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THE CONCEPTUAL DESIGN OF A MAGNETIC TAPE SEAL SYSTEM.(U)
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"The Conceptual Design of a Magnetic Tape Seal System"

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Final Report, 22 January 1981

A thesis submitted to the University of Washington in partial fulfillment of the requirements for the degree of Master's of Science, Nuclear Engineering.

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The design incorporates a microcomputer system that is used to initially

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A preliminary analysis of the economic feasibility of the proposed seal design encourages further investigation of the magnetic tape sealing system concept for improved seal system development.

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The Conceptual Design of a Magnetic Tape

Seal System

by

Houng Y. Soo

A thesis submitted in partial fulfillment
of the requirements for the degree of

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University of Washington

1981

Approved by Norman J. McCormick
(Chairperson of Supervisory Committee)

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Abstract

THE CONCEPTUAL DESIGN OF A MAGNETIC TAPE
SEAL SYSTEM

By Houng Y. Soo

Chairperson of Supervisory Committee: Professor N.J. McCormick
Department of Nuclear Engineering

A conceptual design of a magnetic tape seal system, capable of in-situ verification, is proposed for possible applications in nuclear safeguards systems. The system makes use of magnetic recording techniques for the deposition and retrieval of identification features that are unique for every applied seal.

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A preliminary analysis of the economic feasibility of the proposed seal design encourages further investigation of the magnetic tape sealing system concept.

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CHAPTER 1

INTRODUCTION

1.1 Background

Containment and Surveillance (C/S) functions play an important role in the International Atomic Energy Agency's (IAEA) Safeguards Program, which is administered as part of the Non-Proliferation Treaty (see Appendix A). The mechanisms by which C/S functions can be accomplished include the use of personnel, instruments, and devices capable of detecting the occurrence of specific situations. These mechanisms can be categorized as seals, optical surveillance devices, passage flow monitors, integral presence indicators and human surveillance. Table 1.1 provides a summary of these C/S mechanisms along with some characteristics of each mechanism[1].

The role of the sealing device in IAEA Safeguards is increasing in importance proportionally to the number of Non-Nuclear Weapon States that are acquiring safeguarded nuclear facilities. Several research and development programs, both in the United States and abroad, are currently underway for the development of tamper-indicating, field-verifiable seals for IAEA use. These special seals (e.g. fuel bundle seals) have unique tamper-indicating characteristics and bear unique identification markings[2-10].

1.2 Scope

The purpose of this thesis is to study the feasibility and cost effectiveness of a conceptual seal design which uses magnetic tape as the medium by which a unique identification can be implanted and retrieved for verification. The seal incorporates a mechanical

TABLE 1.1 Characteristics of Containment and Surveillance Mechanisms

Mechanism	Principles of Operation	Typical Examples	Typical/Potential Applications
Seals (tamper indicating devices)	Movable segments of containment structure joined by seal which must be violated for access through sealed segments	Fiber-optic; metal; weld; defect/inclusion; paper tape	Containers for storage, shipment; reactor vessels; sample containers; process or storage areas during inspection; C/S devices
Optical Surveillance Cameras	Provide visual record of activities in defined field of view for later review to prove that material has not been removed, sequence for making and storing frames determined by required time to move objects being safeguarded (may include motion sensor to simplify analysis)	CCTV; Film	Spent fuel storage ponds, storage or process areas during inspection
Passage of Flow Monitors	Observe, record (and possibly alarm) on passage of nuclear material past a point in defined corridor, channel, pipe, etc.	yes/no monitors; Bundle counters; solution flow/level monitors; portal monitors	Personnel/equipment passages near on-load power reactors which should not be used for fuel transport; flow indicators for on-load reactors, reprocessing plants
Integral Presence Indicators	Observe (and possibly record) various phenomena arising from presence of specific nuclear material quantities in specific configurations	Neutron physics parameters e.g. reactor power level, flux distribution, energy spectra, reactivity etc.	Power and research reactors, critical facilities; stores of nuclear material in defined arrays; hold-up monitors, attribute check instruments
Human Surveillance	Observe, record, assess and act on various information related to safeguards		All safeguards activities

(From T. Shea and D. Tolchenkov, "Role of Containment and Surveillance in IAEA Safeguards," Nuclear Safeguards Technology (Proc. Symp. Vienna 1978), Vol. I, IAEA, Vienna, 1979) fastening system with a suitable identification and verification system into a seal system.

The design objectives set for the conceptual seal system were as follows:

(a) The seal and sealing system should be as physically secure as current designs.

(b) The seal should be capable of being uniquely coded and identified in the field.

(c) The seal identification should be repetitively recoverable without damaging or removing the seal after its application.

(d) The method of verification should be quick, simple, and without an excessive amount of supporting equipment.

(e) The seal should be simple in design, easy to manufacture, and relatively inexpensive in cost.

(f) The seal should not be affected by shelf-life limitations nor affected by deterioration of a power source.

This thesis is organized into six chapters. Chapter 2 will present the fundamental concepts of seal employment, an overview of the general trends and current status of security seal research and development, and an overview of the proposed seal system design. The conceptual development of the proposed magnetic tape seal system is described in Chapters 3 and 4. In Chapter 3, the seal support system is outlined, while in Chapter 4, the seal device design is described. The economic feasibility of the system is evaluated in Chapter 5 and, finally, recommendations for future work and conclusions are presented in Chapter 6.

CHAPTER 2

SEALING FUNDAMENTALS AND CURRENT DEVELOPMENTS

2.1 Introduction to Seals and Sealing Systems

The use of seals to protect objects and authenticate documents can be traced back to Biblical times. The early Egyptians extensively used clay seals for the protection of cabinets, rooms, sarcophagi and tombs. Then, as now, the concept of seal employment was predicated on the principle that the contents of a sealed container can be considered intact when the applied seal integrity is not violated[11].

Security seals are devices which are applied at convenient locations to indicate tampering and/or unauthorized entry. They are the part of a sealing system (or safing system) which encompasses the procedures, techniques and devices used in the procurement, storage, identification, application, removal and verification of the integrity of the seal[10-12].

The purpose of the sealing system is twofold. The first is to provide confidence that no tampering or entry has occurred during the period that the seal has been in service. The degree of confidence will vary directly with the effort and time required to compromise or defeat the seal. Also, the level of confidence increases with the amount of additional activities which must be undertaken to obtain or fabricate a counterfeit seal, which might be used to conceal an entry. The second purpose is to serve notice that security measures are in effect; such activities could psychologically deter weakly motivated intruders from continuing further[10-12].

2.2 Possible Modes of Seal System Failure

Seals and sealing systems, like other means of detection and protection, offer no absolute guarantees against failure. A sealing system can fail if the applied seal can be opened and reclosed without leaving any marks that would indicate tampering. Since all seals are characteristically frangible, this possible mode of failure is unlikely to occur(10-12). A more probable cause of seal system failure is the improper placement of the seal. This situation may be prevented by insuring that the container, room or device to be secured is itself tamper proof. The point of affixation must then be carefully chosen to insure that tampering will be indicated.

Another situation that could lead to sealing system failure is the availability of blank seals which could be substituted. Seal blanks possibly could be stolen, fabricated, or otherwise obtained by a potential intruder. This situation can be prevented by the establishment of procedures to account for unused seals and the destruction of used seals.

To prevent failures of the sealing system, it is important to ensure that unique identification features can be applied to seals in use. This effectively gives each seal a unique "fingerprint" which serves to minimize the possibility of undetected substitution. Several proposed techniques on fingerprint application and identification are currently under investigation for possible incorporation into sealing systems(2-10).

Finally, violation of a seal's integrity may go unnoted unless periodic inspections are conducted to verify the status of the applied seals. Inspection also serves the purpose of detecting seal substitution if in-place (in situ) means of verification can be carried out by the inspector.

In short, in order for a seal to be effective, it must be securely affixed to the object it is securing, the method of attachment must be irreversible and the seal must be readily identifiable in the field when periodically inspected for integrity.

2.3 Current Developments in Seal Technology

For commercial (non-nuclear) applications, a number of different seals are readily available, as shown in Figure 2.1. As of this writing, only one of these seals, the type E wire and cup seal, is recommended for use by the Nuclear Regulatory Commission (NRC) for securing special nuclear materials (SNM)[12]. The same seal is also currently in use by the IAEA Safeguards Directorate for safeguards applications[3, 10].

The type E seal is uniquely fingerprinted by the inscription of a random pattern scratched on the inside of the metal cup prior to application. A photograph of the markings is then taken to provide a record of this inscription. Procedures for a post-mortem examination include the dissection of the seal and comparison with the record in order to validate the fingerprint[13].

The label seal, shown in Figure 2.2, is another type of seal that is used by both the NRC and IAEA[7, 10]. This seal is not uniquely identifiable, and because of its characteristics, is used for specialized purposes[14].

