor)

5. Cycle (start sequence of events which typically includes external direction control and the thumbwheel setting)

6. Job (when pushed momentarily, the unit will output one pulse to the motor drive. When the button is held down, the transducer carriage will move until the button is released or the limit is reached).

7. Reset (used as a stop button, it will reset the counters and stop the pulse output)

B.1.3 Control Panel for X and Y Motors

A third chassis to control the interactions required between the X and Y controllers and motors was designed and built. This is the primary control unit for the X and Y axes.

This control system has three modes of operation: manual, auto, and compute. The function of each mode is described on the following page.

Manual Mode

Each of the preset indexers operate from its own individual control chassis when the primary controller is in the "Manual" mode.

Auto Mode

Select scan X, index Y, and place the mode switch on the "Auto" position. Press "GO" button and the X motor will run to its preset limit or manual limit and stop. The Y motor then indexes to its preset limit and stops, whereby the X motor then reverses direction and runs back to its original zero position. This can, index motion shall continue until a "STOP" button is pushed on the control panel or until a mechanical limit switch is closed. The motors will then stop until the operator initiates a new scan or the index direction can be reversed and the cycle continues back over its original path.

If the scan Y, index X is selected, then the motors should scan Y and index in X in the same manner as described in the previous paragraph.

The speed controls on each preset indexer for each motor is set manually when in the manual or auto mode.

Computer Mode

Place the mode switch in compute and select either scan X, index Y, or scan Y, index X. The scan limit is set with the thumbwheel switches for the scan axis and the desired amount of index is set with the thumbwheel switches for the index axis. When "GO" button is pushed and the transducer carriage will scan the selected axis and stop at the preset limit. The rate of scan in this computer mode is determined either by the operator or from the computer. A +5-volt logic signal from the computer then tells the scanner to index its preset amount and stop, after which the scan motor will reverse directions, scan back to zero position, and stop. Upon receipt of a +5-volt logic signal from the computer, the index motor will index its preset amount; then, the scan motor will reverse and scan back to its preset limit or number. This cycle continues until the "STOP" button is pushed or a mechanical limit is closed in the index direction.

B.1.4 Encoders and Displays for X and Y Axes

A Data Tech heavy-duty industrial encoder that operates in the incremental mode is geared to the drive chains for both the X and Y axes. These encoders are geared in such a manner that for each 0.010 inch of transducer carriage movement, one pulse is sent to the up-down counter. This rotary motion that occurs in the encoder is digitized into high-level square waves in quadrature, and these quadrature square waves are fed to a digital display.

The dual display is a Summit Engineering Model 8102 B and each of the channels contains a bi-directional counter and display designed to be used with an encoder operating from a numerical control system. The power supply for the encoder is contained in this display chassis. This display continuously monitors and transducer position in both the X and Y axes and displays it in four digits of position information to the nearest 0.010 inch, i.e., if the transducer had moved 36 inches in the Y axis, the display would read +036.00 inches. A master zero button is available so that the displays can be zeroed at any zero reference point.

Connectors on the rear of the display chassis contain BCD logic information that will be fed to the computer so that the position of the transducer can be monitored continuously by the computer.

B.1.5 Z Axis Drive and Control

The vertical movement of the transducer is controlled by a dc stepping motor with 250 inch ounces of torque geared to the vertical tube through a 21.6:1 gear reducer to give a rated torque of 2000 inch ounces at the gear that drives the transducer tube. Each pulse to the stepping motor moves the transducer tube up or down 0.001 inch. The vertical tube moves 30.240 inches inside the tank.

The transducer can be moved vertically, either up or down by setting thumbwheel switches between 00.000 and 30.240 inches and pushing a polarity and start button on the control panel. The transducer then moves to this preset position

and stops. Ramp up and ramp down circuits are installed to prohibit abrupt starts and stops. The maximum speed can be adjusted by setting an internal potentiometer. The speed may then be varied externally with a knob on the control chassis up to the maximum internal speed adjustment. A jog switch also moves the transducer either one step or continuously at a slow rate either up or down.

A rotary incremental encoder is attached to the shaft of the gear that drives the vertical Z tube. This gear moves the vertical Z tube $\pm$4.320 inches per gear revolution. The encoder attached to this shaft outputs 432 pulses for each shaft revolution. Therefore, the encoder display reads directly in 0.010 inch increments and displays from $\pm$00.000 to $\pm$30.24 inches. The display is identical to the displays used for the X and Y position information.

B.1.6 Tilt (θ) Axis Drive and Control

The tilt motor and controls move the transducer through 180 degrees of movement. A dc stepping motor with 50 inch ounces of torque rotates a rod inside the vertical manipulator tube and the rod is geared to the transducer. The motor and encoder are mounted on a casting at the top of the manipulator and the motor is geared to the rod through a clutch, pulley, and timing belt. There is an 8.8:1 gear reduction between the motor and the transducer and each pulse to the stepping motor moves the transducer 0.20°. Therefore, 880 motor pulses are required to move the transducer through 180°. The speed of transducer movement is variable from 2 to 45° seconds and the maximum speed is only limited by the mechanical linkage.

B.1.7 Rotate (ϕ) Axis and Control

The rotate motor and controls move the transducer through $\pm 180^{\circ}$ of movement in a horizontal manner. A dc stepping motor with 50 inch ounces of torque rotates the vertical tube to which the transducers are attached. This motor is mounted on top of the manipulator and is geared to the vertical tube through a clutch and belt drive. There is a 4:1 gear reduction from the stepping motor gear and clutch to the gear around the vertical tube. The stepping

motor makes two revolutions while the transducer rotates 180°. The stepping motor receives 400 pulses for the two revolutions. The angular movement of the transducer per stepping motor pulse is therefore 0.45°. The rate or speed of the stepping motor is adjustable from 10 to 1000 steps per second. Therefore, the minimum speed of the transducer in angular movement is 4.5° seconds and the maximum speed is only limited by the mechanical linkage.

An incremental rotary encoder is geared through a rubber timing belt to a large gear around the vertical tube. The gear relationship between the vertical tube and the shaft encoder is an 8:1 increase. The encoder turns four times while the vertical tube and transducer move 180°. The encloder has an output of 450 quadrature pulses per revolution for a total output of 1800 pulses while the transducer moves the 180°. These pulses will be displayed on a 4-digit visual display that reads from 000.0 to 180.0° with an accuracy of $\pm$.1°.

B.2 NORMALCY CONTROL CIRCUITS

The normalcy control citcuits for tilt and rotation as shown in the first annual report were built and tested. The tests indicated two major faults with the circuits which made redesign a necessity. One fault was chat the one shot multivibrator (MV) IC6 and IC7 in the original circuit did not time out at the same time and if no time error existed between the two signals from the transducers, an output pulse would exist when the first MV recovered and cause a motor step. These logic elements were replaced with flip flops (FFs) and one MV is used in time resetting of both FFs. When coincident signals occur from both transducers in either tilt or rotate channels no stepping pulse is produced. The second fault resulted from a misunderstanding of the motor drive circuit purchased from Summit Engineering. Our circuit had been designed to provide either an UP pulse on one output or a DOWN pulse on another output. The Summit system required stepping pulses on one line and a direction logic signal on another line. Our circuit was redesigned and modified to provide these signals. Figure 75 is a block diagram of the new TILT control circuit. The ROTATE control circuit is identical except it has no IC6 or IC7. The transmit pulse hold off signal and flip flop reset signal which these ICs provide are obtained from the TILT circuit.

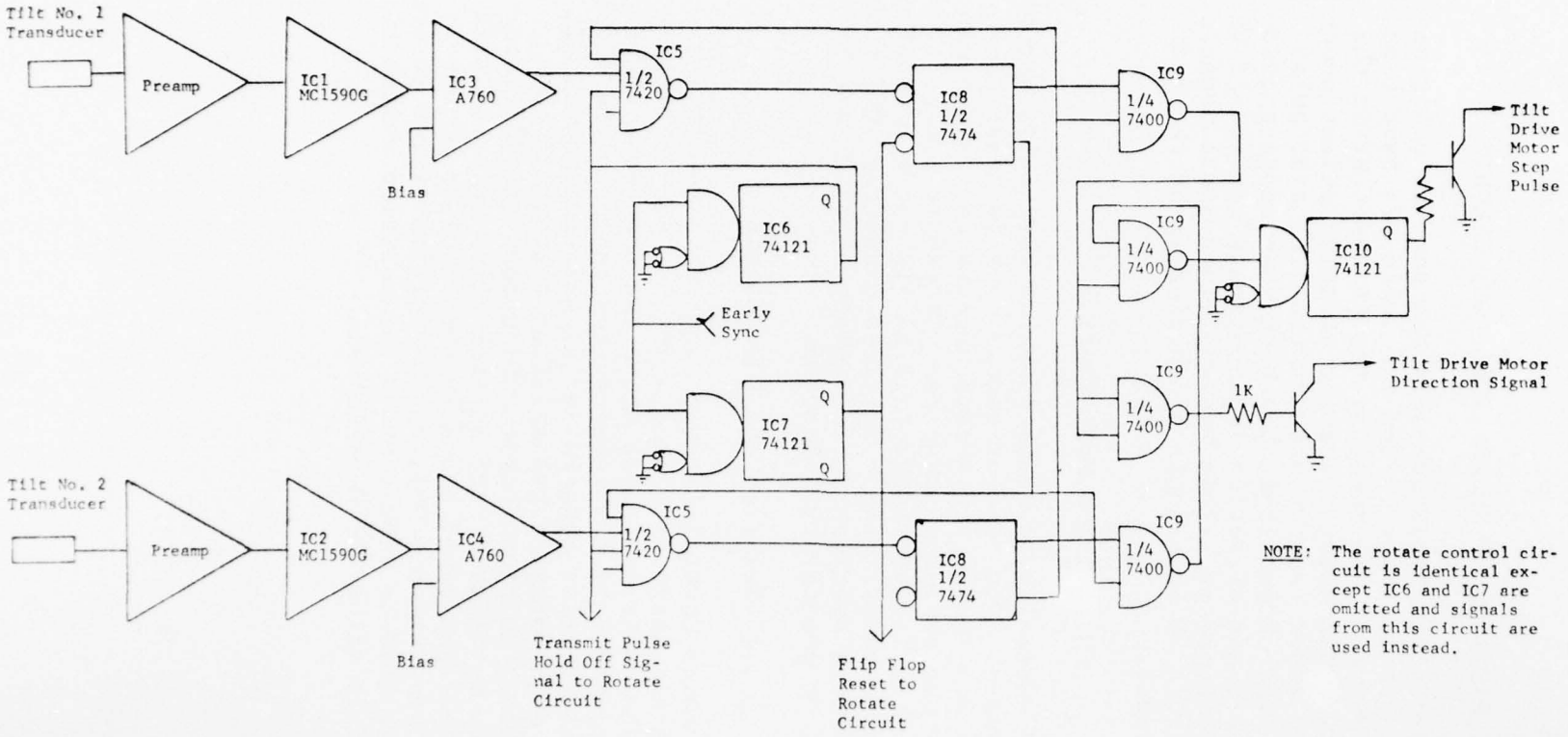


Figure 75 Normalcy Tilt Control Circuit Block Diagram

B.3 DISTANCE OF SEPARATION (DOS) CIRCUIT

The DOS circuit is essentially the same as described in the first annual report. The two logic MVs have been changed to FFs which are reset by the FF reset MV in the TILT circuit. This assures that no stepping pulses occur when the time error is zero between the I.F. sync pulse and DOS MV. The output logic has been changed to provide stepping pulses and direction logic signals instead of UP pulses and DOWN pulses. This was explained under normalcy control. Figure 76 is a logic block diagram of the modified DOS circuit.

B.3.1 DOS Modification

The DOS control system has operated very satisfactorily except for speed. The rate of change of Z is restricted to a maximum of 0.5 inches per second because the system can produce only one stepping pulse per ultrasonic cycle. The ultrasonic cycle is restricted to 2 milliseconds because of computer requirements. The Z drive is presently .001 inch per step. With a specimen surface slope of 45° X and Y speed cannot be greater than Z speed.

B.3.2 Normalcy and DOS Chassis

The Normalcy Control Circuits and DOS circuits are contained in a chassis with a $3\frac{1}{2}$ X 19-inch panel which is mounted in the control console above the scanner control panel. It connects by a multiconductor cable to the ultrasonic special function chassis for signals and power. It connects to each normalcy preamplifier through 75 ohm subminax cable. Multiconductor cables connect tilt rotor drive, rotate motor drive and Z motor drive units to this chassis. The front panel has a 10-turn dial to adjust distance of separation (DOS), a two-position switch to set DOS in either AUTO or MANUAL and a two-position switch to set NORMALCY in either AUTO or MANUAL.

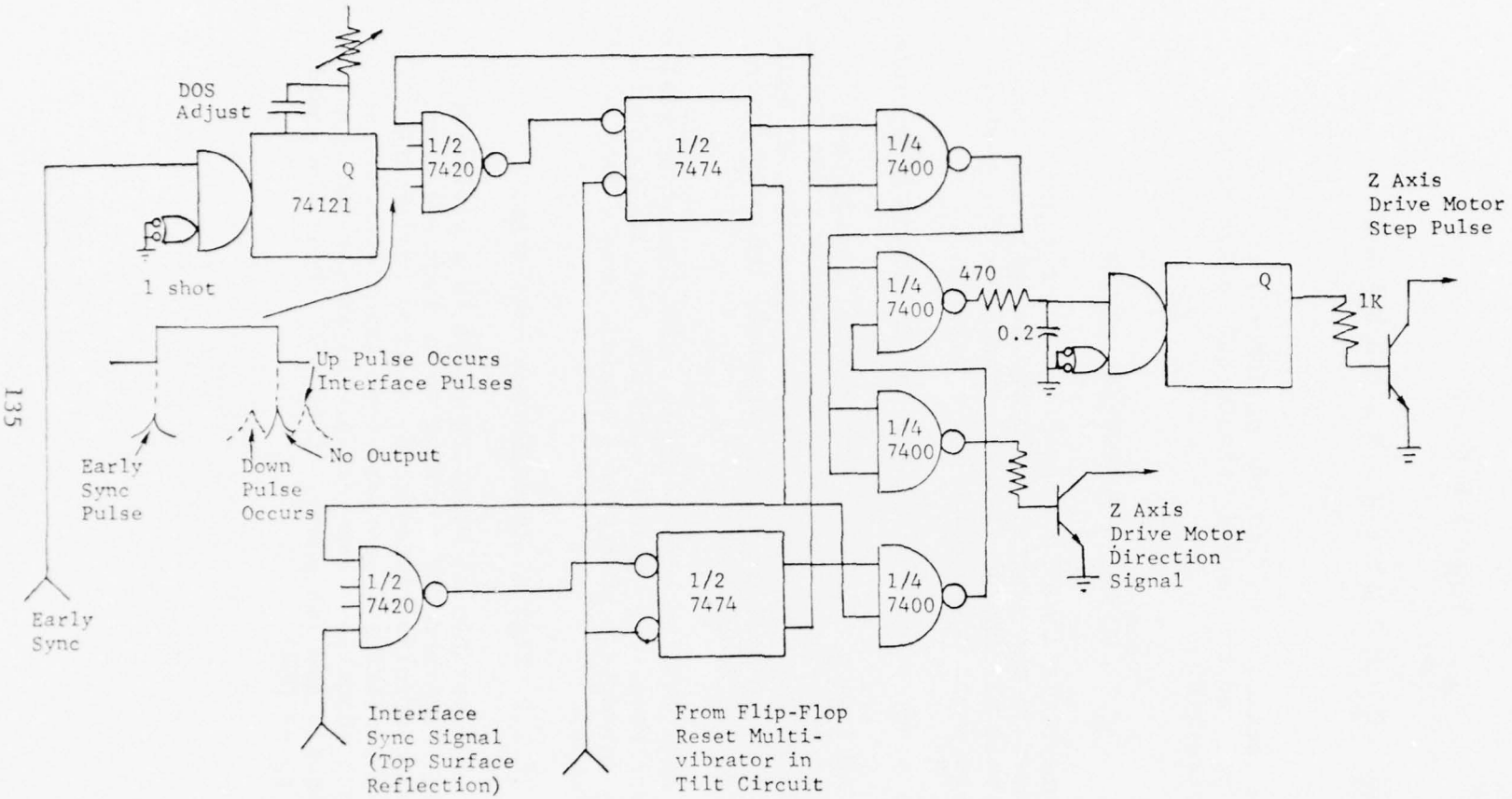


Figure 76 Distance of Separation Control Circuit

APPENDIX C

COMPUTER HARDWARE

This section describes the peripheral devices, module utilization, and the modification required for proper system operation.