Exploratory work began in the late 1960's to develop improved seals

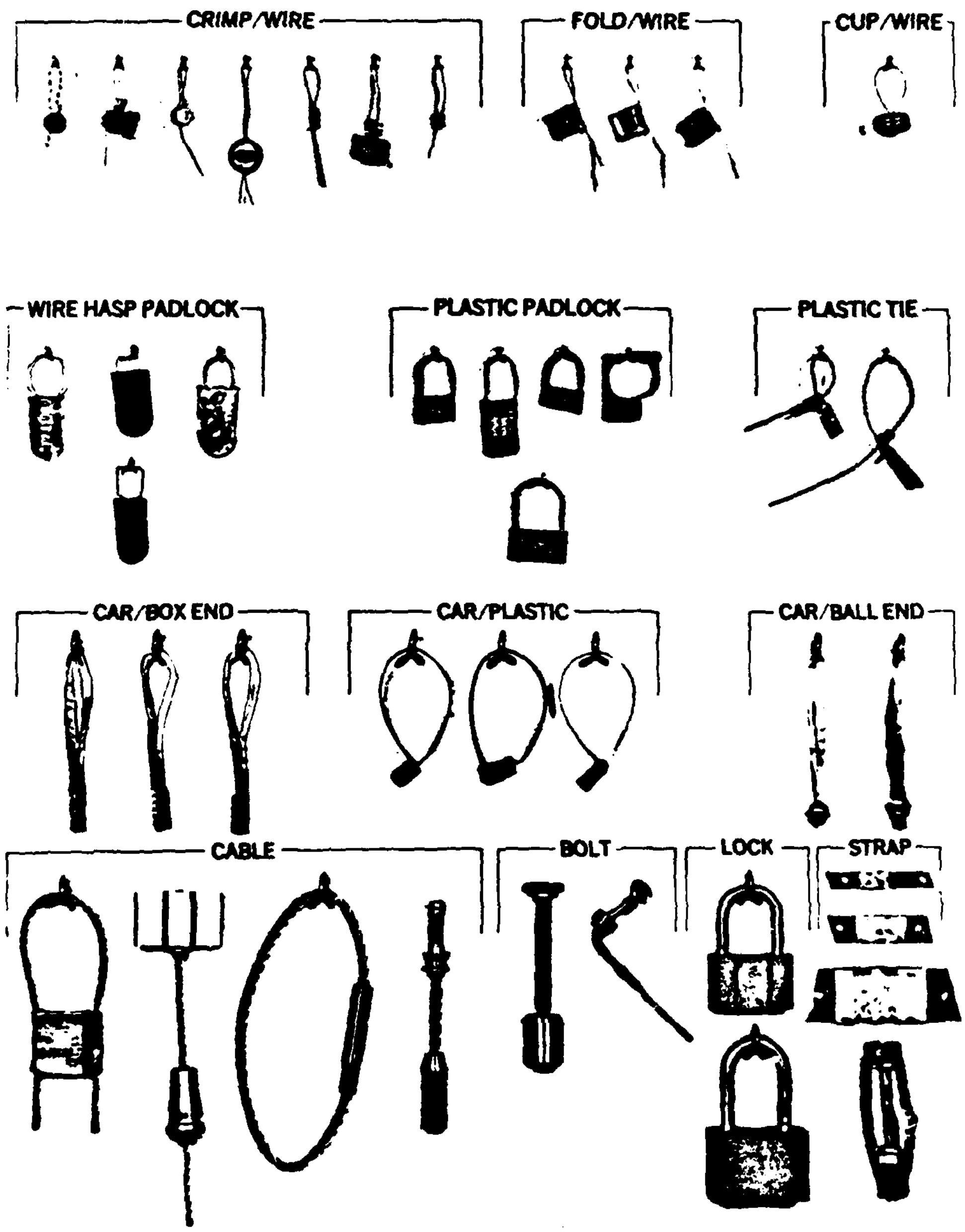


FIGURE 2.1 Commercially Available Seals (From D.L. Poli, "Security Seal Handbook," Sand 78-0400, Sandia Laboratories, Albuquerque, New Mexico, 1978)

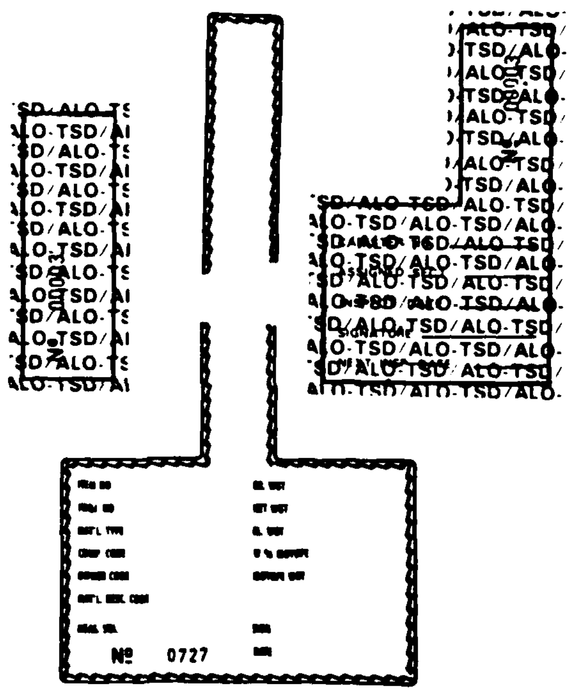


FIGURE 2.2 Label Seal
(From D.L. Poli, "Security Seal Handbook," SAND 78-0400, Sandia Laboratories, Albuquerque, New Mexico, 1978)

which incorporated unique identification features and were capable of being field verified. Two prototypes were introduced by Crutzen of EURATOM (Ispra)[15] and Steif of the United States Arms Control and Disarmament Agency[3]. These two prototypes represented the two fundamental approaches to seal development which dominated research and development efforts for the next decade.

The EURATOM approach was based on the application of ultrasonic scanning techniques to uniquely identify applied seals. Several types of special usage seals (eg, fuel bundle seals, fuel pin cup seals) and a general purpose seal were developed. Unique marking of the seal was made possible by the introduction of randomly distributed inclusions within the seal. A signature can be obtained by ultrasonic scanning of the seal with a specially designed transducer apparatus. A combination of photographic, analog, and/or digital outputs are obtainable; verification is accomplished by comparing the results of an interrogation scanning with previous records[2].

The United States Arms Control and Disarmament Agency, on the other hand, introduced a multistrand fiber optic bundle seal which was uniquely identifiable by the random orientation of individual fiber optic strands within the bundle. The random pattern of the intermingled fiber optic strands can be photographed using an applied light source at one end. Subsequent verification of the identity of the seal can be accomplished by comparing a photograph of the bundle with the original photograph[3].

In the early 1970's, several other improved seal prototypes were introduced to the safeguards community. Illustrations and specifications of these prototypes and some interesting conceptual designs have been presented by Poli of Sandia National Laboratories[10, 17]; a summary of some characteristics of these developments are provided in Table 2.1.

As of this writing, the EURATON ultrasonic tamper resistant seal is in limited use by EURATOM and is being considered for possible use by the IAEA. Some testing has already been conducted by placing ultrasonic seals on the fuel bundles in a 600 MW CANDU Reactor, and encouraging results were obtained[4]. Development of in situ ultrasonic verification techniques are currently being investigated to improve the seal system[16].

The fiber optic seal development program is now administered by the Sandia National Laboratory under the sponsorship of the Department of Energy and the Program of Technical Assistance to the IAEA[16]. An improved fiber optic seal, capable of in situ verification, is in the final stages of development and will soon be tested by the IAEA. Also being investigated by Sandia National Laboratory are modifications to the type E seal in an effort to improve it[16-18]. Finally, the International Safeguards Division of Sandia National Laboratory is developing a new seal design (tentatively named the type "X" seal) which will be introduced in the near future[16].

2.4 Overview of the Proposed Seal System

The conceptual seal system proposed here uses magnetic tape as the medium onto which a unique seal label can be transcribed, and later verified during use. Magnetic recording is a simple and inexpensive

TABLE 2.1 Summary of Characteristics of Improved Seals under Development

Seal Type	Seal Construction	Seal Attachment Method	Verification System	Unusual Environmental Limitations	General Comments
Passive Fiber Optic Fiber-Lock Corp. USA	Plastic body	Fiber optic bundle-fixed length	Photomicrographic in-situ adapt. for RECOVER	Fiber optic material limitations such as radiation, bend radius, etc.	Verification system is bulky
Active Fiber Optic Sandia Laboratories USA	Plastic housing containing electronics	Fiber optic bundle-fixed length	Visual read. of coded elec. output in-situ	Restricted on outdoor use & fiber optic limitations	Good tamper resistance
Active Fiber Optics Julich KFA	Metal case containing electronics	Fiber optic bundle-fixed length	Adapter box and separate computer	Restricted on outdoor use & fiber optic limitations	
General-Purpose Joint Research Centre Ispra, Italy/ EURATOM	Plastic or metal housings with high density inclusions	Stranded wire variable length	Ultrasonic in-situ or at Hdqrs.	None	IAEA has requested evaluation. Limited use by EURATOM
Fuel Assembly Joint Research Centre Ispra, Italy/ EURATOM	Metal housing with inclusions	Screw, snap-on rivet, & weld-fixed size	Ultrasonic in-situ including underwater	None	Four different systems are in development

TABLE 2.1 Summary of Characteristics of Improved Seals under Development (Cont.)