C.1 COMPUTER PERIPHERAL DEVICES

Figure 10 is a block diagram showing the peripheral devices used in the system. With the exception of the BB11-CTN unit all the devices are standard off-the-shelf Digital Equipment Corporation (DEC) modules.

C.1.1 Analog-to-Digital and Digital-to-Analog Subsystems

The AD11 is a flexible, multichannel analog data acquisition system. This system has 8 analog input channels, expandable to 32; programmable input range selector; control; and a sample and hold amplifier to reduce the conversion aperture to 100 nanosecond.

The AA11 is a high performance multichannel digital-to-analog converter. The AA11-D controls four 12-bit digital-to-analog converters that have a maximum update rate of 50K Hz per channel.

C.1.2 Digital Input/Output Subsystems

The DD11 peripheral mounting panel is a pre-wired system unit designed for mounting up to four (4) small peripheral controller interfaces, and the BB11-H DEC kit when fully configured, provides four input channels and four output channels. They are pre-wired for logic and UNIBUS signals and for power. Figure 77 shows the module utilization of DD11.

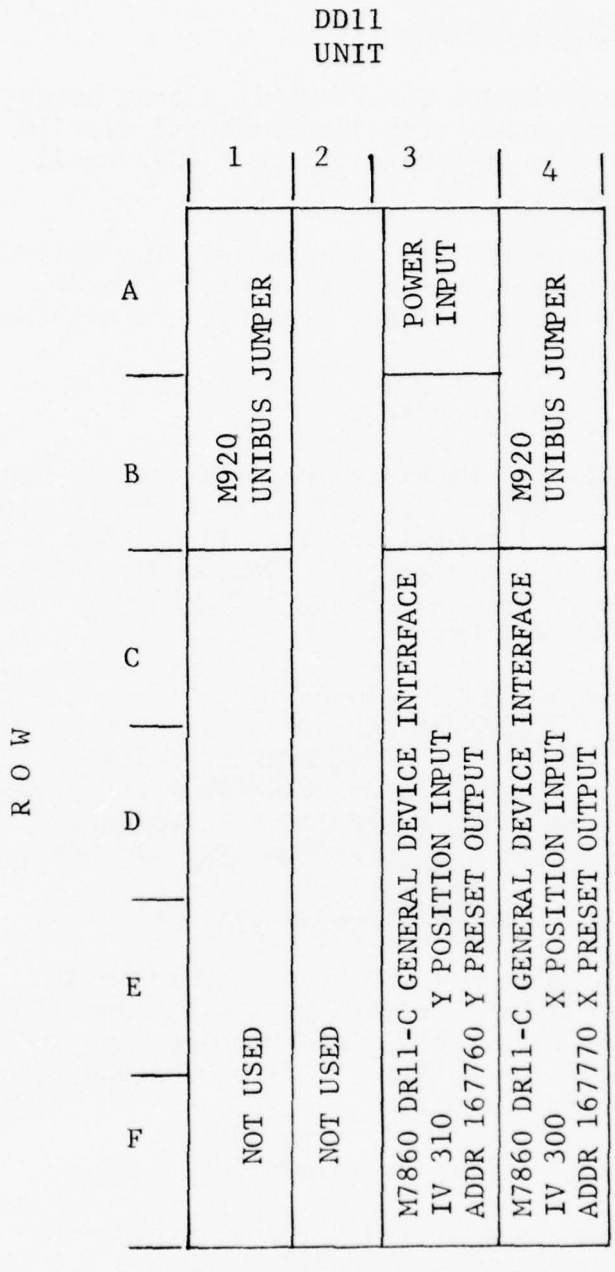


FIGURE 77 MODULE UTILIZATION OF THE DD11 SYSTEM UNIT

C.1.2.1 General Device Interfaces

The DR11-C general device interface is a quad height module that plugs into either a small peripheral slot in the processor or into one of four slots in a DD11 small peripheral mounting panel.

This system contains two DR11-C modules. The DR11-C contains three functional sections - a 16-bit buffered output register, a 16-bit data input circuit, and a 2-channel flag and interrupt control.

C.1.2.2 DEC Kit 11-H I/O Interface

The BB11-H DEC kit is capable of reading four 16-bit words from a peripheral device or writing four 16-bit words or eight 8-bit byte to peripheral device. Each input word is supplied with interrupt capability. The module utilization layouts of the two BB11-H DEC kits for this system are shown in Figures 78 and 79.

C.1.3 System Clock

The features of the KW11-P programmable real-time clock are: four clock rates, program selectable and crystal-controlled clock for accuracy, three modes of operation, two external inputs, and interrupt at the line frequency.

C.1.4 Hi-Speed Reader/Punch Subsystem

The PC11 high speed reader and punch subsystem is capable of reading eight-hole unoiled perforated paper tape at 300 characters per second, and punching tape at 50 characters per second. The system consists of a paper tape reader/punch, and control module.

C.1.5 Graphic Display Terminal

The display device is a Tektronix 4010 cathode-ray storage tube. The viewing screen is 7.5 inches by 5.6 inches and has the capacity of 35 lines by 72 characters per line. For graphic, the unit has a resolution of 1024 addressable point in both X and Y axes. This unit uses a DL11-E interface unit setup for a transfer rate of 9600 BAUD.

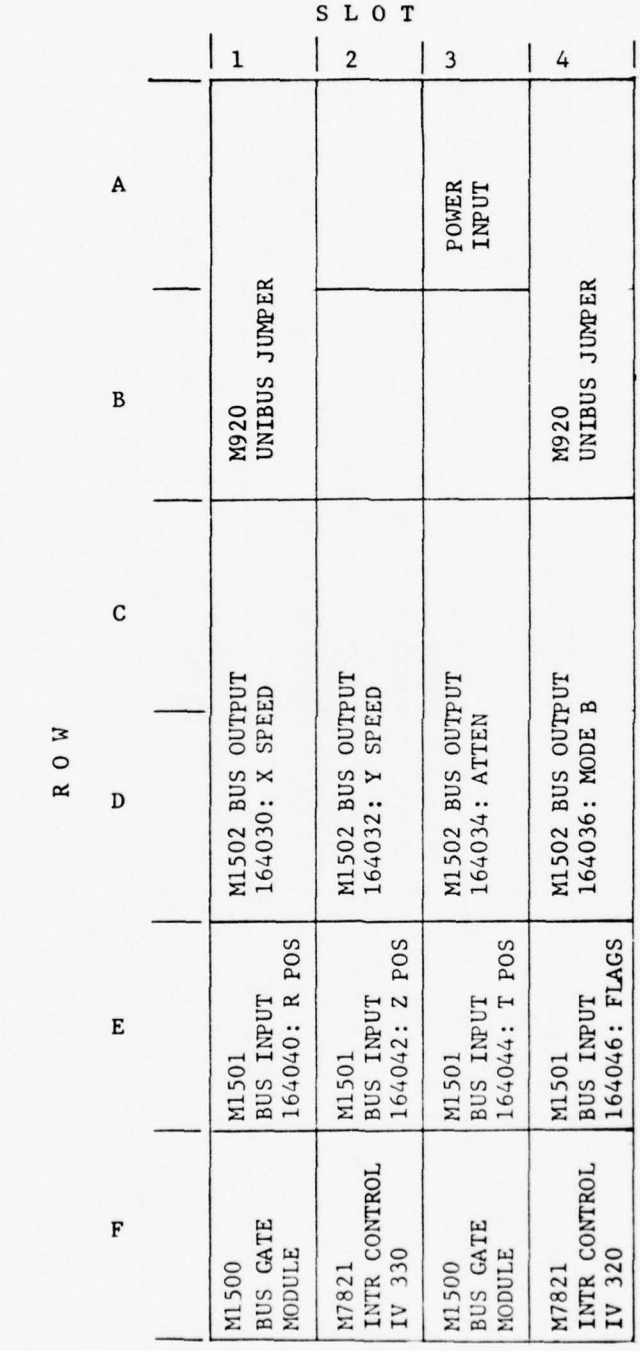


Figure 78 Module Utilization of BB11-H Digital I/O System No. 1

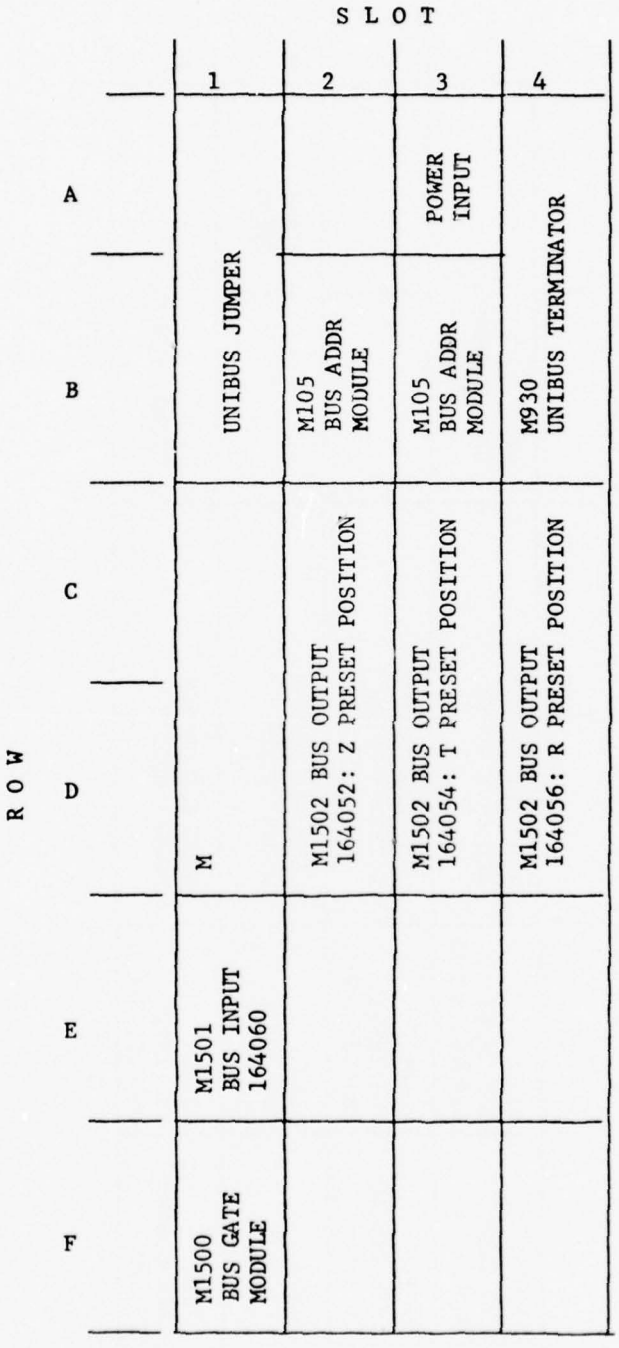


Figure 79 Module Utilization of BB11-H Digital I/O System No. 2

C.1.6 Dual Counter Subsystem

This system is used to obtain pulse length and event counts in a form that can be input to the computer. This is done by a modified DEC M795 word count and bus address unit. A dual counter unit consists of four modified M795 units and two M105 address selector units. Figure 80 shows the module utilization of B11-CTS unit.

C.1.7 Signal Conditioning Subsystems

All high speed digital signals are transmitted by differential line-drivers and received by differential line-recrivers to preserve effective waveshape. Output buffers were required on the DR11-C and M1502 bus output devices due to loading effect of the long cable going to scanner control console. Figure 81 and 82 show the module utilization for the BB11s.

C.1.8 Interface Address Assignments

Table 3 is a complete list of the hardwired address assignments that were being used at the completion of Phase I.

C.2 INTERFACE DEVELOPMENT

This section describes the line-driver/receiver modification and the dual counter subsystem that were designed and fabricated by General Dynamics

C.2.1 Line Driver and Receivers

The DEC line receiver (Y90) and line driver (Y91) schematics are shown in Figures 83 and 84.

The line driver/receiver setup had to be modified to prevent degradation of high-speed signal. Table 4 lists the signals and their leading edge rise times before and after modification.

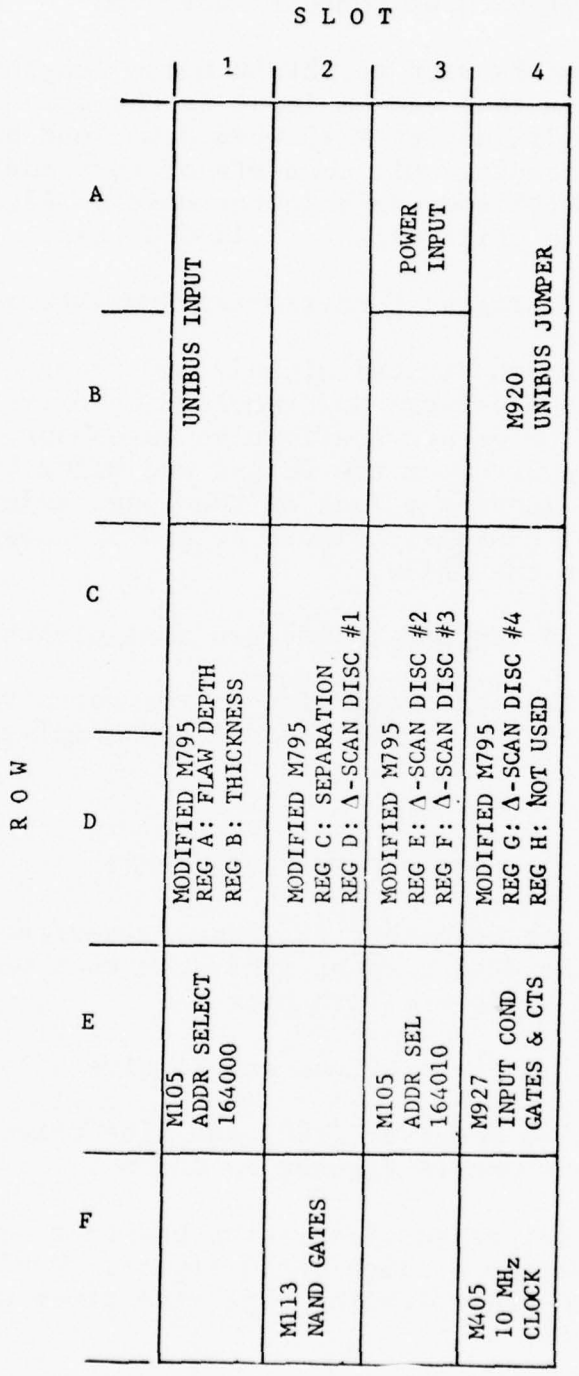


Figure 80 Module Utilization of BB11-CTS System

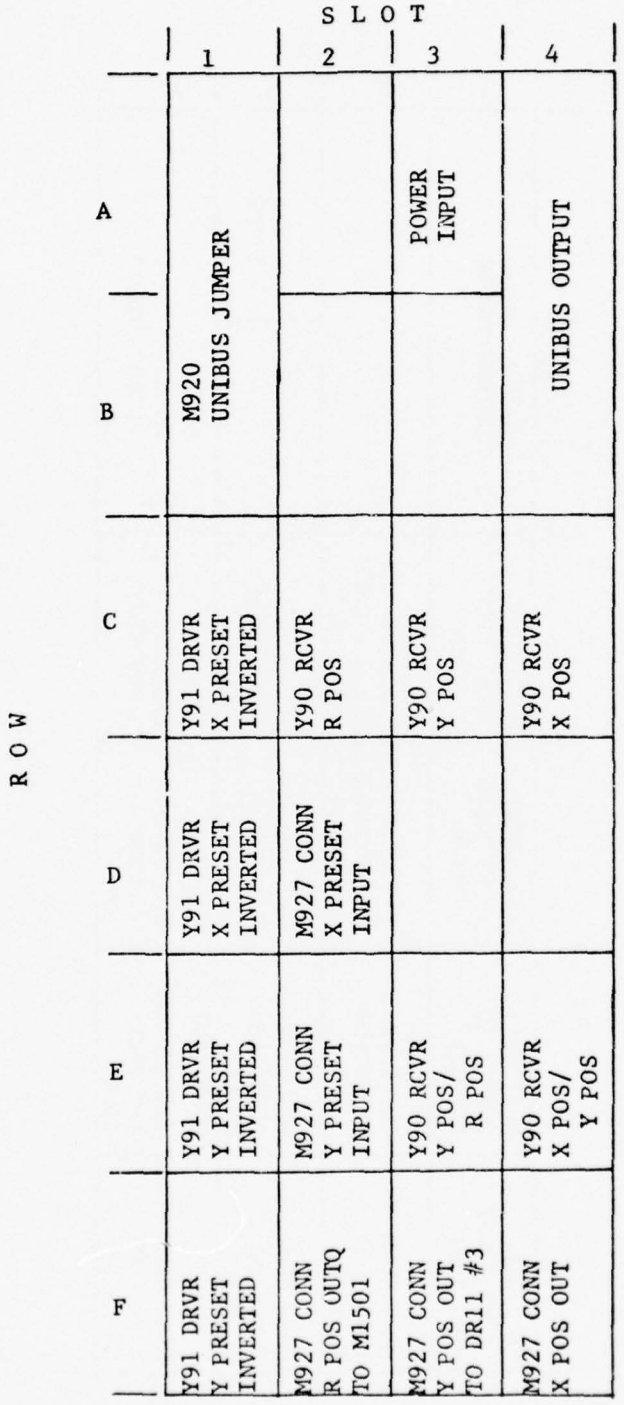


Figure 81 Module Utilization of Line Driver/ Receiver System Unit No. 1

ROW	SLOT 1	SLOT 2	SLOT 3	SLOT 4
A	M920 UNIBUS JUMPER		POWER INPUT	
B				M920 UNIBUS JUMPER
C	M927 CONN INPUT FROM X SPEED	Y90 RCVR GATES & CNTS (MODIFIED)	Y90 RCVR T POSITION	Y90 RCVR Z POSITION
D	M927 CONN INPUT FROM Y SPEED	Y91 DRVR X SPEED OUT	Y91 DRVR X/Y SPEED OUT	Y91 DRVR Y SPEED OUT
E	M927 CONN OUTPUT TO COUNTERS	Y91 DRVR ATTEN OUT	Y90 RCVR FLAGS AND GATES (MODIFIED)	Y90 RCVR Z/T POSITION
F	M927 CONN ATTEN INPUT FROM 1502	M927 CONN FLAGS OUT TO M1501	M927 CONN T POS OUT TO M1501	M927 CONN Z POS OUT TO M1501

Figure 82 Module Utilization of Line Driver/ Receiver System Unit No. 2

TABLE 3

PERIPHERAL DEVICE ADDRESS ASSIGNMENTS

DEVICE	ADDRESS	V.A.*/(CHANEL)	COMMENTS
Dual Counter # 1	164000		Depth (FG # 2)
	164002		Thickness (FG # 4)
Dual Counter # 2	164004		DOS (FG # 1)
	164006		Delta Counter # 1
Dual Counter # 3	164010		Delta Counter # 2
	164012		Delta Counter # 3
Dual Counter # 4	164014		Delta Counter # 4
	164016		(FG # 3)
Bus Input (M1501)	164020		Rotate
	164022		Z
	164024		Tilt
	164026	320	Flags and Sync
Bus Output (M1502)	164030		X Speed
	164032		Y Speed
	164034		Attenuator
Bus Input (M1501)	164040		Rotate, Tilt, Z Flags
Bus Output (M1502)	164052		Rotate
	164054		Tilt
	164056		Z
DR11-C	167760	310	Control and Status
	167762		X Output
	167764		X Input
DR11-C	167770	300	Control and Status
	167772		Y Output
	167774		Y Input
D/A Converter (AA11)	176760	(1)	Flaw Gate Width
A/D Converter (AD11)	176770		Control and Status
	176772		A/D Buffer
		0	Reflection Flaw Ampl.
		(1)	Shear Flaw Ampl.
		(2)	Top Surface
		(3)	FG # 3 Amplitude
		(4)	FG # 4 Amplitude
KW11-D	172540	104	Programmable Clock
M782YCD	173110		Bootstrap Loader
DL11-E	175610	3703	Tektronix 4010
PC11	177550	70	Paper Tape R/P
Teletype	177560	60	System Console

* Vector Address

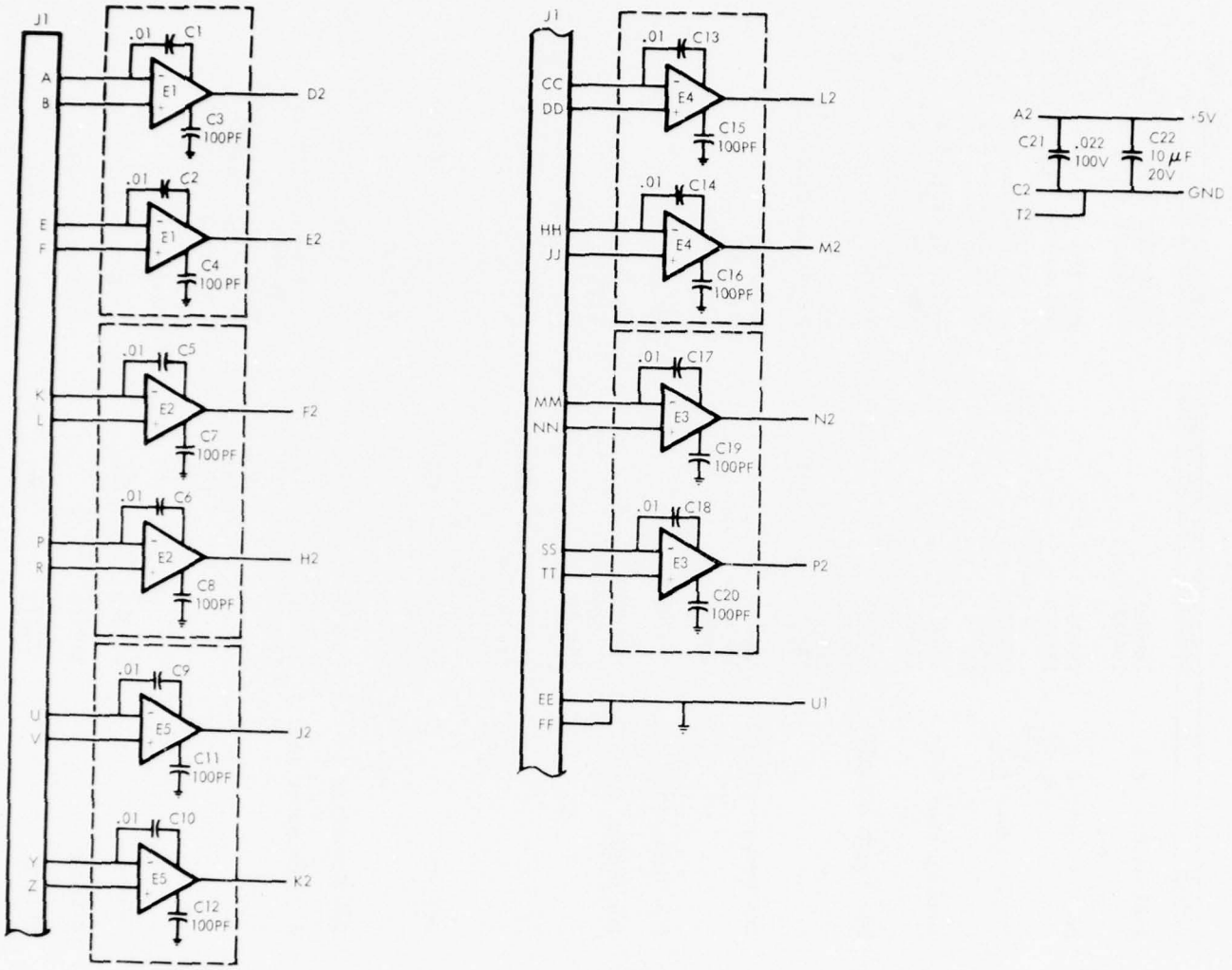


Figure 83 Y90 Line Receiver Schematic

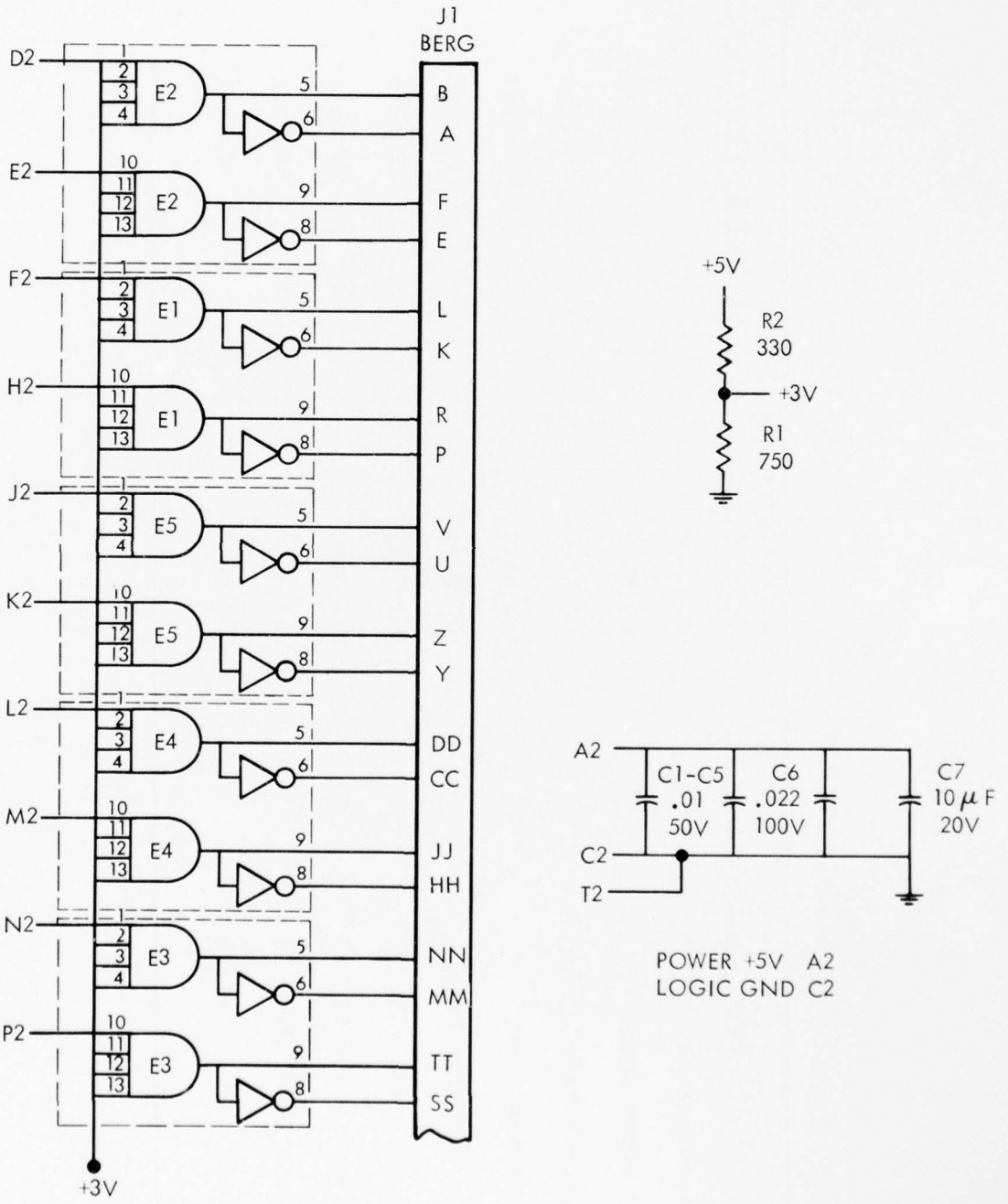


Figure 84 Y91 Line Driver Schematic

TABLE 4

SIGNALS THAT REQUIRED LINE-RECEIVER MODIFICATION

Signal Name	Standard Driver/Receiver Rise Time	Modified Receiver Rise Time
Clear Counters	150 Nsec	40 Nsec
Flaw Depth Gate	200 Nsec	40 Nsec
Thickness Gate	180 Nsec	40 Nsec
Separation Gate	180 Nsec	40 Nsec
Delta Counting Gate	300 Nsec	50 Nsec
-Scan Level Disc #1	200 Nsec	40 Nsec
-Scan Level Disc #2	160 Nsec	40 Nsec
-Scan Level Disc #3	150 Nsec	40 Nsec
-Scan Level Disc #4	150 Nsec	40 Nsec

The modification to the line receivers was required because the leading edge (positive-going) rise time was too great and this was found to be the result of the design of the DM 8820A output, which is a wired OR circuit. To obtain the required operating speed, the response capacitors (100PF) were removed and a 220 Q, 1/4-watt pullup resistor was added to the output. Figure 85 shows the modified line-driver/receiver circuit.

C.2.2 Dual Counter Subsystem

The dual counter system is comprised of four modified DEC M795 modules, two M105 Address Selector modules, one M405 10-MHz clock module, and one M113 NAND Gate module installed in a BB11 prewired system unit as shown in Figure 80. The dual counter BB11 was wired by General Dynamics.

C.2.3 M795 Unit Modification

The DEC standard M795 word count and bus address unit was modified to operate as two synchronous, 16-bit binary counters. Figure 86 is a schematic of the M795 incorporating the following modifications:

1. Register A

    a. Circuit board etch cut between IC E3 Pin 6 and IC E9 Pin 6.

    b. Circuit board etch cut between ICE11 Pin 9 and ICE9 Pin 5.

    c. Circuit board etch cut between Pins 1 and 2 of IC E3.

    d. Jumper added between Pin 5 and Pin 6 of IC E9.

    e. Jumper added between Pin 2 and Pin 13 of IC E3.