Seal Type	Seal Construction	Seal Attachment Method	Verification System	Unusual Environmental Limitations	General Comments
Linear Array Atlantic Research Corp. USA	Metal or plastic bolt together housing	Fiber optic bundle-fixed length	Electronic in-situ & adapt. for RECOVER	Fiber optic material limitations	First prototypes available by 7/79 for evaluation
Fuel Assembly Ident. Device Sandia Laboratories USA	Metal housings with high density in-clusions metal link	Screw, snap on & welded fixed size	Ultrasonic eddy current in-situ including underwater	None	Three different systems are in early develop-ment
Tamper-Indicating Reusable Argonne National Lab. USA	Plastic housing con-taining colored balls	Stranded wire-variable length	Visual in-situ	None	Too complicated reusability not required
Passive Fiber Optic Harry Diamond Lab. USA	Compression collar type housing	Fiber optic bundle-fixed length	Photomicro-graphic in-situ	Fiber optic material limitations	System difficult to install & verify

(Extracted from D.L. Poli, Characteristics of Seal Systems for International Use, Unpublished Notes, Sandia Laboratories, Albuquerque, New Mexico) technique for information storage and retrieval that is practically invulnerable to environmental conditions. Magnetic recording technology is highly developed, readily available and easily adaptable to on-location processing by the use of microprocessor based microcomputer systems.

Figure 2.3 is a block diagram of the major components of the seal system. The seal is an integrated system that consists of a mechanical fastening system, a mechanical counter and an identification tape that is encapsulated in a plastic housing. The details of the seal configuration will be discussed in Chapter 4.

The labeling and interrogation unit (LIU) is the support system for the magnetic tape seal. It serves the dual function of initially "labeling" the seal, at the time of application, by transcribing a unique identification message onto the seal's magnetic tape and "interrogating" the seal to validate its integrity during seal verification inspection. The LIU consists of a microcomputer system and a seal interface device, the design of which will be discussed in Chapter 3.

The seal identification message is structured in such a way that it uniquely identifies an individual seal in a format that can be interpreted by a digital information processing system. The format selected consist of two information segments. The first segment is a visual seal serial number which is uniquely assigned during the manufacture of the seal. The second segment is a unique identification which is generated at the time the seal is applied.

The seal serial number identifies a particular seal within the seal

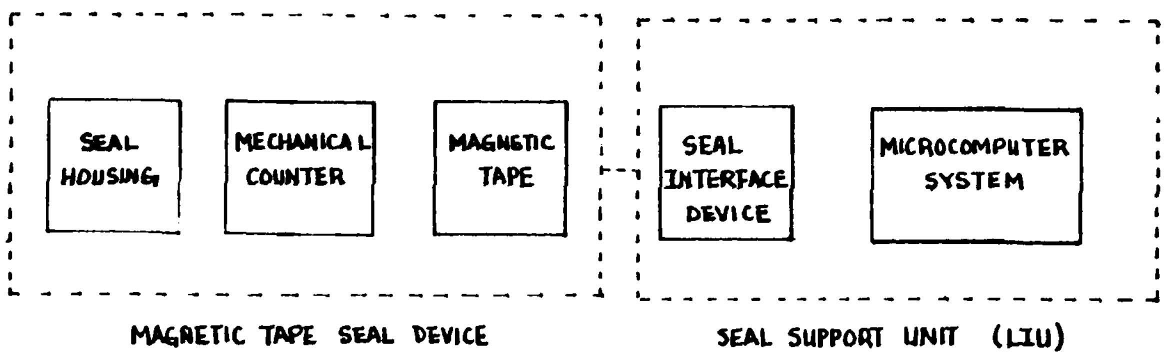


FIGURE 2.3 Block Diagram of the Basic Components of Magnetic Tape Seal System

system, while the unique identification message insures that a substitution of the seal has not occurred. The seal serial number, inscribed on the exterior of the seal to facilitate rapid visual seal identification, requires the capability for manual input of the serial number into the LIU by the inspector at the time of inspection and verification. Use of the seal serial number as part of the identification message also provides a means for information management with the LIU's memory file.

The process by which the identification message can be structured, recorded in the LIU's memory, and labeled on the seal is illustrated in the flow chart of Figure 2.4. The seal serial number is input by manually using a keyboard on the LIU. A 50 digit pseudorandom number is then generated within the LIU by means of a pseudorandom number generator program based on the congruence method for generating random numbers (see Appendix B). The complete message is then formed by combining the seal serial number and the 50 digit pseudorandom number. The message is simultaneously stored in the LIU's memory file for verification purposes at a later date and transcribed on to the seal's magnetic tape using the seal interface device. The entire operation takes place within the LIU's microcomputer, and the message would be concealed from the user; this provides an added degree of protection against a compromise of the seal system by the operator.

The process by which the seal is queried and validated is illustrated in the flow chart of Figure 2.5. The inspector inputs manually the seal serial number, then the seal interface device is used to "read" the contents of the seal tape into the LIU. The LIU's

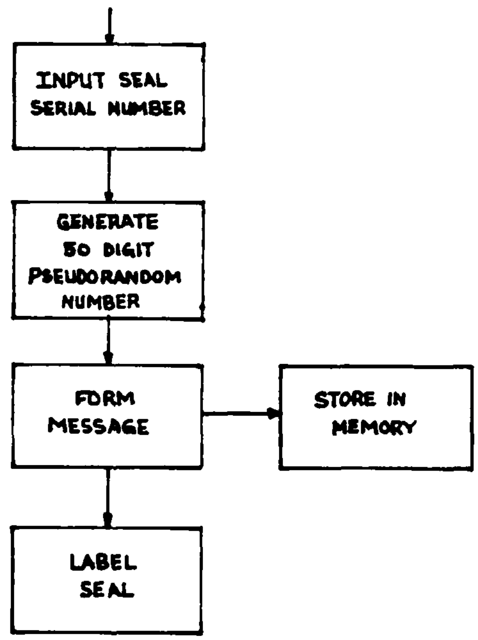


FIGURE 2.4 Flow Chart of Seal Labeling Process

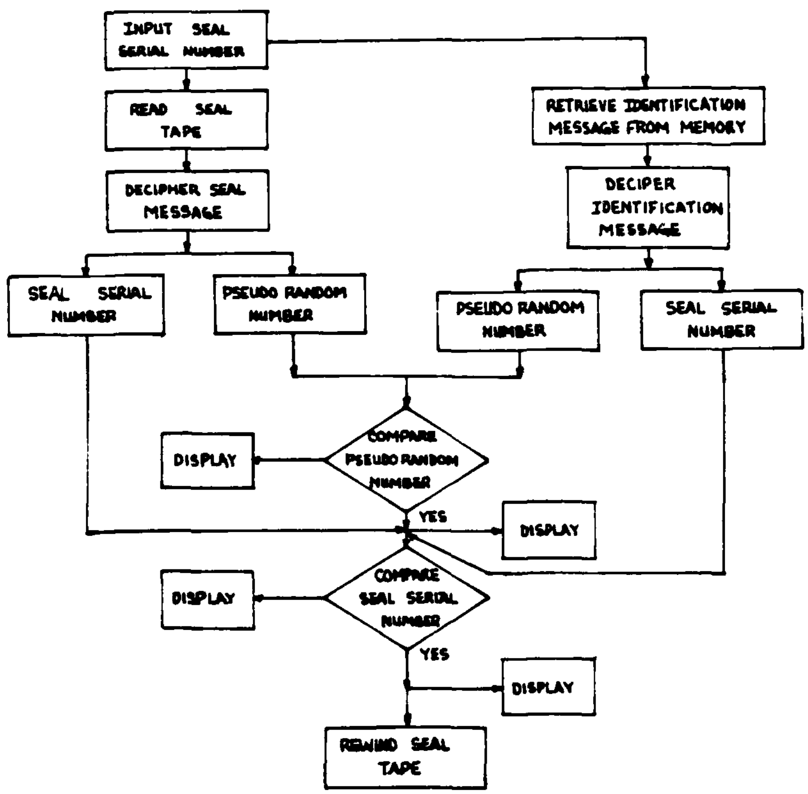


FIGURE 2.5 Flow Chart of Seal Labeling Process

microcomputer searches its memory file for the appropriate seal message using the seal serial number as the flag for the message. Once the message is found, the microcomputer will compare the seal serial number and the seal identification message of the input and memory. Verification would occur when all the input information and memory information matches. The operator of the LIU is notified by a visual display of the veracity of the seals integrity. If either the visual serial number on the seal exterior or the seal's identification message does not match with the LIU's memory file, this would be displayed on the LIU to indicate that the verification sequence failed. The procedure of reading the seal message into the LIU ends by rewinding the seal tape.