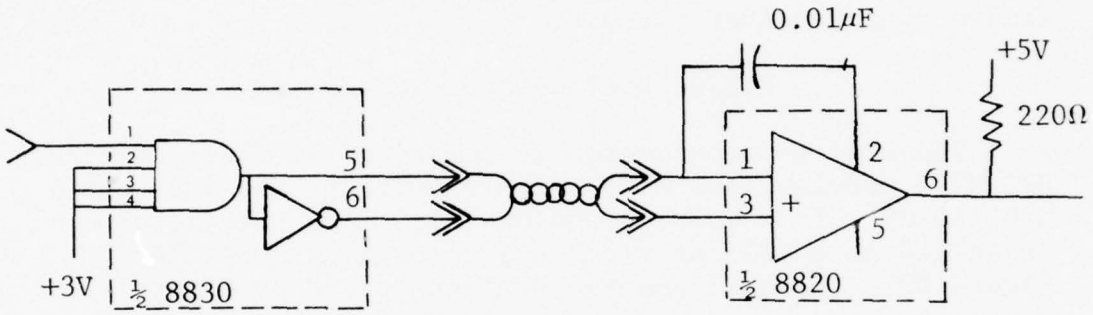


Figure 85 Modified Line Driver/Receiver Setup

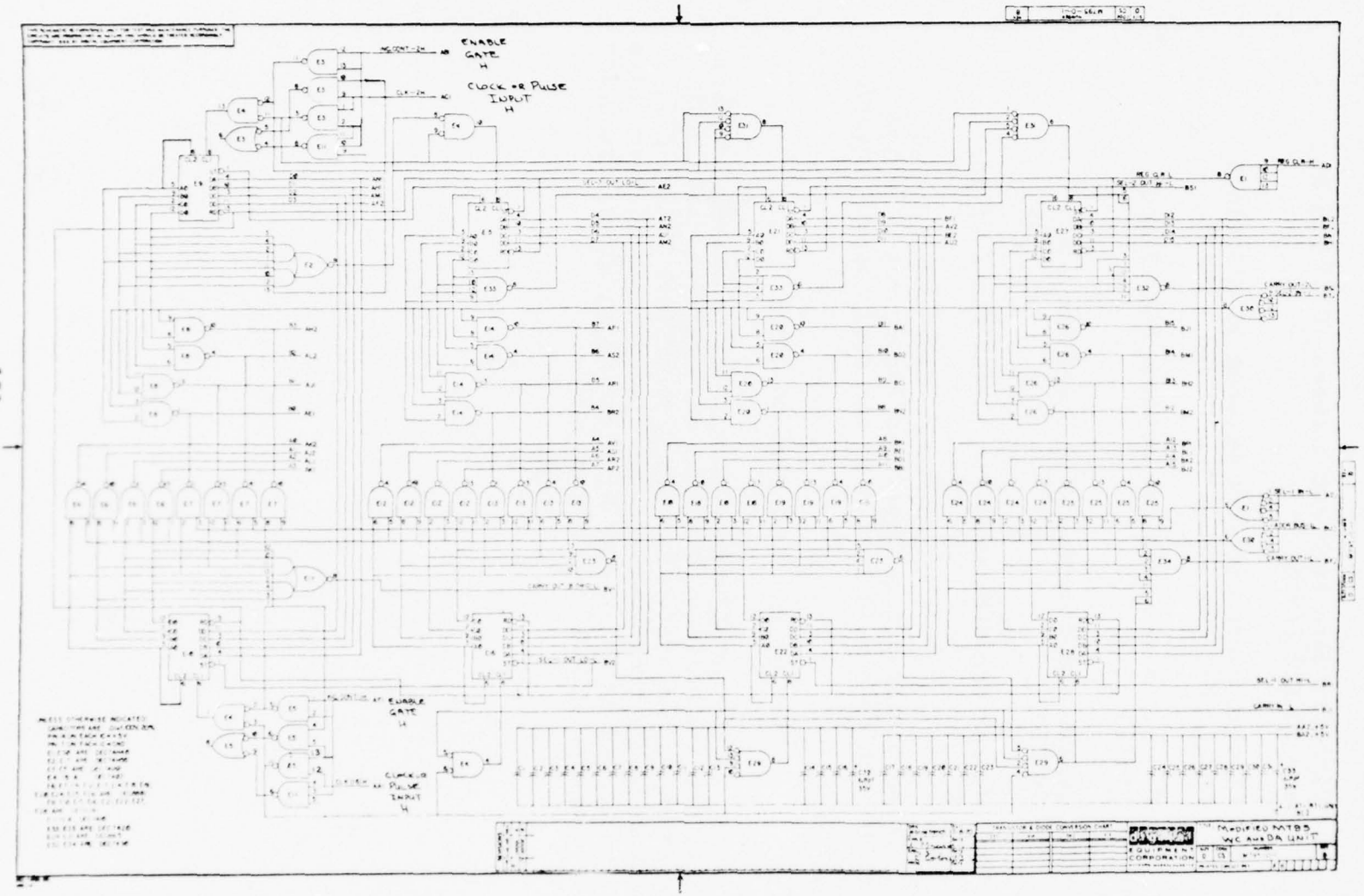


Figure 86 Dual Counter (Modified M795) Schematic

2. Register B

a. Circuit board etch cut between IC E5 Pin 8 and IC E10 Pin 6.

b. Circuit board etch cut between IC E11 Pin 5 and IC E10 Pin 5.

c. Circuit board etch cut between Pin 12 and Pin 13 of IC E5.

d. Jumper added between Pin 5 and Pin 6 of IC E10.

e. Jumper added between Pin 13 and Pin 2 of IC E5.

These modifications have been incorporated in the four M795 units now installed in the dual counter interface unit.

C.2.4 System Interconnection

The interconnections between the line driver/receiver units, the scanner control unit, and the ultrasonic unit are shown in the system harness diagram (see Figure 87). The interconnections between the line driver/receiver units and the computer interface units are shown in the extension box harness diagram, (see Figure 88).

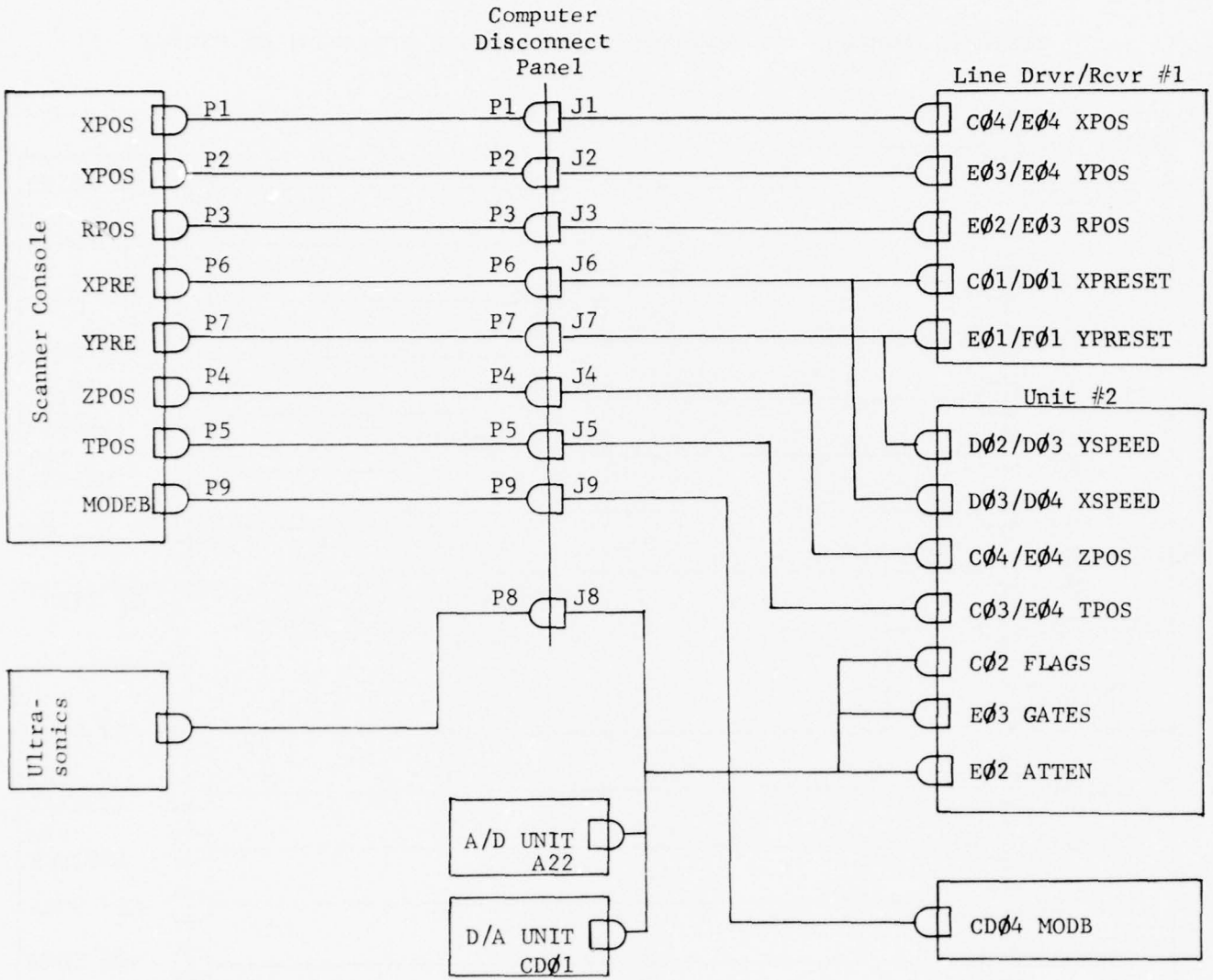


Figure 87 Computer System Interconnect Harness Diagram

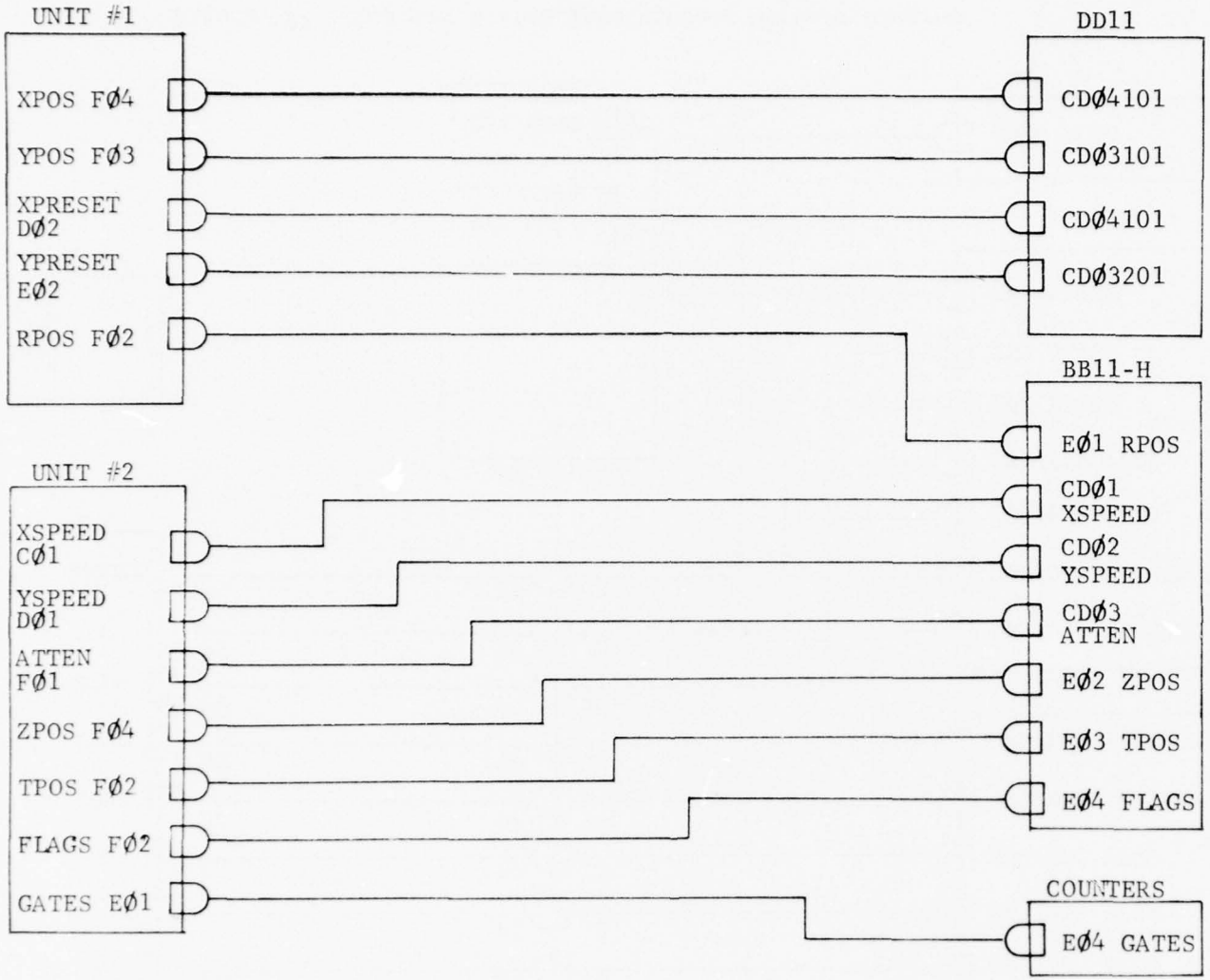


Figure 88 Interface Extension Box Interconnect Harness Diagrams

APPENDIX D

COMPUTER SOFTWARE

This section describes the software that is used to control the scanner, acquire the ultrasonic data, and process and display the data. A complete listing of the software is available upon request to AFML/LLP.

D.1 DATA ACQUISITION PROGRAMS

The circular scan, 'AFML B' and rectangular scan, 'AFML A', programs are very similar, the only significant differences are the coordinate storage formats and scanner control routines.

The program has seven functions or run modes. They are listed and briefly described below:

- o INITIAL = Allocate new disk and then take data
- o DATA = Perform a scan and store data
- o DISPLAY = The data from a prior run is displayed on the 4010 scope
- o REPORT = The data from a prior run is listed on the 4010 scope
- o LIST = The data runs stored on disk and the amount of disk space used are listed
- o DELETE = The last data run stored is deleted from the disk
- o HALT = The linkage to the disk is released and program exists to monitor

The program variable scan mode is used to choose between one of three ultrasonic inspection modes reflection, shear-wave, and multiple flaw gate. These programs each contain seven overlays described below.

D.1.1 Resident Main

The resident for "AFML A' and 'AFML B' is identical. It contains the communication area (commons) and calls all other overlays. It occupies 3K of the available 16K of memory space.

D.1.2 Overlay 0

This overlay handles the selection of the run mode and scan modes. It includes routines for the execution of the three run modes HALT, DELETE and LIST.

D.1.3 Overlay 1 - Overlay 4 (Initial Data)

These overlays perform the function of the data acquisition phase. Overlay 1, 2, and 3 are preparatory in nature.

Overlay 1 allows the operator to change the input parameters.

Overlay 2 sets up the various commons, sets scan limits for shear, sets the attenuator for calibration, and allows operator interaction for adjusting the flaw gate width.

Overlay 3 draws the grid, labels the axis and writes the identification information.

Overlay 4 performs the actual data acquisition. It contains the elements for real-time data transfer, scanner control, near real-time data display, the data screening routines.

D.1.4 Overlay 5 (DISPLAY)

This overlay enables the operator to display previously recorded data. Features include variable size grid limits, selection of data based on its depth, amplitude, and the condition of the back surface gate. These features are referred to as 'filters.'

D.1.5 Overlay 6 (REPORT)

This overlay lists the previously recorded data. The same features are available as in Overlay 5. All the variables recorded for each flaw detected during the data taking phase are listed in one line. This listing takes place on the 4010 scope.

D.1.6 Disk Usage

The DOS monitor and all user routines and subroutines reside on disk unit Ø (DKØ). The data file is 4790 blocks in length and resides on disk 1 (DK1). Each block has 256 words for a total of 1.2 million 16 bit words. The blocks are written out sequentially during the data run.

The format for each data run consists of two header blocks that contain all the pertinent information relating to setup, ultrasonic scan method, number of blocks used for data storage, calibration information. These blocks are followed by the data blocks. A special bit pattern is written after each data acquisition run to mark the end of the used portion of the disk. Table 5 describes the formats of the data blocks.

A utility program has been written to transfer a specific run from one data disk to another.

D.2 ISOMETRIC DISPLAY PROGRAMS AFML C AND AFML D

These programs differ only in the type of scan data that is handled. One program is used with rectangular scans and the other is used with circular scans. These programs are functionally equivalent to the DISPLAY and REPORT run modes. The flaw data are presented in isometric view and the amplitude profiles are plotted.

D.3 FLAW ORIENTATION AND FOURIER TRANSFORM

This program consists of a resident main and four overlays. It has two basic functions. One, search for the optimum angle inspection of an inclined flaw; two, transform a RF waveform into the frequency domain and plot the spectrum.

TABLE 5

Data Storage for Each Inspection Routine

	REFLECTION	SHEAR	MULTIPLE FLAW GATE
1	Scan Number	Scan Number	Scan Number
2	Index Position (Radius)*	Index Position (Radius)*	Index Position (Radius)*
3	Scan Position (Angle)*	Scan Position (Angle)*	Scan Position (Angle)*
4	Thickness	Thickness	Gate 4 Depth
5	Flaw Depth	Flaw Depth	Gate 2 Depth
6	Flaw Amplitude	Flaw Amplitude	Gate 2 Amplitude
7	Tilt Angle	Tilt Angle	Tilt Angle
8	Rotate Angle	Rotate Angle	Rotate Angle
9	Z Position	Z Position	Z Position
10	Scan Position ⎫	Scan Position ⎫	Gate 3 Depth
11	Thickness ⎪	Thickness ⎪	Gate 3 Amplitude
12	Flaw Depth ⎪	Flaw Depth ⎪	Gate 4 Amplitude
13	Flaw Amplitude ⎬ Φ	Flaw Amplitude ⎬ Φ	Key Word
14	Tilt Angle ⎪	Tilt Angle ⎪	Scan Position ⎫
15	Rotate Angle ⎪	Rotate Angle ⎪	Gate 4 Depth ⎪
16	Z Position ⎭	Z Position ⎭	Gate 2 Depth ⎪
17	.	.	Tilt Angle ⎪
18	.	.	Rotate Angle ⎪
19	.	.	Z Position ⎬ Φ
20	.	.	Gate 3 Depth ⎪
21	.	.	Gate 3 Amplitude ⎪
22	.	.	Gate 4 Amplitude ⎪
23	.	.	Key Word ⎭
24	.	.	.
25	.	.	.
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.	.	.	.
256	Link Word	Link Word	Link Word

* Circular Scan

Φ Data Record

D.4 FLOW DIAGRAMS

This section describes and charts the flow diagrams.

D.4.1 Resident Main

The resident main is not an overlay, therefore it and all routines it calls reside in core at all times. The actual overlays are brought into core by the routine LINK. The parameter run mode, set in Overlay 0, is used to select which overlay is called. After each run mode is executed, control is returned to the resident and then to Overlay 0. This program is flow charted in Figure 89.

D.4.2 Overlay Ø

This overlay performs much of the setup and operator I/O for the program.

The first operation performed is the selection of one of seven run modes. For run modes of INITIAL or DATA, the inspection technique (scan mode) is entered. INITIAL run mode allows a new disk to have the data of file (FDF.01) to be allocated or an old data disk to be initialized.

For run modes 'LIST' and 'DELETE' these functions are performed within the overlay. Control is then returned to the top of the overlay.

For run mode 'HALT', the file linkage is released and the program is terminated.

For run modes INITIAL, DATA, DISPLAY or REPORT, the specific run number must be entered. This allows a search to be initiated for the start block number. In the case of INITIAL no checking is performed and the first block of the disk file is designated the start block. In the case of 'DATA' the entered run number must not appear before the end of data mark is found, if it does the run number can be re-entered. If the run number is not re-entered, the run mode is set to LIST and the run numbers are listed.

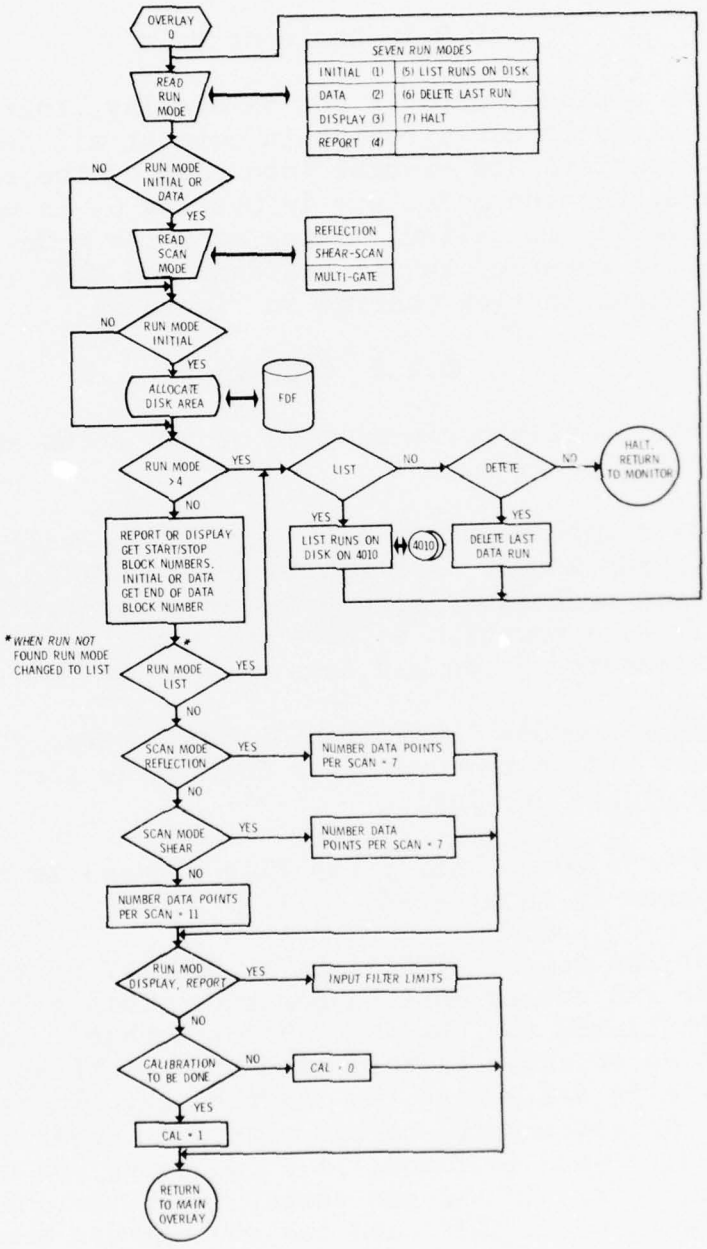


Figure 89 Flow Diagram for Overlay Ø

After the end of data mark is located the header blocks of the previous run are used as the header blocks of the new data run. These blocks can be changed in Overlay 1 if required.

In the case of 'DISPLAY' or 'REPORT' the run number should be found before the end of data mark. If it is not found, the run number is either re-entered or the run mode is changed to LIST, and run numbers are listed.

If the data run has been found, the inputs which select the features (filters) for post data analysis are then selected. The flow diagram is shown in Figure .

D.4.3 Data Acquisition Control Module

The data acquisition control module (DACM) sets up the interrupt vector, enables and disables the interrupt, interfaces with the scanner module (SCNITZ, SETSPD, SCNSTR, SFDBK, INDEX, SCNMST, IFBDK, ONEHAF), disk I/O modules (DBSTAT, DBOUT, EOSWM), near real-time display module (NRDM), monitor the switch register (direct operator control).

After each ultrasonic cycle has been completed an interrupt is generated which starts the processing of the ultrasonic information. Then, DACM routine scans various flags to determine the next control function. If no flags are set, it places itself in the wait mode. The generation of an interrupt awakens the routine from the wait mode. The flow diagram for this routine is shown in Figure 90.

D.4.4 Reflection Data Acquisition Interrupt Control

This routine processes the interrupt generated at the end of each ultrasonic cycle when in the reflection mode. The first operation is to ascertain the condition of the back surface gate.

After this is done, the routine checks the various flags to see if data should be moved to the buffers. The first flag checked is the indexing flag. If the scanner is indexing, no data is taken. If the front surface back surface flag (FS/BS) is set, data is taken. If the scanner is not over the part, (IEDGE = 0), data is not taken. Finally, if the flaw flag is set, data is taken. The flaw flag is set by the ultrasonics.

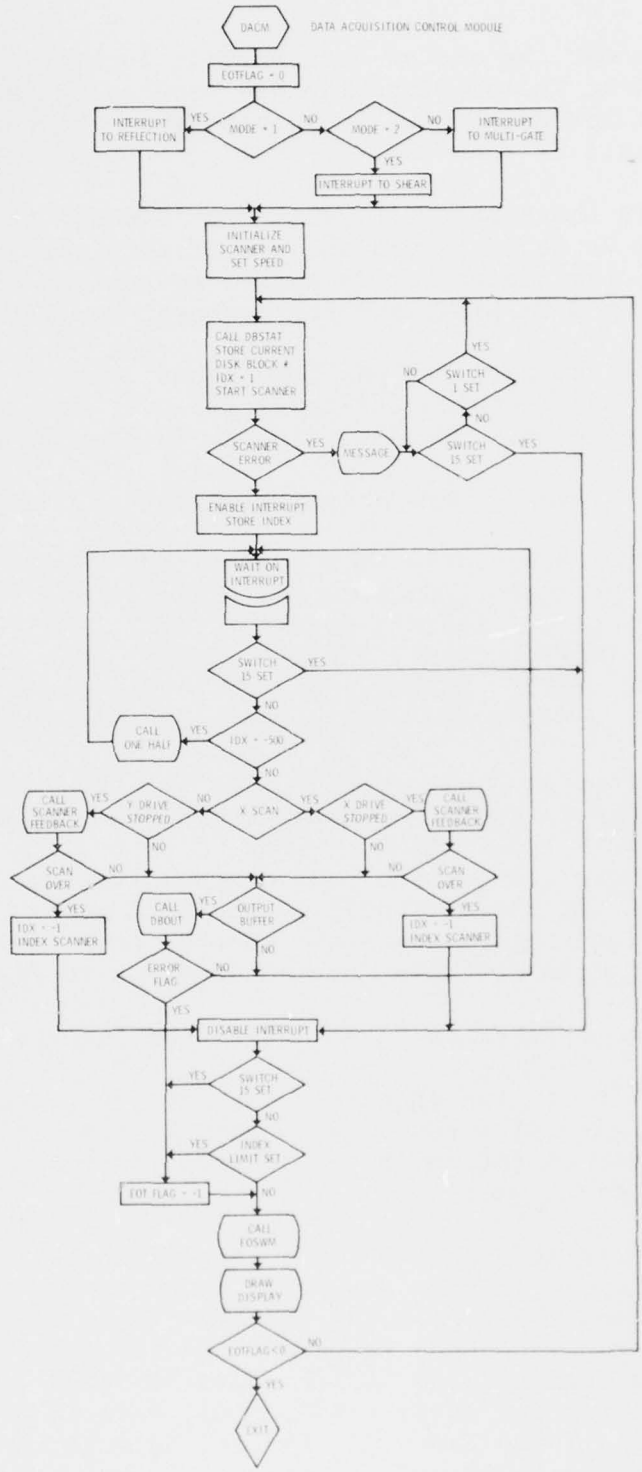


Figure 90 Flow Diagram for Data Acquisition Control

During the data-taking sequence, the part thickness is stored as zero if no back surface exists (NOBS = 1).

After data has been moved to the buffers the buffers are checked for depletion by calling (DBCM).

The flow diagram is shown in Figure 91.

D.4.5 Flaw Gate Width Control Module

This module checks on the need for speed control, distance of separation for edge changes, and the back surface flag. It also adjusts the back surface gate or seeks a new back surface.

The new back surface is declared under three possible circumstances.

1. After the program acquires a new edge or crosses on to the surface of the part, it takes the value of the first flaw depth encountered and uses it as the back surface depth.

2. When the flaw depth is equal to maximum part thickness, this thickness is output as a back surface.

3. When a flaw persists for Ø.25 inches, the amplitude does not decrease from the start, the amplitude becomes nearly saturated at the end, and the depth does not vary more than $\pm$.1 inch it is declared a back surface.

Figure 92 is the flow diagram for the Flaw Gate Width Control Module.

Definition for the flow diagram:

DOS — Distance of Separation, distance between face of transducer and part being scanned

FS/BS — Front Surface/Back Surface Flag

= 1, flags leaving surface part
= 2, flags moving onto surface of part
= 3, flags loss of back surface gate
= 4, flags continuing search for back surface