CHAPTER 3

DESIGN OF THE LABELING AND INTERROGATION UNIT

3.1 General Discussion

A support system is required to initially label the magnetic tape seal and to validate its identity and integrity during periodic seal inspections. Some desirable characteristics include field portability, small size, simple user operation, and moderate cost. A system block diagram of the seal support system, the labeling and interrogation unit (LIU), is shown in Figure 3.1.

The LIU is basically a microcomputer system consisting of a main central processing unit (CPU), a read only memory (ROM), a random access memory (RAM), a long term memory storage device, a keyboard and display subsystem, and a seal tape interface subsystem.

The system design takes advantage of predesigned microcomputer subsystems that are currently available from microprocessor manufacturers. In particular, the Intel Corporation's microprocessor family was selected as the basic building block of the LIU's microcomputer system. This choice was based on the availability of predesigned microcomputer interface devices and the availability of literature on system interfacing[19-25].

Field portability is achieved by the use of rechargeable nickel-cadmium batteries for the power supply. The total weight of the power supply is approximately 7 pounds[26]. A bank of 8 Eveready N-91 Ni-Cd batteries connected in parallel is capable of delivering 2.4 amperes for 4 hours which should be sufficient to permit 8 hours of normal intermittent usage.

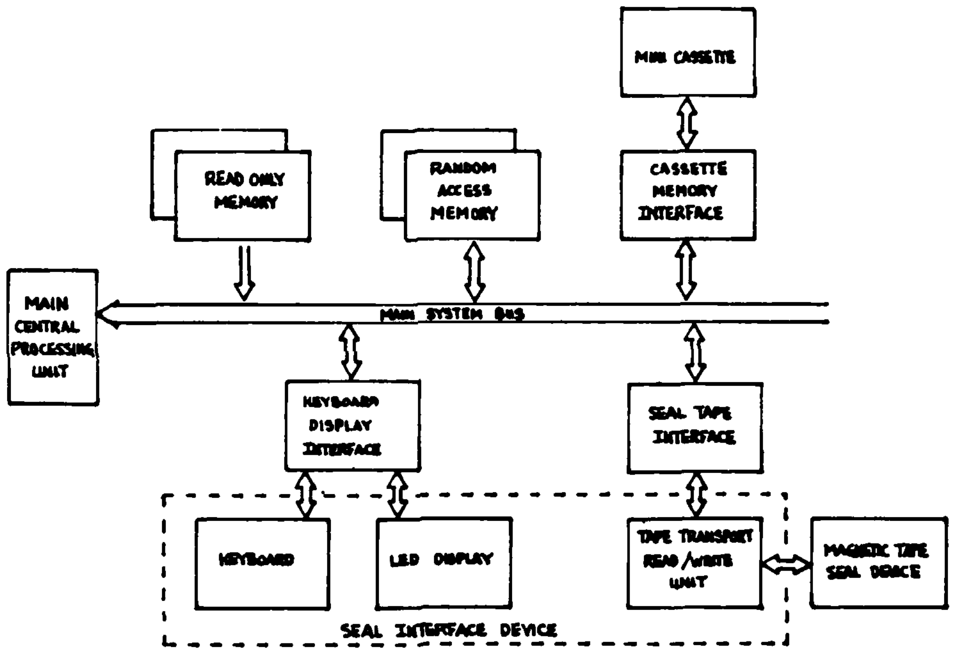


FIGURE 3.1 The Labeling and Interrogation Unit System Block Diagram

A 110/220 volt 50/60 Hz recharging system is also provided to permit overnight recharging of the power pack. The recharging characteristics of the N-91 Ni-Cd batteries will require a charging time of 14 hours at 100 mA when the power pack is completely discharged.

Figure 3.2 illustrates the power system to be used in the LIU. A terminal voltage of 5 volts ± 5% is required by the microcomputer system. A low voltage indicator designed into the power circuit is triggered when the terminal voltage goes below 4.75 volts[27, 28].

The microcomputer-based LIU is envisioned to be packaged in a small and compact case with the same dimensions of a medium sized attaché case. The seal interfacing device will be hand portable and attached to the LIU case by means of a retractable umbilical cord. When not in use the seal interface device would be stored in a compartment of the LIU. A conceptual drawing of the LIU components is presented as Figure 3.3.

3.2 Microcomputer System Description

The central element of the LIU's microcomputer system is the Intel 8085 central processing unit (CPU). This chip is an improved version of the widely used Intel 8080 microprocessor chip and is compatible with the Intel family of microprocessor chips, memory devices, and peripheral interface devices. The 8085 is an 8-bit parallel central processor which contains an arithmetic and logic unit, an accumulator, a control unit, a clock and associated buffers as shown in Figure 3.4.

The heart of the CPU is the arithmetic and logic unit (ALU) where the arithmetic operations and instruction information are received and implemented. The accumulator serves as a temporary register and acts as a scratch pad for the CPU. The control unit directs the flow of data