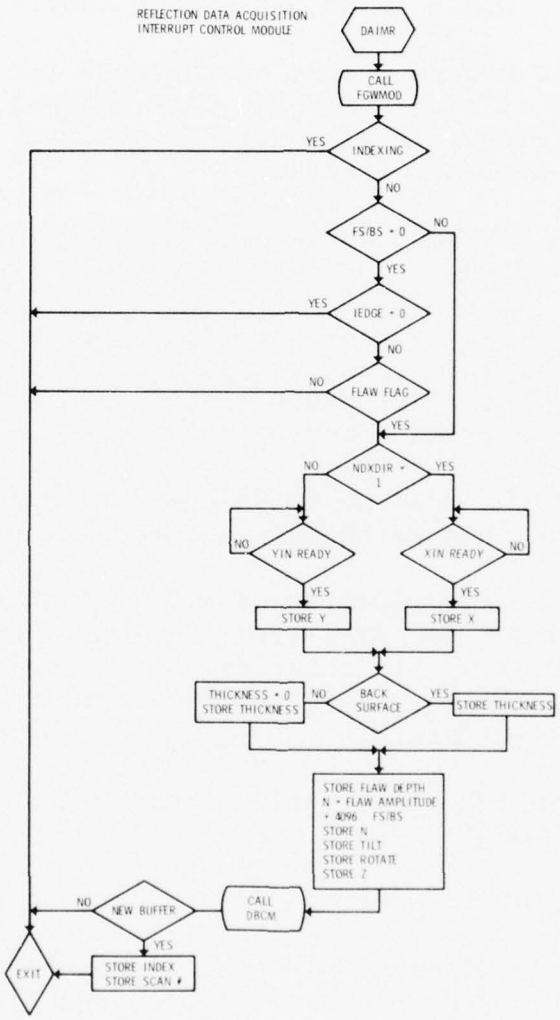


Figure 91 Flow Diagram for Interrupt Control

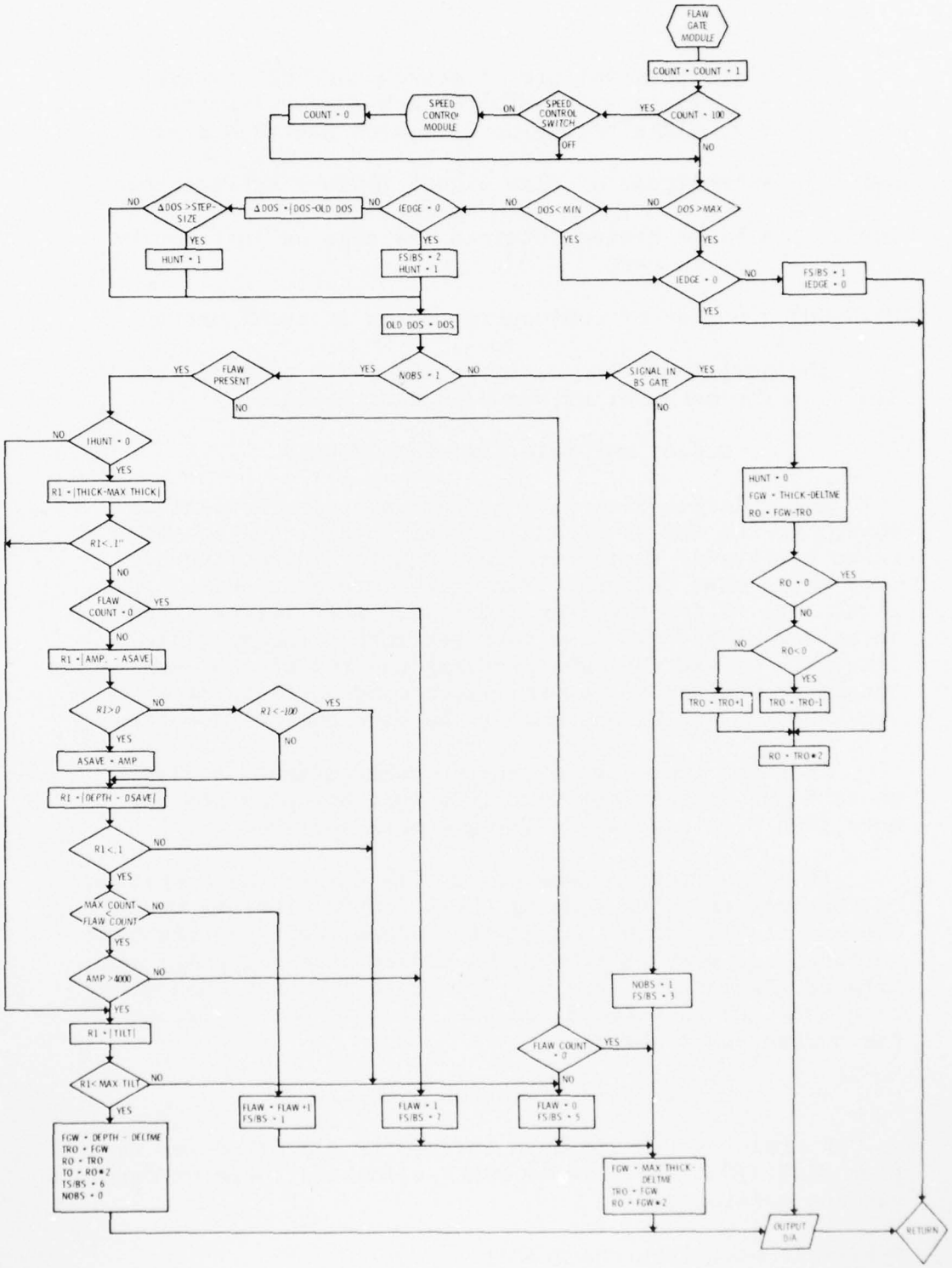


Figure 92 Flow Diagram for Flaw Gate Width Control

= 5, flags failure of search for back surface
= 6, flags successful search for back surface
= 7, flags beginning of search for back surface

AMP = Amplitude of flaw signal (4096 = saturation)

IHUNT = Flags having obtained new edge or just moved on to part

FLAW* COUNT = Number of consecutive flaws at equal depth

The purpose of the variable TRØ is to place a rate limit on the movement of the back surface gate.

D.4.6 Multiple Flaw Gate Module

The multiple flaw gate system operates in flection mode. At the end of each ultrasonic cycle, the computer reads a register that contains a counter indicating how many gates were tripped. Four gates are available. The first gate is for the front surface. This leaves three gates for either flaws or back surfaces. The multiple flaw gate module (MFGMOD) performs the function of determining whether or not the gates contain flaws or a back surface and keep track of the back surface location.

Assuming there is no current back surface, a flaw whose depth varies less than .024 inch and persists for more than 0.25 inch is declared a back surface.

The flow diagram (see Figure 93) charts the operation of the program. The routine CMPTR (COMPARATOR) is used to check a single depth against the current depth of the back surface. It must therefore, be called once for every gate tripped (except for Gate No. 1). Data is taken when more than one gate is tripped and the value in Gate 2 is not the current back surface.

D.4.7 Real Time Disk Software

A chain of ten 256-word buffers is allocated for real-time disk I/O. The routine DSBUF allocates these buffers and various pointer tables.

* Flaw is used interchangeably

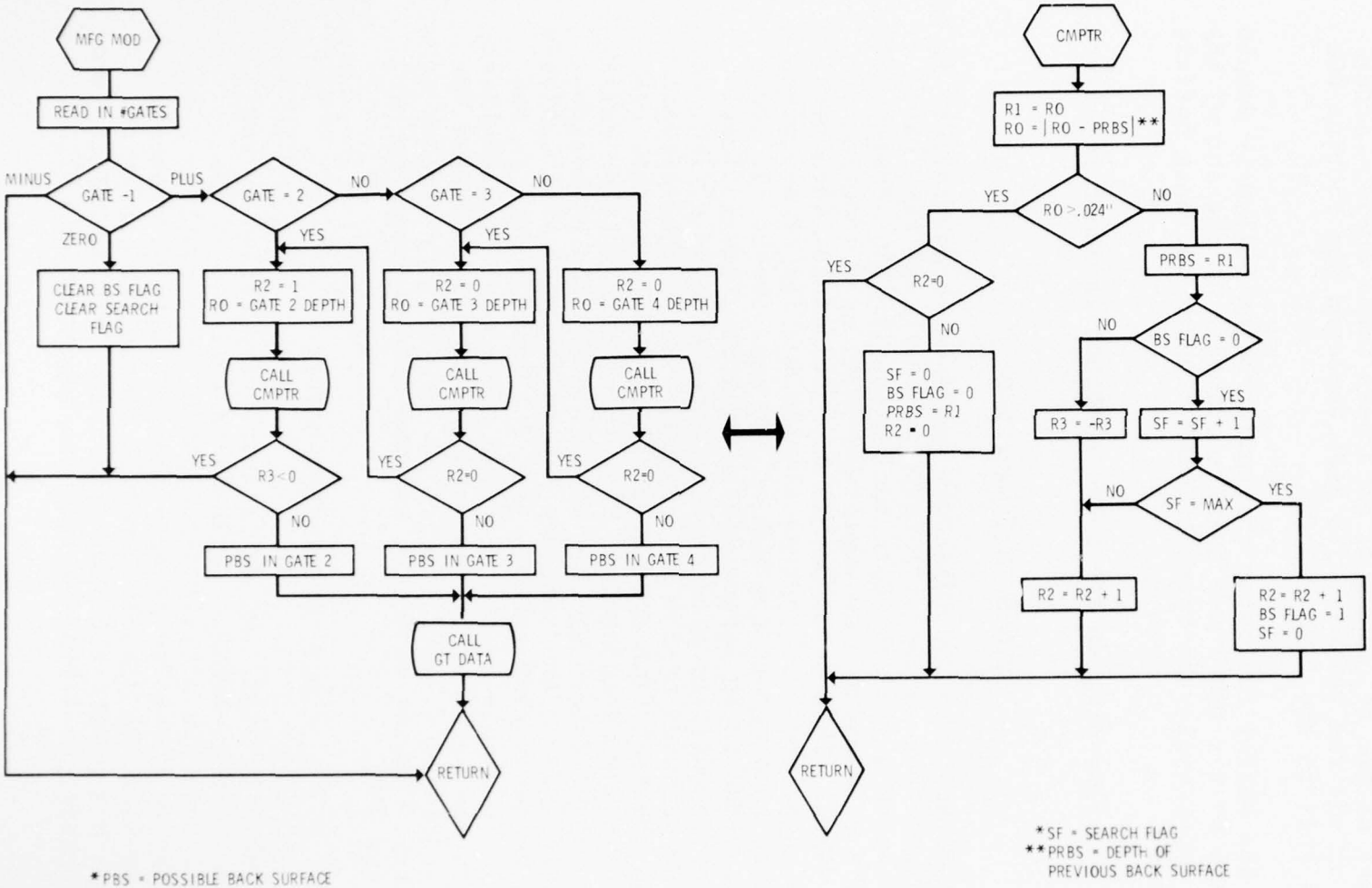


Figure 93 Flow Diagram for Multi-Gate Module

The routine DBSTAT sets up the buffers for storage of data at the beginning of each scan index cycle. After nine of the ten buffers have been depleted the routine DCM flags this to the DACM routine.

The buffer following the buffer being filled is dumped to disk by the DBOUT and DSWRT routines. At the end of the scan index cycle the routine EOSWM flushes the data buffers to disk.

The flow diagram for these routines is shown in Figure 94.

D.4.8 Software DAC

The software DAC (distance amplitude compensation) is an option that can be selected in either real time data acquisition or in post data analysis. The DAC consists of a table of minimum flaw amplitude (MFA) as a function of flaw depth. This table has to be obtained for each metal to be inspected. The actual flaw indication at any given depth is compared to the MFA at the same depth. If the MFA is found to be larger of the two, the flaw indication will not be displayed or stored on the disk as a flaw, depending on which option is selected. Using the software DAC in the real time data acquisition mode, the data rejected is lost completely. Therefore, care must be exercised in the makeup of this MFA table and the rejection criteria. Using the software DAC in the post data analysis mode, no meaningful data is lost (all data stored on the disk). The table may be modified to account for peculiarities in the metal under test and the transducers used for data acquisition. This use of the DAC is very similar to a filter. Figures 95 and 96 are the flow diagrams for the software DAC.

D.5 OVERLAY STRUCTURE

Table 6 lists the major subroutine called by run programs AFMLA, AFMLB. Table 6 is followed by the routine name and a brief description. The routines peculiar to the circular scan are listed in parentheses ( ). Overlay 4 of the circular scan is dissimilar enough to warrant a separate section. The names OPTLIB, TEKLIB, and NRMLIB refer to libraries that are concatenated collections