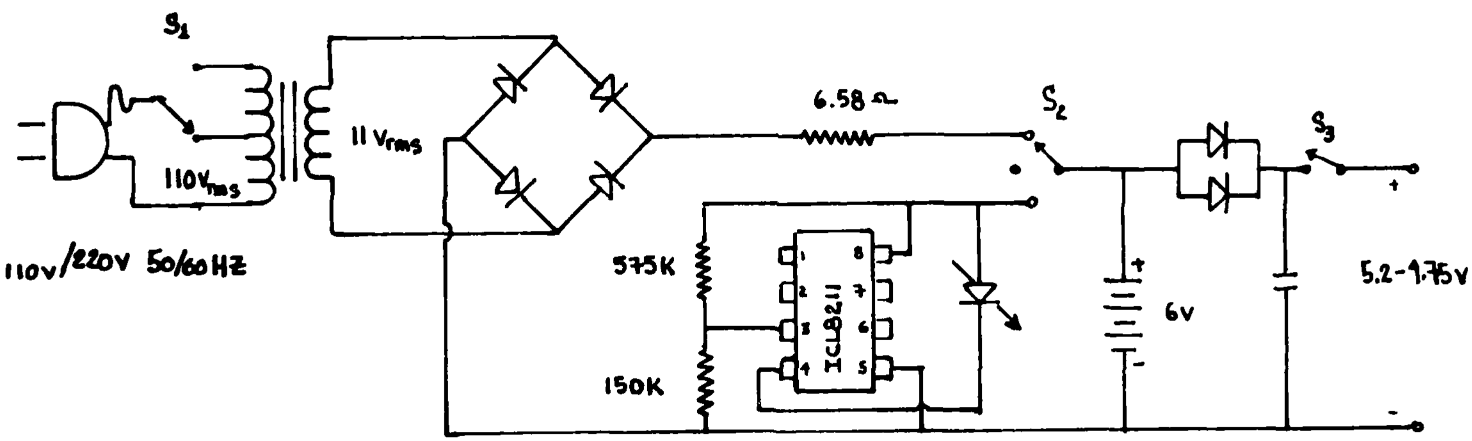


FIGURE 3.2 Microcomputer Power Supply Schematic Diagram

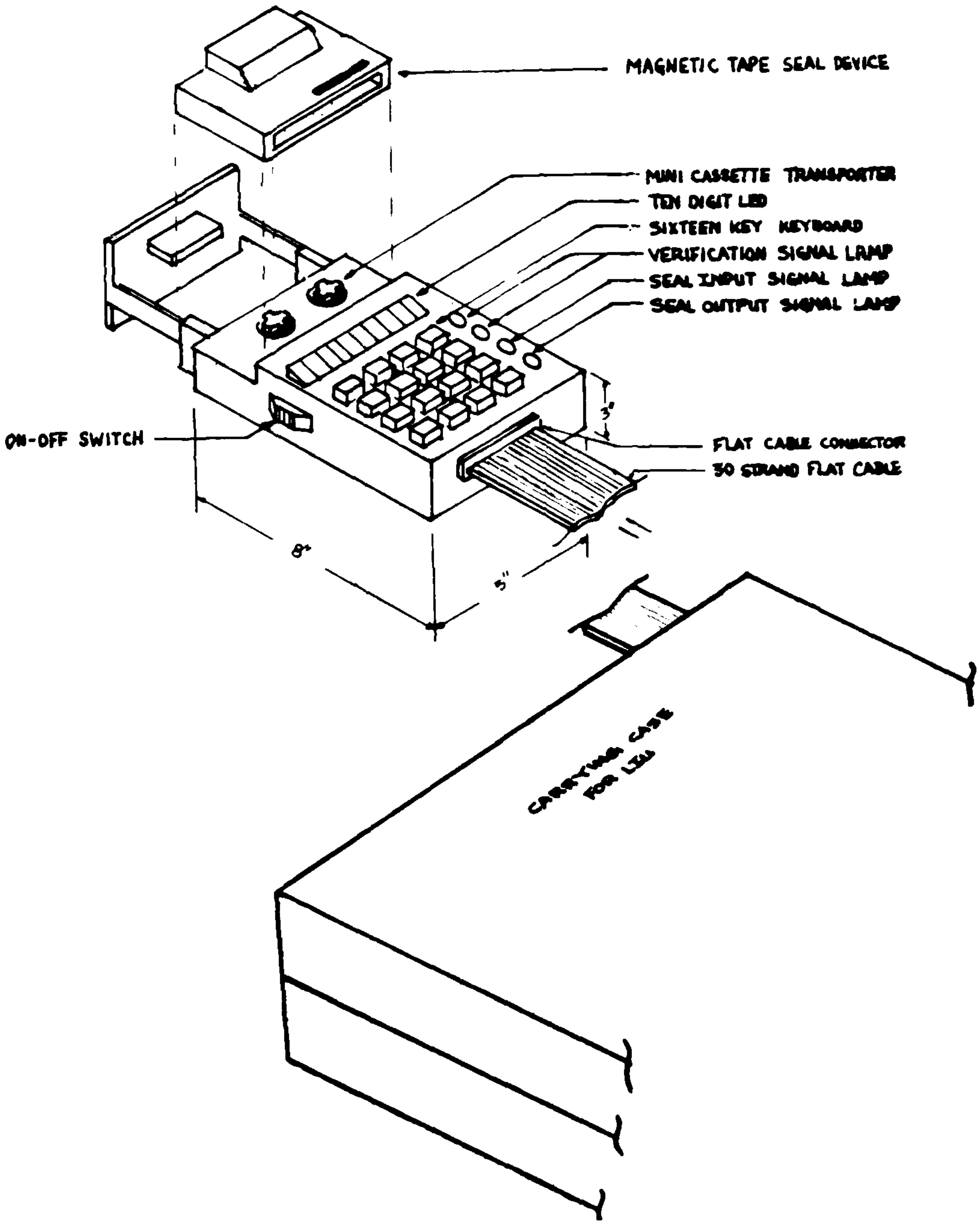


FIGURE 3.3 Conceptual Configuration of the LIU

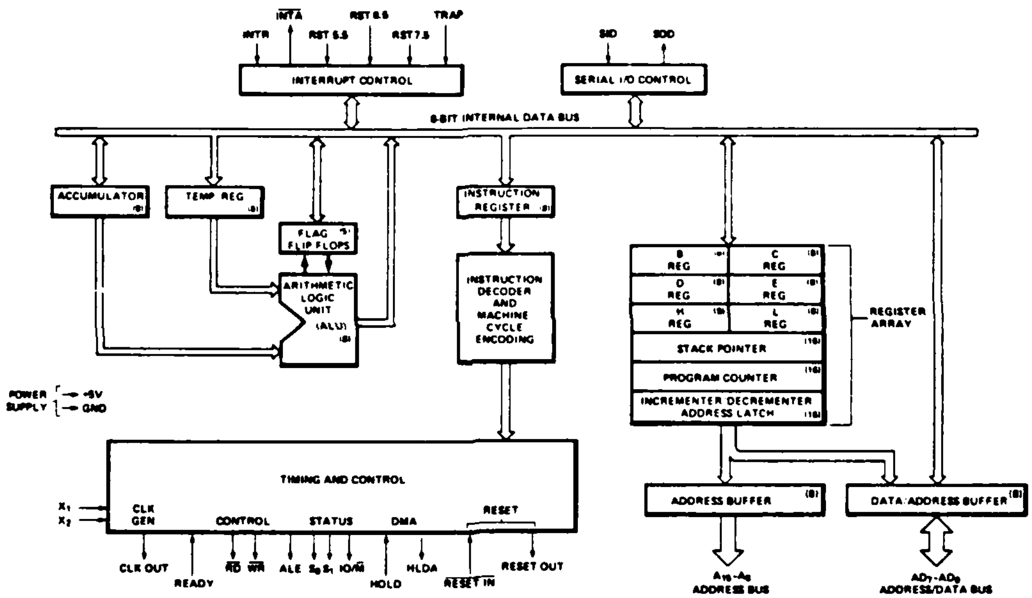


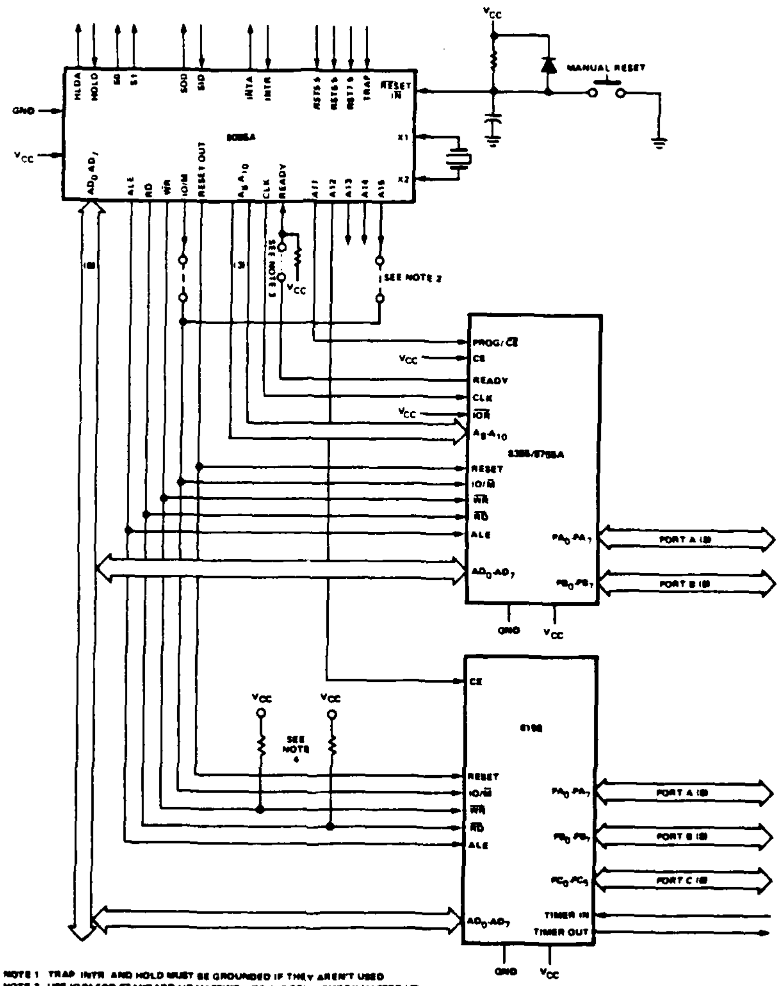
FIGURE 3.4 Intel 8085 Functional Block Diagram (From MCS-80/85 Family User's Manual, Intel Corp.)

and instruction bits from register to register and to the ALU. The buffer isolates the CPU from other devices in the system and acts as a holding area for data and instruction bits prior to transmission on the main system bus. The clock times all the operations of the CPU and serves as a reference for system operations. An external crystal is required for the 8085's clock.

Illustrated in Figure 3.5 is the minimum system configuration of an 8085 microcomputer system detailing the required supporting memories and pin connections. As shown, the data and address bus of the 8085 is multiplexed to reduce the number of pins (and hence connectors) required. Normally 8 data pins and 16 address pins are required, but by using a multiplexed bus only 16 pins are required. Notice that a multiplexed read only memory and a multiplexed random access memory is used to form the system.

Standard (24 data and address pin) read only memory chips and random access memory chips will require the use of a latch chip, connected between the CPU and the memory chips to demultiplex the 8085 data and address bus[21], into two standard separate data and address components.

A bank of read only memories (ROMs) will store the required instruction programs to operate the LIU. A ROM is a nonvolatile memory device that does not lose information stored in the chip when power is disconnected. Two types of ROMs are available, a mask programmable ROM that is permanently programmed during the manufacturing process and a programmable read only memory (PROM) which can be custom programmed by the user after the chip is manufactured. This second type was selected



NOTE 1 TRAP INTR AND HOLD MUST BE GROUNDED IF THEY AREN'T USED
NOTE 2 USE IO/M FOR STANDARD I/O MAPPING USE A15 FOR MEMORY MAPPED I/O
NOTE 3 CONNECTION IS NECESSARY ONLY IF ONE T_{WAIT} STATE IS DESIRED
NOTE 4 PULL UP RESISTORS RECOMMENDED TO AVOID SPURIOUS SELECTION WHEN $\overline{RD}$ AND $\overline{WR}$ ARE 3 STATED THESE RESISTORS ARE NOT INCLUDED ON THE PC BOARD LAYOUT OF FIGURE 3-7

FIGURE 3.5 Minimum System Configuration of an 8085 Microcomputer System (From MCS-80/85 Family User's Manual, Intel Corp.)

here for its versatility.