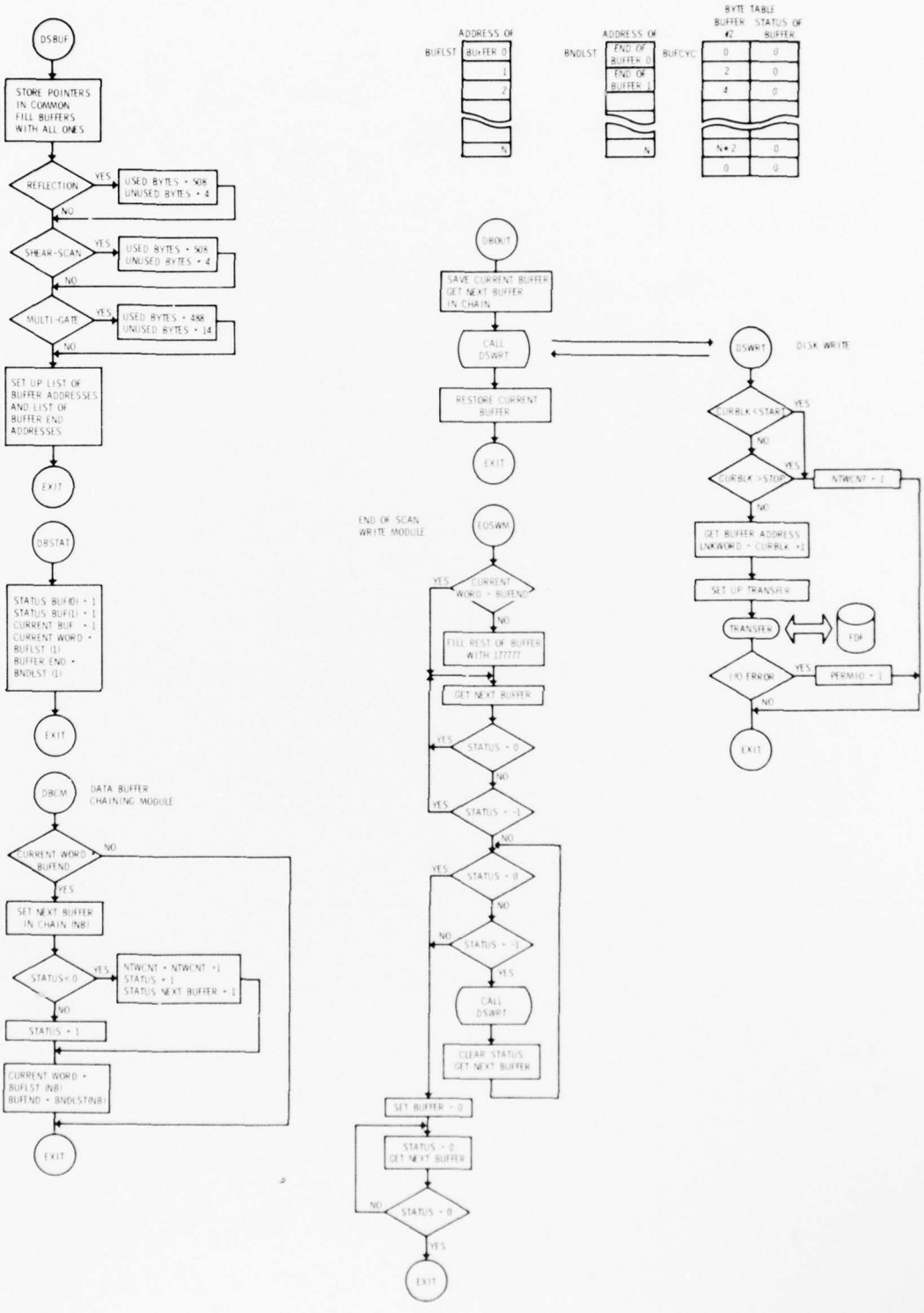


Figure 94 Flow Diagram for Real-Time Disk I/O

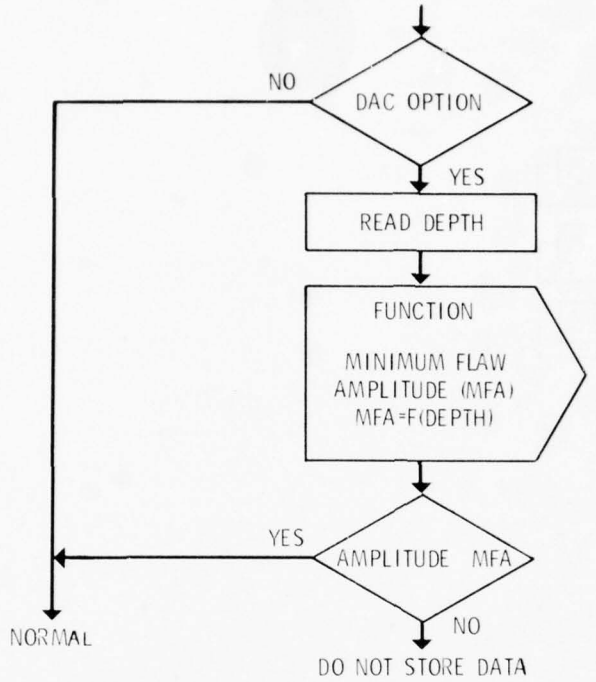


Figure 95 Flow Diagram for DAC Option in Data Acquisition

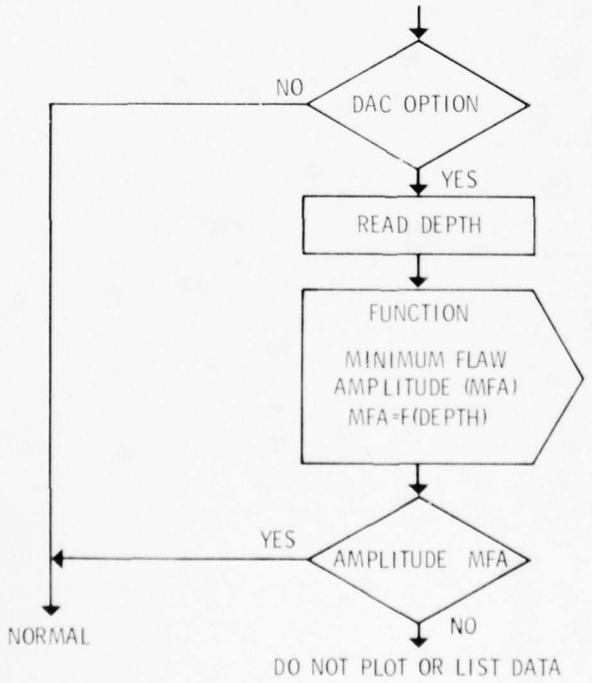
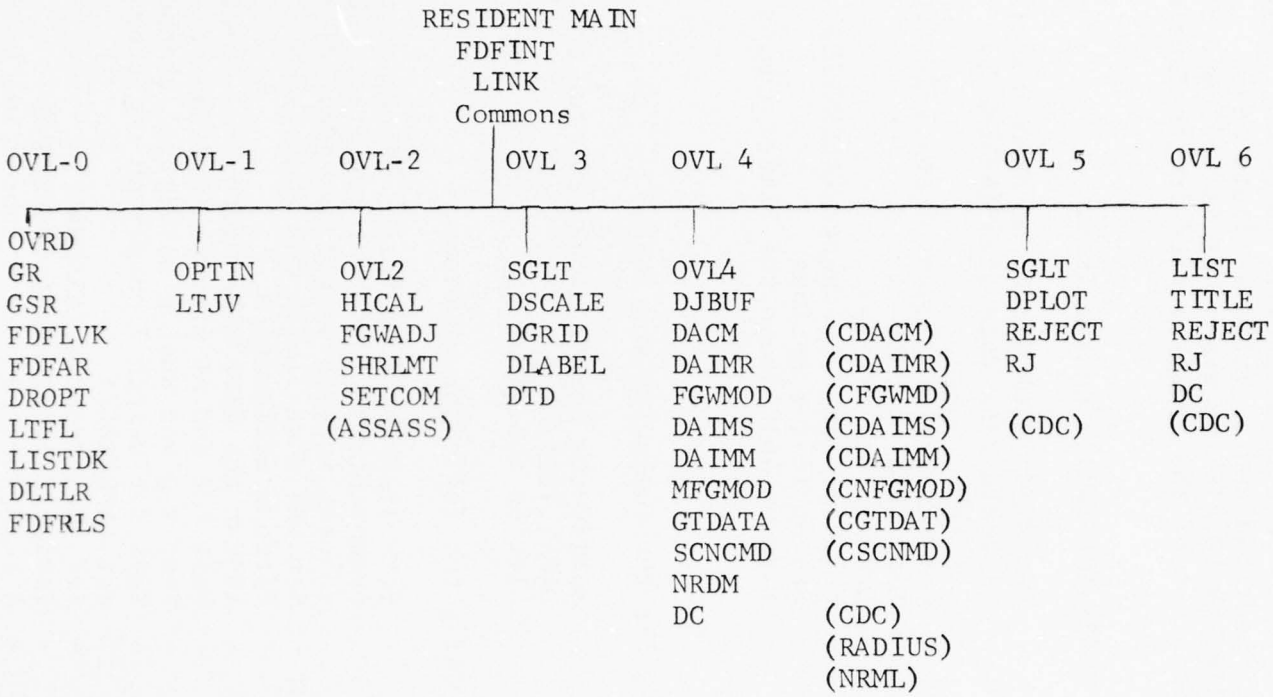


Figure 96 Flow Diagram for DAC Option in Display and List Modes

TABLE 6

RESIDENT MAIN CALL TABLE



* ( ) Denotes 0 Routines in Circular Scan (AFMLB)

AFMLA, AFMLB MAJOR ROUTINES IN EACH OVERLAY

of routines used to perform a specific function, these routines are described next. Table 7 lists major routines called by FOURIER program; it is followed by a brief description of the routines used in the Fourier program.

Overlay 0 - Calls the following routines.

FDFLUK	-	Get START/STOP blocks of data file (ASSEMBLY)
FDFAR	-	Allocate flaw data file (ASSEMBLY)
GR	-	Get RUN
GSR	-	Get START/STOP blocks of specific run
LISTDK	-	List RUNS on data disk
DLTLR	-	Delete the last run
FDFRLS	-	Release disk I/O linkage (ASSEMBLY)
DROPT	-	Select filter options
LTFL	-	List on 4010 scope the filter limits
TEKLIB		

Overlay 1 - Calls the following routines.

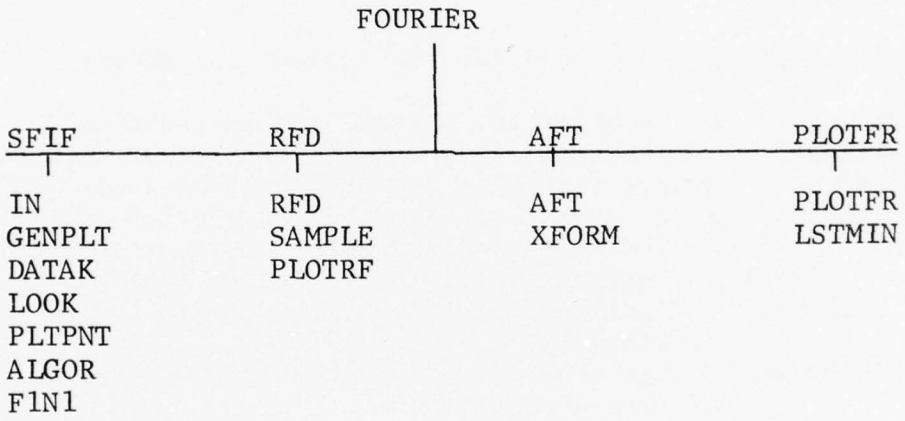
OPTION	-	Modify the header blocks for run modes of DATA, INITIAL
LTV	-	List on the scope the input options

Overlay 2 - Calls the following routines.

SETCOM	-	Set variables from header blocks to various common blocks in format required (i.e., convert integer to binary codes (decimal)
SHRLMT		Set the scan limits for shear scan
HICAL	-	Perform calibration
FGWAJ	-	Adjust the flaw gate width bias number
SYNC	-	Wait for end of ultrasonic data cycle (ASSEMBLY)
ADC	-	Read a given analog to digital channel (ASSEMBLY)
REG	-	Wait for switch 7 on switch register to be set (ASSEMBLY)
ATNOUT	-	Set the computer (ASSEMBLY)
KWIIW	-	Variable length wait (ASSEMBLY)
(ASSASS)	-	A scan/sort and store subroutine to set up breaks for the circular scan
GETTHK	-	Read value of thickness (ASSEMBLY)

TABLE 7

FOURIER CALL TABLE



Overlay 3 - Calls the following routines.

```
SGLT     - Scale, grid, label, title
  DSCALE - Selects the scales for the grid from the
           input options, optimizes the grid usage
           by rotating X and Y scales
  DGRID  - Draws the grid
  DLABEL - Labels the two axes
  DID    - Writes the labels below the grid

  TEKLIB
```

Overlay 4 - Rectangular scan calls the following routines.

```
DACM     - Data acquisition control module (ASSEMBLY)
  DAIMR  - Handles reflection mode of inspection (ASSEMBLY)
    FGWMOD - Control flaw gate and back surface (ASSEMBLY)
  DAIMS  - Handles shear-wave mode of inspection (ASSEMBLY)
  DAIMM  - Handles multiple flaw gate interrupt (ASSEMBLY)
      MFGMOD - Sorts out multiple flaw gates (ASSEMBLY)
      GTDATA - Moves multiple flaw gate data to buffer
               (ASSEMBLY)
  SCNCMD - Scanner control module, has entry points for:
           (All are ASSEMBLY)
      SCNITZ - Initialize scanner
      SCNSTR - Start scanner
      SFDBK  - Handles feedback for scanning axis
      INDEX  - Indexes scanner
      IFDBK  - Handles feedback for index axis
      SCNDIS - Stops scanner in middle of scan
      SCNMST - Restarts scanner in middle of scan
  SDCMOD - Speed control module, senses the necessity
           for increasing or decreasing speed of
           scanning axis.  Also contain entry points
           for the following: (ALL ASSEMBLY)

      SETSPD - Output initial speed
      ONEHAF - This divides the scanning speed in half
DSBUF    - Allocates the chain of buffers for disk I/O,
           also contains entry points for the following:
           (ALL ASSEMBLY)

  DBSTAT - Sets buffer status
  DBCM   - Checks buffer status
  EOSWM  - Flushes buffers at end of scanner index cycle
```

DBOUT - Initiates buffer output
DSWRT - Performs transfer to disk
NRDM - Near real time display module
DC - Convert from BCD to binary, convert time counters to distances, perform coordinate transformation

Overlay 4 - Circular scan calls the following routines.

CDACM - Similar to DACM
RADIUS - Controls scanner indexing
SETTHK - Reset flaw gate for new part thickness (ASSEMBLY)
SINDEX - Modify index value (ASSEMBLY)
NRMLIB -
CDAIMR - Handles reflection interrupt (ASSEMBLY)
CFGWMOD - Controls flaw gate (ASSEMBLY)
CDAIMS - Handles shear interrupt (ASSEMBLY)
CDAIMMS - Handles multiple flaw gate interrupt (ASSEMBLY)
CMFGMOD - Sorts out multiple flaw gates (ASSEMBLY)
CGTDAT - Stores MFG data in buffer
DSBUF - Previously described (ASSEMBLY)
CIRSCN - Controls scanner (ASSEMBLY)
NRDM - Previously described
CDC - Converts data for circular scan mode

Overlay 5 - Calls the following routines.

SGLT - Previously described
DPLOT - Display data for analysis
BLKIO - Read/write N number of words from/to block M
FDFIN - Initiate reading of a disk block N (ASSEMBLY)
FDRFD-Transfer block N from Disk 1 (ASSEMBLY)
DC - Previously described
CHIPHER - Decode the key word for multiple flaw gate mode (ASSEMBLY)
AS - Retrieve the FS/BS flag (ASSEMBLY)
REJECT - Filters the data to determine which should or should not be plotted
RJ - Performs same function for multiple flaw gate
BSP - Determines if flow was a back surface (ASSEMBLY)

TEKLIB

AD-A037 633 GENERAL DYNAMICS/FORT WORTH TEX FORT WORTH DIV F/G 13/8
COMPUTER-AUTOMATED ULTRASONIC INSPECTION SYSTEM FOR AIRCRAFT FO--ETC(U)
MAY 75 B G YEE, J S KUNSELMAN, T C WALKER F33615-72-C-1828

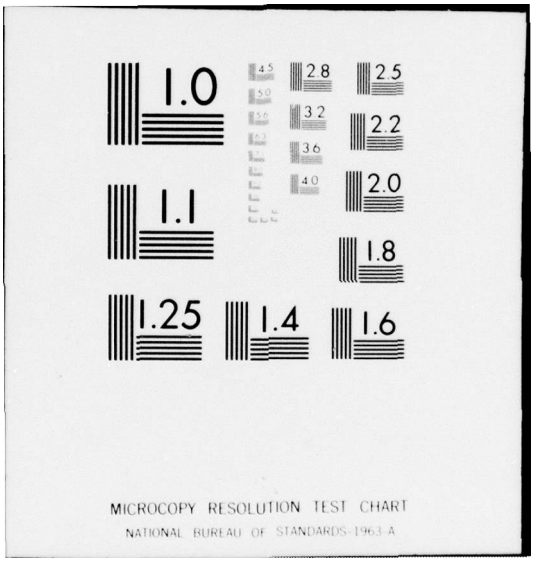
UNCLASSIFIED AFML-TR-75-82 NL

3 OF 3
ADA037 633



END

DATE
FILMED
4-77


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Overlay 6 - Calls the following routines.

LIST	-	Lists the data on 4010 scope
TITLE	-	Write title page
HDRI	-	Write line one of header
HDR2	-	Write line two of header
DC	-	Previously described

OPTLIB - This library contains the routines used to perform I/O with the teletype.

RDIN	-	Read in a fixed point number
RDFPN	-	Read in a floating point number
RDASC	-	Read in a string of alphanumerics
YESNO	-	Read in a YES (ON) or a NO (OFF) keyboard entry
CHRSCN	-	Scan through a series of characters and remove blanks
LJSTFY	-	Left justifies a string of characters
FXDATA	-	Decode a string of characters to computer fixed point words
DTB	-	Convert BCD number to binary (ASSEMBLY)
BTD	-	Convert binary number to BCD (ASSEMBLY)

TEKLIB - This library contains routines to facilitate writing and drawing graphs on the Tektronic 4010 Storage Scope

AXIS	-	Draws grid
ABOR	-	Labels grid
PLTPAK	-	Performs I/O with the scope, has entry points to draw line, plot a dot (ASSEMBLY)
PGEJ	-	Erases screen
HCPE	-	Copy screen to Tektronic 4610 Hard Copy unit
FLUSH	-	Flushes the 96 character buffer associated with the 4010 scope
WAITF	-	Flushes the 96 character buffer then waits for a key to be pressed on the 4010 scope
CRTIO	-	Output a character to scope (ASSEMBLY)

NRMLIB - Normalcy library contains routines to maintain normalcy in the peaking mode

- NORMAL - Obtain tilt angle for normalcy, increments scanner for index
  - NRML - Control search for tilt angle required for normalcy, obtain DOS number
  - PEAKER - Control scanner tilt axis and read front surface amplitude (ASSEMBLY)
  - SWEEP - Initiate scanner on tilt sweep and record tilt angle at which maximum front surface amplitude occurred
  - GDOS - Read DOS value and convert to distance (ASSEMBLY)
  - MTN - Using tilt angle calculates change in index (Y) axis and Z axis required to maintain normalcy and correct DOS (ASSEMBLY)
  - TLTCMD - Similar to peaker (ASSEMBLY)

SFIF - Search for an inclined flaw

- IN - Read in the input parameters
- SRCH - Control scanner search pattern and plotting
  - GENPLT - Draw axes, label axes
  - DATAK - Control search and data acquire
    - LOOK - Sample data and flag a flaw
  - ALGOR - Algorithm to calculate optimum incidence angle
- FINI - Write on scope coordinates at which optimum incidence angle occurred + drive scanner to that position

RFD - Radio frequency digitizer

- SAMPLE - Sets D/A and reads A/O for digitizer
- PLOTRF - Plot stored RF waveform

AFT - Analytical Fourier transform

- XFORM - Contains code for performing transform

PLOTFR - Plot frequency spectrum of transform

- LSTMIN - Lists the minimum frequency spectrum

A P P E N D I X E

S Y S T E M O P E R A T I O N

When the procedures given in this section are followed, ultrasonic inspection can be performed in near real time. Only care in choosing the proper settings on ultrasonic equipment and careful calibration adjustments are required to operate the system in either the reflected compressional or shear wave mode. A complete description of the software is presented in Appendix D.

E.1 SYSTEM START UP

A typical "start up" procedure is as follows:

Computer

1. Turn main power circuit breaker to ON.
2. Press processor switch to HALT.
3. Turn key to POWER.
4. Put in disk packs if load light is on.

   NOTE: System device is DKØ and must contain the operating system pack. The bottom line unit is designated DK1 and is used for DATA storage.

5. Position disk drives to RUN.
6. Place 173110 - in switch register.
7. Depress LOAD ADDRESS.
8. Set processor switch to HALT TO ENABLE.
9. Depress START switch.

Computer teletype response unit: (see footnote)

DOSØØ1
DOSV08-Ø2
DA 19-MAR-75 ↵
TI 07:30:00 ↵
LOG 2ØØ,2ØØ ↵

DATE: 19-MAR-75
TIME: 07:30:05

Graphic Display

1. Graphic Terminal

   (a) Turn power switch to ON.
   (b) After 10 seconds, push PAGE button (Erases the screen)

2. Hardcopy Unit

   (a) Turn power switch to ON.