The Intel 8755A/8755A-2 erasable and electrically reprogrammable read only memory (EPROM) with a capacity of 16 K bits (2048 bytes x 8 bits) has been selected for use in the main microcomputer system. This particular chip is custom programmed using an Intel Universal PROM Programmer[21]. The EPROM program can be erased by exposure to an ultraviolet light source having a wavelength of 2537 Angstroms and reprogrammed with a new program. This feature will be extremely useful during system development and allows for customizing of the seal system for different users.

The block diagram of the 8755A/8755A-2 EPROM is illustrated in Figure 3.6. The 8755A/8755A-2 EPROM was designed to be directly compatible with the 8085 CPU.

The total number of EPROMs required in the main microcomputer system will depend on the size of the required machine language instruction programs. At least two programs, a labeling program and an interrogation and verification program will be needed. Separate EPROMs should be dedicated to each program to permit selection by the user of either the labeling or interrogation operation. For the purpose of this initial system design, two EPROMs are required, one for each operation. Additional EPROMs could be added in parallel if additional instructional memory were required.

The information handling or data processing capacity of the LIU's microcomputer system will be determined by the size of its random access memory (RAM) device. The RAM serves as an information storage device for the CPU and is used for both input and output data (to and from the

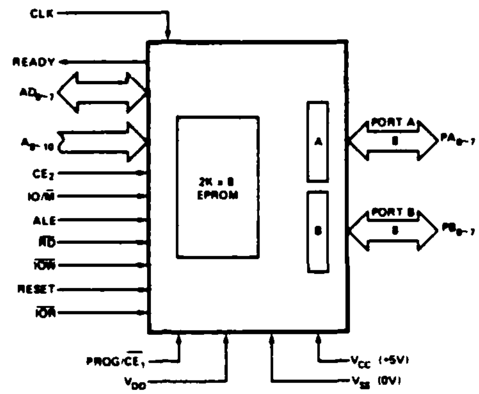


FIGURE 3.6 Intel 8755A/8755A-2 Block Diagram (From MCS-80/85 Family User's Manual, Intel Corp.)

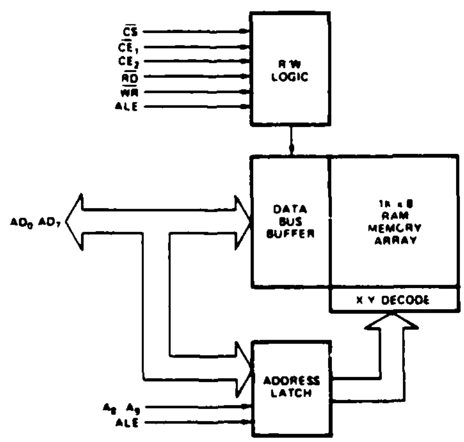


FIGURE 3.7 Intel 8185 Block Diagram (From MCS-80/85 Family User's Manual, Intel Corp.)

CPU). The information stored in the RAM is volatile and will be lost when power is disconnected.

A capacity of 1 K bytes (1024 bytes x 8 bits) can be obtained by using an Intel 8185 STATIC RAM. The block diagram of the 8185 is illustrated in Figure 3.7. The 8185 uses a multiplexed address and data bus which is directly interfaced to the 8085.

Because the system's RAM is volatile, a long term memory storage device for the LIU is required. A particularly suitable tape storage subsystem that is compatible with the LIU's microcomputer system consists of a Braemar CM-600 Mini-Dek minicassette transport and an Intel 8741A/8041A digital cassette controller[23, 24]. This subsystem was designed by Intel Corporation to provide a low cost, non-volatile, high capacity memory storage for microcomputer systems. The subsystem is ideal for the LIU because of its small size, microcomputer controlled automatic operation and compatibility with the 8085 main system CPU.

The minicassette used is similar to, but not compatible with, commercially available dictation cassettes. The minicassette contains approximately 100 feet of tape and provides a capacity of 200 K bytes of storage when both sides of the tape are used. The characteristics of the Braemar CM-600 Mini-Dek minicassette transport are presented in Table 3.1 while the block diagram of the Braemar CM-600 is presented in Figure 3.8.

The controller is a self contained microcomputer based Universal Peripheral Interface (UPI) device marketed by Intel Corporation as the Intel 8741A/8041A digital cassette controller. As illustrated in Figure 3.9, the 8741A has its own instruction program and it interfaces

TABLE 3.1 Characteristics of the Braemar CM-600 Mini-Dek

Single head	
Single motor	
Power requirements	
read/write	5 volts 200 mA
rewind	5 volts 700 mA
Tape speeds	
read/write	3 inches per second (IPS)
fast forward	5 inches per second (IPS)
rewind	15 inches per second (IPS)
Maximum recording density	800 bits per inch (BPI)
Maximum data rate	2400 bits per second (BAUD)
Size	3" x 3" x 2.5"

(Extracted from Intel Peripheral Design Handbook, August 1980)

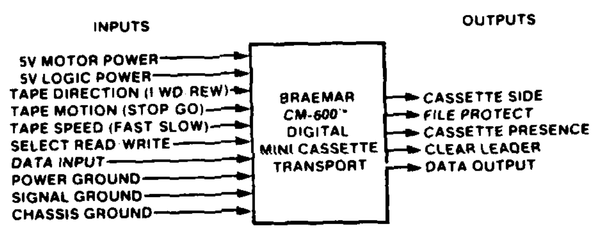


FIGURE 3.8 Braemar CM-600 Block Diagram (From Peripheral Design Handbook, Intel Corp.)

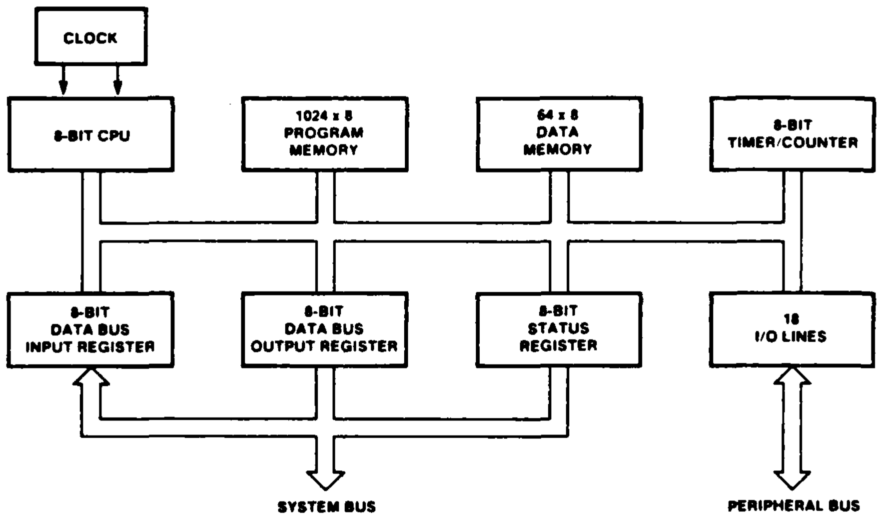


FIGURE 3.9 Intel 8741A/8041A Block Diagram (From Peripheral Design Handbook, Intel Corp.)

directly with the Braemar CM-600 Mini-Dek and the main system CPU, as shown in Figure 3.10. The 8741A acts as a slave processor to the main system CPU. It accepts commands from the main system CPU to implement the read, write, rewind or skip operations and returns the outcome of the requested operation to the main system CPU.

The 8741A chip converts the parallel data bits into a serial format for transmission onto the minicassette tape. The recording technique used in this subsystem is a self-clocking phase modulation scheme that encodes the hexidecimal data into a binary serial data format (see Appendix C). The encoding scheme specifies a logic "0" as two bits of the same polarity within a message space and a logic "1" as two bits of alternating polarity within a message space; this technique minimizes decoding misinterpretations of a binary message which may contain a string of logic "1's" or "0's".

The encoding and decoding process is best explained by examining the waveforms of Figure 3.11. The decimal character 8 in binary form (00001000) is encoded using the self-clocked phase modulation encoding scheme, as illustrated in Figure 3.11(a). Notice that there is always a "clocking" transition at the beginning of the message space or cell. The magnetic pattern that is transcribed on the magnetic tape is shown in Figure 3.11(b). In direct digital recording, the tape is fully saturated North or South as depicted. This is accomplished by the read/write head of the recorder, as shown in Figure 3.12.

During playback of the tape, the output waveform of the read/write head appears as illustrated in Figure 3.11(c). This waveform can be shown to be the derivative of the original waveform[29, 30]. Decoding

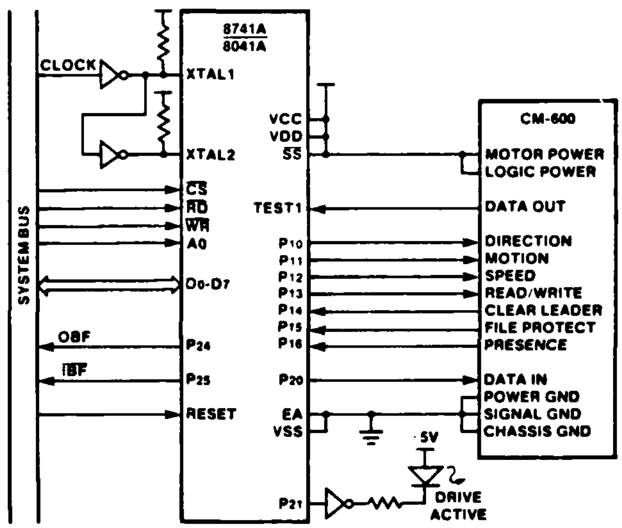


FIGURE 3.10 Intel 8741A Controller/Braemar Tape Transport System Schematic (From Peripheral Design Handbook, Intel Corp.)

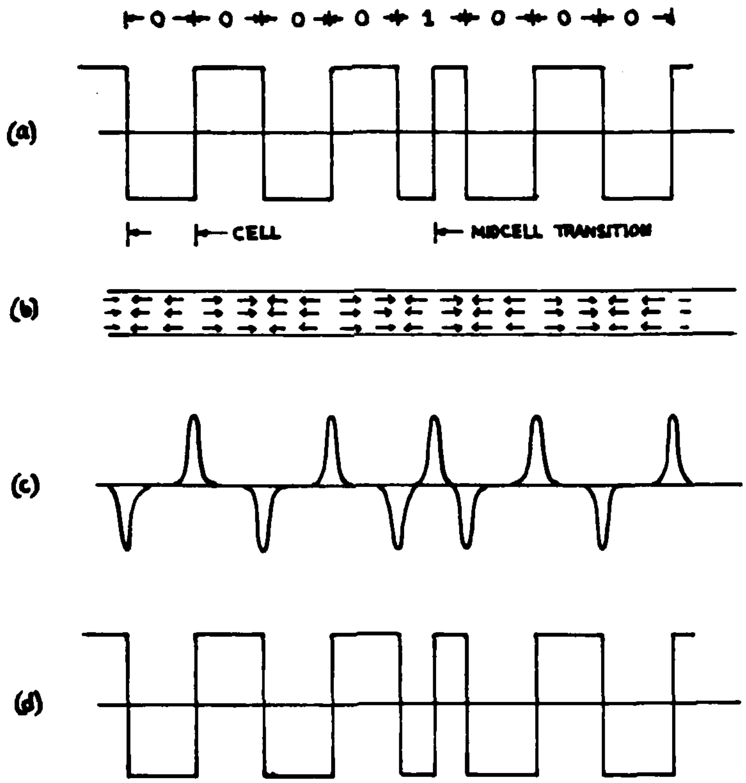


FIGURE 3.11 Self Clocked Phase Modulation Waveforms

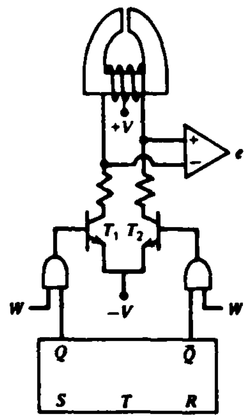


FIGURE 3.12 Typical Digital Read/Write Head Configuration (From J.K. Watson, Applications of Magnetism, Wiley & Sons, NY, 1980)

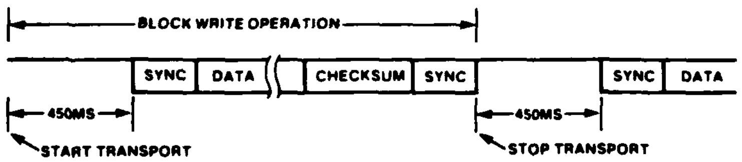


FIGURE 3.13 Data Block Format (From Peripheral Design Handbook, Intel Corp.)

of this waveform is accomplished by triggering on the "clocking" transition; Figure 3.11(d) shows the decoded waveform.

The tape format of the recorded data is designed to efficiently store the identification message in a manner that facilitates information management. The subsystem uses a variable byte length, checksum-protected block format which is illustrated in Figure 3.13. Every data block starts and ends with a SYNC character. The SYNC character is the hexidecimal character OA (see Appendix C). The character immediately preceding the last SYNC is the checksum which is capable of catching 2 bit errors. The number of characters within the block is limited to 64 K bytes (64 K x 8 bits). The blocks are separated by an Inter-Record Gap (IRG)[24].

The particular length of the IRG shown in Figure 3.13 is based on the maximum start and stop time of the tape transport. In the case of the Braemar CM-600, a time of 450 msec provides plenty of margin for the tape transport to start and stop within the IRG[24].

3.3 Seal Interfacing Device System Description

A hand-held seal interfacing device (SID) is required to interface the seal's magnetic tape to the LIU. The SID consists of a reconfigured dictation type micro cassette tape recorder, a sixteen key keyboard and a ten digit light emitting diode (LED) display. These subsystems are combined into a single device to simplify user operation during the seal labeling and/or interrogation operation. The seal interface device will be connected to the LIU by means of an umbilical cord that supplies power to the device and carries the electrical signals to and from the LIU.

The keyboard and display subsystem consists of a 16 key keyboard and a 10 digit LED display. The sixteen keys of the keyboard include ten numeric keys (0-9), two program select keys and a reset key. The keyboard will be used to select either the labeling or interrogating function of the LIU and to input the serial number of the seal to be labeled or interrogated. The LED display will serve to display the keyboard entries. Three separate LED lamps will be used to display the microcomputer output to indicate the verification status at the end of the program cycle.

To interface the keyboard and display subsystem to the microcomputer, the Intel 8279 keyboard and display peripheral interface device is used. As shown in the 8279 block diagram of Figure 3.14, the 8279 has two sections, a keyboard section and a display section. The keyboard section is capable of being interfaced to any standard 8 bit keyboard while the display section is capable of driving any standard LED display. Figure 3.15 illustrates the 8279 interfacing the keyboard and the display with the main system CPU.

The tape interface subsystem consists of a dictation microcassette tape transport and read/write assembly, and a microcomputer based peripheral device interface. The tape transport and read/write assembly is the physical interface of the LIU's microcomputer system to the magnetic tape seal. The tape transport and read/write assembly is envisioned to be a reconfigured dictation cassette recorder designed to accommodate the seal. The functions of read, write, and rewind will be manually operated by the user upon command from the LIU.

To interface the dictation microcassette tape transport and read/

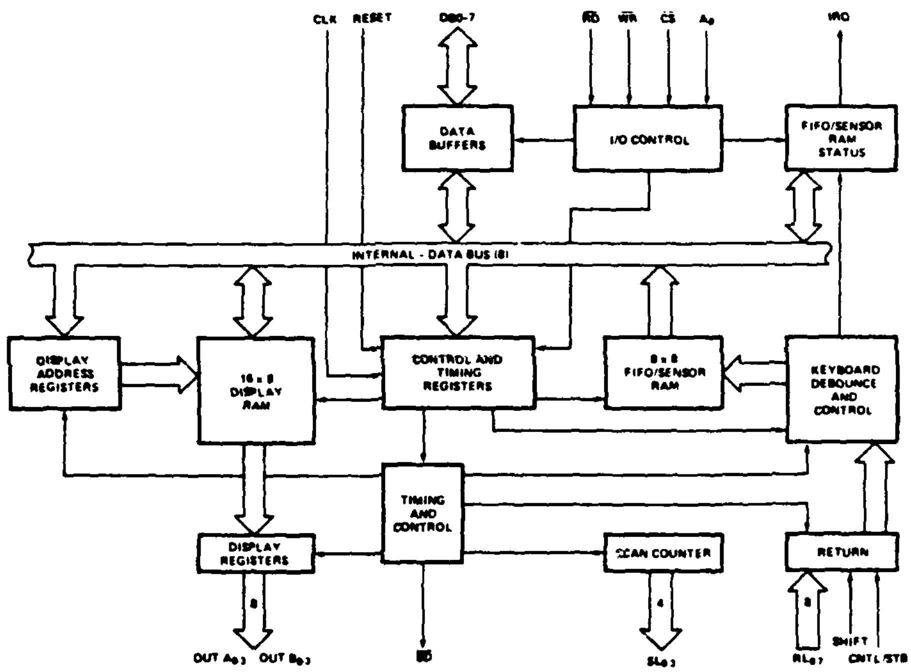


FIGURE 3.14 Intel 8279 Functional Block Diagram (From Peripheral Design Handbook, Intel Corp.)