Ultrasonics

1. Depress power switch (switch should light up).

Scanner System

1. Turn power switch to ON for the control and display units for all five axes.

2. Position transducer over calibration block with 3 inch water path.

*Footnote

The communication with the computer is presented in standard format used by Digital Equipment Corporation (DEC). All computer output is unnderlined while the operator-typed input is not underlined. The carriage return terminator at the end of each typed line is represented by the symbol ↵.

E.1.1 Run Mode: Initial

After the typical start up sequence has been performed as described in System Start Up, the computer corresponds with a $ as shown in paragraph E.1, showing that the DOS monitor is ready to perform the RUN commands. The initiation of the test starts with the operator typing of RUN AFML and follows with one of the following responses:

The INITIAL run mode prepares the system to start a new file for test data and consequently, it clears files of all old test data * as well as calibration settings stored in DK1. Hard copies of the desired records should be made of any scans before going into the INITIAL input string.

Since the DK1 disk is cleared by the INITIAL program, either a zeroed disk or a disk that has been used previously with the RUN AFML program has to be used. The program allocates a contiguous block of 4700 out of a total of 4800 blocks on the disk. If the disk has been used previously, the format is set so that it can be cleaned or zeroed and made ready to start over with the new data files.

An example of the Compressional Mode Initialization Communication is shown in Figure 97.

E.1.2 Run Mode: List

The LIST routine prepares a list on the Tektronix CRT of all of the test runs that have been made and stored on DK1. It shows the run number, the part number, scan type, scan mode, and percent of disk memory used for each of the runs.

The listing is used to aid the operator in identifying the runs for data retrieval and presentation. Example of the LIST procedure and of the output information is shown in Figures 98 and 99.

---

* The operator should be aware of the computer action taken after receipt of a run mode command in order to prevent a loss of old data.

```
RUN MODE = INITIAL)

SCAN MODE = REFLECTION)

RUN NUMBER : 1)
IS CALIBRATION TO BE DONE ? YES)
*1)
PART NAME : AFML TB 1)
*2)
PART SERIAL NUMBER : S/N 1)
*3)
OPERATOR : B.G.W. YEE)
*4)
TEST FREQUENCY : 5.0)
*5)
TRANSDUECER S/N : 1003)
*6)
TEST SITE : GD/FW/MRL)
*7)
SHEAR ROTATION ANGLE : 0)
*8)
REFERENCE STANDARD TYPE : 5/64 FBH)
*9)
SPEED CONTROL : OFF)
*10)
SCAN TYPE : RECTANGULAR)
*11)
TEST MATERIAL : ALUMINUM)
*12)
SCAN DIRECTION : Y)
*13)
MODE : A)
*14)
SCAN SPEED : 6.00)
*15)
INDEX SPEED : 1.00)
*16)
INDEX INCREMENT : 100)
*17)
X STOP POSITION : 12.0)
*18)
Y STOP POSITION : 27.0)
*19)
TILT OF TRANSDUCER : 0)
*20)
CRITICAL ANGLE : 5.0)
*21)
MATERIAL THICKNESS : 3.5)
*22)
STEP SIZE : 0.5)
*23)
THICKNESS DIFFERENCE : 1.6)
*24)
GATE SIZE : 4.2)
*0)
CHANGE ANYTHING ? NO)
```

Figure 97 Initial Operator Communication

```
$RUN AFMLA)
RUN MODE = LIST)
```

Figure 98 Typical LIST Communication

RUN	PART NAME	SCAN TYPE	SCAN MODE	% USED
1	TWO STEP	RECTANGULAR	MULTI-GATE	11.40
2	F--111 FORGIN	RECTANGULAR	REFLECTION	24.47
3	F-111 FORGIN	RECTANGULAR	REFLECTION	14.55
4	AFML #1 (29D	RECTANGULAR	MULTI-GATE	5.58
5	AFML TB 1	RECTANGULAR	REFLECTION	3.30
6	AFML TB 1	RECTANGULAR	REFLECTION	2.19

TOTAL USED : 61.50 %

Figure 99 : Typical Listing of Data Runs Stored on Disk

E.1.3 Run Mode: DATA

At the completion of the "Typical Start-up" procedure, the system is ready for operation. Either of two modes of operation are available. One is the initial procedure for cleaning the disk; the other is the routine method of data taking. The former is used only in re-zeroing a used disk pack. The DATA mode adds the new information to the existing data records on the disk.

Typing DATA in response to the computer question of run mode starts the data acquisition sequence. The input values from the last data cycle will be used for identifying the current data run when the operator elects to skip further inputs. An example of the communication for DATA mode is shown in Figure 100. The input values are displayed on the Tektronix scope for review, see Figure 101.

The input values are displayed again after a change has been made as shown in Figure 101. If the operator does not elect to skip the input information, he can selectively edit the information by typing YES in response to CHANGE ANYTHING. The system responds with an *. The number of the line to be changed is input and the information can be changed. In Figure 102 the operator's name has been changed. This sequence is repeated for each line to be edited.

If the test run is not terminated properly, the data will not be stored on DK1. Furthermore, the input information taken during start up will not be kept. When the program is restarted, the input files that were used for that run will be those from the last properly terminated run.

The operator can properly terminate a data run by allowing the scanner to complete its required scan or manually actuating switch 15 (raises it up to the one's position) of the computer switch register. Any other method will result in the loss of the data.

RUN MODE = DATA)

SCAN MODE = REFLECTION)

RUN NUMBER : 7)

COMMONS WRONG ? NO)

IS CALIBRATION TO BE DONE ? YES)

CHANGE ANYTHING ? YES)

* 3)

OPERATOR : JOHN S. KUNSELMAN)

* 0)

CHANGE ANYTHING ? NO)

Figure 100 Typical DATA Run Communication

```
 1) PART NAME : AFML TB 1
 2) PART SERIAL NUMBER : #1
 3) OPERATOR : JSK
 4) TEST FREQUENCY :  5.0
 5) TRANSDUCER SERIAL NUMBER : 1003
 6) TEST SITE : GD/FW/AML
 7) SHEAR ROTATION ANGLE :  0
 8) REFERENCE STANDARD TYPE : 5/64 FBH
 9) SPEED CONTROL : OFF
10) SCAN TYPE : RECTANGULAR
11) TEST MATERIAL TYPE : ALUMINUM
12) SCAN DIRECTION : Y
13) SCAN MODE : A
14) SCAN SPEED :  6.00
15) INDEX SPEED :  1.00
16) INDEX INCREMENT :  100
17) X STOP POSITION : 12.0
18) Y STOP POSITION : 27.0
19) TILT OF TRANSDUCER :  0
20) CRITICAL ANGLE :  5.0
21) MATERIAL THICKNESS :  3.7
22) STEP SIZE :  0.5
23) THICKNESS DIFFERENCE :  1.4
24) GATE SIZE :  4.2
```

Figure 101 Listing of Input Parameters Displayed for the Operator

```
 1) PART NAME : AFML TB 1
 2) PART SERIAL NUMBER : #1
 3) OPERATOR : JOHN S. KUNSELMAN
 4) TEST FREQUENCY :  5.0
 5) TRANSDUCER SERIAL NUMBER : 1003
 6) TEST SITE : GD/FW/AML
 7) SHEAR ROTATION ANGLE :  0
 8) REFERENCE STANDARD TYPE : 5/64 FBH
 9) SPEED CONTROL : OFF
10) SCAN TYPE : RECTANGULAR
11) TEST MATERIAL TYPE : ALUMINUM
12) SCAN DIRECTION : Y
13) SCAN MODE : A
14) SCAN SPEED :  6.00
15) INDEX SPEED :  1.00
16) INDEX INCREMENT :  100
17) X STOP POSITION : 12.0
18) Y STOP POSITION : 27.0
19) TILT OF TRANSDUCER :  0
20) CRITICAL ANGLE :  5.0
21) MATERIAL THICKNESS :  3.7
22) STEP SIZE :  0.5
23) THICKNESS DIFFERENCE :  1.4
24) GATE SIZE :  4.2
```

Figure 102 Display of Input Parameters After a Change

E.1.4 Run Mode: DISPLAY

The DISPLAY routine prepares a graph on the cathode-ray tube of selected test data. Data from any portion of the test specimen under inspection can be selected for display. The minimum area from the test specimen that can be selected is one square inch. Unless different input limits are input into the computer, the display is for data obtained for the entire test specimen.

A routine has been developed with the display mode to aid in data analysis. The operator is asked if he wants to input a report limit. The question is to be answered YES or NO. If the answer is NO, the display routine presents all flaw levels and display option values in the original record. If the answer is YES, the input limits will be displayed on the Tektronix CRT as shown in Figure 103.

The input limits are the X and Y values of a selected area of the test specimen for presentation on the Tektronix Display, see Figure 104. An area of the test specimen can be magnified a 1 x 1 inch area for display to a 4 x 4 inch area on the display unit. An example of display communication is shown in Figure 105.

E.1.5 Run Mode: REPORT

The selection of REPORT allows the operator to list all of the initialization data and test data in a report form. A tabular listing of all ultrasonic signals above the selected threshold level from the selected area of the test specimen will be displayed and/or copied.

In the compressional mode, the operator can select the area of interest and the threshold value for report limits. A threshold value of between 0 and 100% of the calibration value can be selected to reduce the amount of output data or aid in data analysis. For the results reported in this work, 20% of calibration value or screen height is selected as the threshold value. An example of the communication is shown in Figure 106.

```
    FILTER REMOVES FROM PLOT OF RUN 5

  VOLUME FILTER

 1) X OUTSIDE              :    0.00-12.00
 2) Y OUTSIDE              :    0.00-27.00
 3) DEPTH GREATER THAN     :    3.70

  AMPLITUDE FILTER

 4) AMPLITUDES GREATER     :     .4096
 5) AMPLITUDES EQUAL TO    :        0
 6) AMPLITUDES LESS THAN   :        0

  DEPTH FILTER

 7) DEPTHS BETWEEN         :    0.00-0.00
 8) DEPTHS BETWEEN         :    0.00-0.00
10) BACK SURFACE SWITCH    :    OFF

** SWITCH BELOW FORCES PLOTTING OF POINTS WITH A BACK SURFACE WITHIN
   THE VOLUME BEING PLOTTED

11) POINTS WITH B.S.       :    OFF
```

Figure 103 Example of Standard Filters Display

```
    FILTER REMOVES FROM PLOT OF RUN 5

  VOLUME FILTER

 1) X OUTSIDE              :    7.00- 8.00
 2) Y OUTSIDE              :    3.00- 5.00
 3) DEPTH GREATER THAN     :    3.70

  AMPLITUDE FILTER

 4) AMPLITUDES GREATER     :      4096
 5) AMPLITUDES EQUAL TO    :         0
 6) AMPLITUDES LESS THAN   :         0

  DEPTH FILTER

 7) DEPTHS BETWEEN         :    0.00-0.00
 8) DEPTHS BETWEEN         :    0.00-0.00
10) BACK SURFACE SWITCH    :    OFF

** SWITCH BELOW FORCES PLOTTING OF POINTS WITH A BACK SURFACE WITHIN
   THE VOLUME BEING PLOTTED

11) POINTS WITH B.S.       :    OFF
```

Figure 104 Example of Changed Volume Filter

```
RUN MODE = DISPLAY⟩
RUN NUMBER : 5⟩
CLEAR SWITCHES. REPORT LIMITS ? YES⟩
FILTER NUMBER : 1⟩
 1) : 7.⟩
8.⟩
 2) : 3.⟩
5.⟩
NEXT : 0⟩
LIMITS OK ? YES⟩
```

Figure 105 Typical DISPLAY Run Communication

```
RUN MODE = REPORT⟩
RUN NUMBER : 5⟩
CLEAR SWITCHES. REPORT LIMITS ? YES⟩
FILTER NUMBER : 1⟩
 1) : 7.⟩
8.⟩
NEXT : 2⟩
 2) : 3.0⟩
5.⟩
NEXT : 0⟩
LIMITS OK ? YES⟩
```

Figure 106 Typical REPORT Mode Communication

E.1.6 Run Mode: DELETE

The DELETE routine is used to remove the data from the last run from DK1. It will remove only the data from the last run on the disk. The DELETE routine can be used repeatedly to remove the test data and input information from the disk.

E.1.7 General Information on Input Commands

The part serial number and run number are used to catalog the test data. These values must be unique (distinctive and separate) for each scan. These values are used for filing the data on DK1 for retrieval later. The run numbers start at 1 and continue numerically up to a 6-digit number. However, 6 letters or any combination of unique alphanumeric characters can be used. The part serial number can be any designation up to 14 alphanumeric characters.

E.2 SYSTEM CALIBRATION

The system is calibrated for compressional wave operation by performing the following steps:

1. A reference standard which contains a flat bottom hole of the desired size, is fabricated with the same type of material as the test specimen, and is of comparable thickness to the test specimen as selected and placed in the tank.

2. The transducer is placed manually, by console controlled, or by computer control directly over the flat bottom hole. The desired distance of separation between the transducer and the surface of the test specimen is selected and input to the computer. The computer commands the Z axis motor drive to achieve this desired distance of separation.

3. The width of the flaw gate on the ultrasonic instrument is manually adjusted to accommodate the thickness of the reference standard.

4. The switches on the programmable attenuator of the ultrasonic instrument are placed in the computer position. Switch 7 on the computer console is activated. The computer will now automatically step the programmable attenuator until the ultrasonic signal from the flat bottom hole reaches a value equal to 80% of screen height.

5. The transducer is now placed over a flat or relatively flat portion of the test specimen. The computer automatically adjusts the width of the flaw gate to accommodate the thickness of the test specimen by using the arrival time of the signal from the back surface and the appropriate velocity of sound. The value of the velocity of sound has to be input to the computer.

The computer system is now initialized, calibrated, and ready for data acquisition in the reflected compressional wave mode. Figure 107 is an example of the calibration communication.

Calibration of the system for shear wave mode of operation follows similar steps. They are:

1. A reference standard which contains a elox slot of the desired size, is fabricated out of the same type of material as the test specimen, and is of comparable thickness to the test specimen as selected and placed in the tank.

2. The transducer is placed manually, by console control, or by computer control at the proper angle and distance from the elox slot. The type of material is input to the computer. The computer commands the tilt and Z axes motor drives to achieve the desired distance of separation and tilt angle for the proper shear wave angle in the material.

3. The width of the flaw gate and the position of the front surface gate (delayed mode) are manually adjusted to accommodate the thickness of the reference standard. The flaw depth switch, in the gate and logic module, is switched from compressional to shear position.

```
RUN MODE = DATA)

SCAN MODE = REFLECTION)

RUN NUMBER : 7)

COMMONS WRONG ? NO)

IS CALIBRATION TO BE DONE ? YES)

CHANGE ANYTHING ? NO)

REFLECTION CALIBRATION


***POSITION TRANSDUCER OVER REFERENCE FLAW***
***SET ATTENUATOR TO COMPUTER MODE***
***TOGGLE SWITCH 7 WHEN TRANSDUCER IN POSITION***

ATTENUATOR SETTING = 27 DB.
80% LEVEL = 3398

IS HIGH CAL ACCEPTABLE ? YES)

PLACE SCANNER OVER INITIAL POSITION. HIT SWITCH 7 TO GO

SEPARATION =     952  FGW =  12.9

IS THIS OK
YES )

MAX DOS :   1501  DELTA DOS FOR NEW SURFACE :    170
THICKNESS =  3.696  IS THIS OK ? YES)

OK ?YES)

CLEAR SWITCHES
HIT SPACE ON 4010 to GO
RUN MODE = HALT )
```

Figure 107 Example of DATA Run and Calibration Communication

4. The switches on the programmable attenuator are placed in the computer position. Switch 7 on the computer console is activated. The computer will automatically step the programmable attenuator until the shear wave signal from the elox slot reaches a value equal to 80% of screen height.

The computer system is now initialized, calibrated and ready for data acquisition in the shear-wave mode.

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