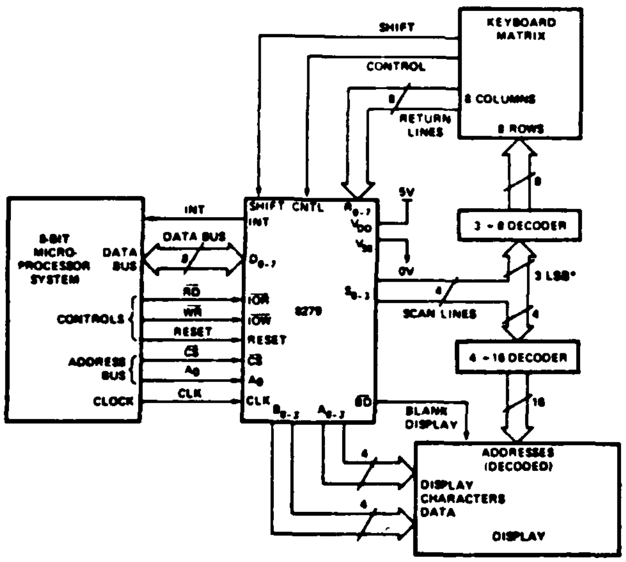


FIGURE 3.15 Keyboard and Display System Schematic Diagram
(From Peripheral Design Handbook, Intel Corp.)

write assembly to the main system CPU, a separate microcomputer system is required, that will act as a slave processor to the main CPU. The block diagram of the interfacing system is shown in Figure 3.16. The microcomputer system is designed to use the serial input/output lines of the 8085 microprocessor to convert the 8-bit parallel data into a binary serial format. This in turn is encoded into an audio signal for transmission onto the magnetic tape of the seal. The circuit diagram of the encoding and decoding circuit is presented as Figure 3.17.

The recording technique to be used is based on an encoding scheme commonly known as the ratio or "1/3 - 2/3" method[25, 30]. This is a self-clocking frequency modulated encoding scheme that specifies a logic "0" as 1-0-0 and a logic "1" as 1-1-0. The message space consists of three bit spaces as illustrated in Figure 3.18. The encoding and decoding of the data is performed by the microcomputer through the use of a software program.

The output signal is composed of a tone burst which is followed by either a pause or another tone burst. Then a pause signals the end of the message space (corresponding to a logic "0" or logic "1").

The decoding process is illustrated using the analog signal waveforms of Figure 3.19. Here the waveform of a tone burst, as seen by the encoding and decoding circuit, is depicted at various parts of the circuit. The circled letters A - H correspond to the locations labeled in the circuit of Figure 3.17.

The frequency of the tone burst is selected to be within the passband of the tape and the audio amplifier of the recorder. A data rate of 330 bits per second can be obtained using a 10 KHz tone

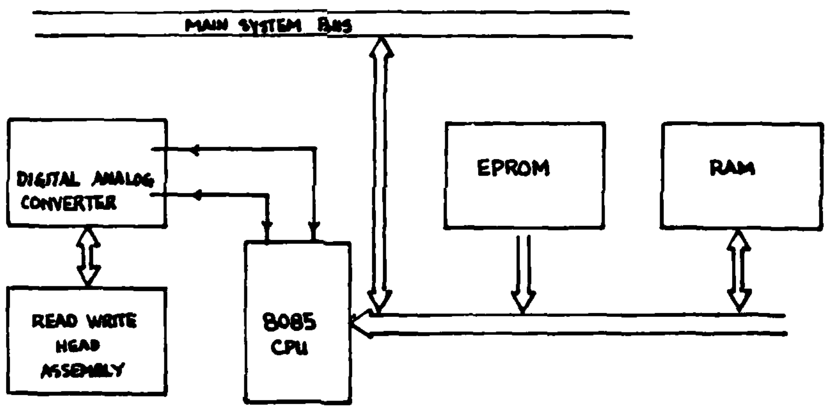


FIGURE 3.16 Seal Tape Interface Subsystem Block Diagram

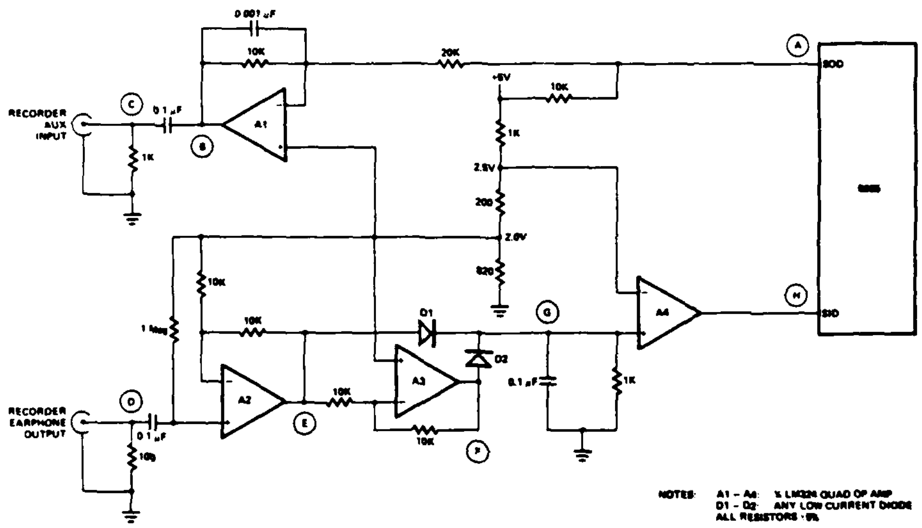


FIGURE 3.17 Encoding and Decoding Circuit Diagram (From Peripheral Design Handbook, Intel Corp.)

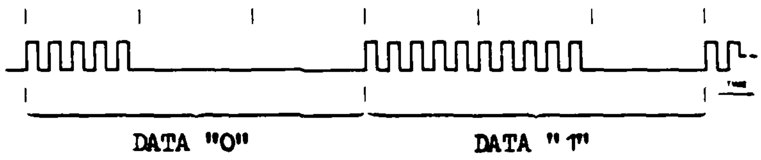


Figure 3.18 Ratio Method Encoding Scheme (From Peripheral Design Handbook, Intel Corp.)

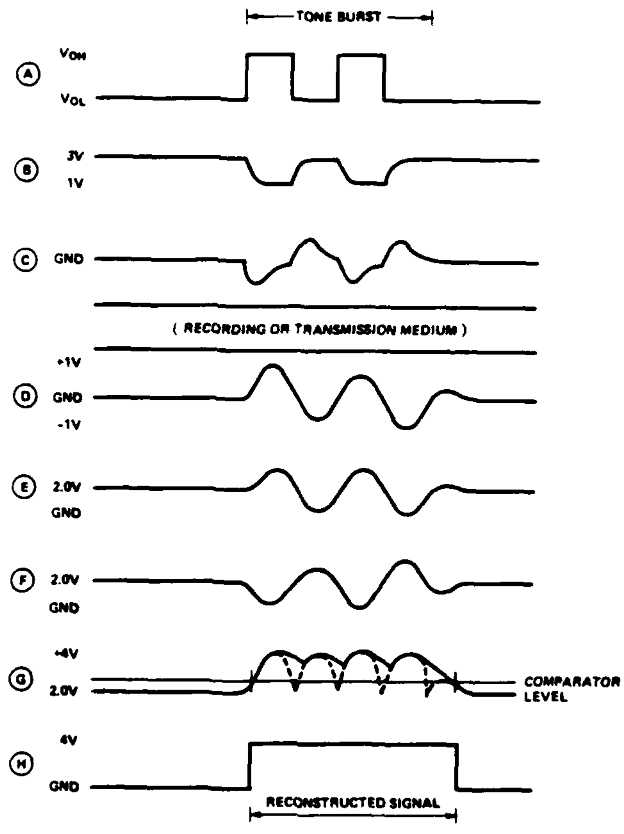


FIGURE 3.19 Analog Signal Waveforms (From Peripheral Design Handbook, Intel Corp.)

frequency. For a 15 second tape time, a total of 4.95×10^3 bits (618 bytes) can be recorded[25].

This particular recording technique has two advantages. First, it can withstand significant fluctuations on tape speeds and is especially suitable to recording with inexpensive tape recorders. Also because the interface with the magnetic tape seal may not be perfect, this recording technique will allow considerable leeway in positioning the seal within the seal interface device.

3.4 System Operation

So far the discussion has covered the LIU's overall system hardware and data transfer techniques. The actual operation of the microcomputer system requires an extensive software package of machine language instruction programs to perform the necessary functions required. The necessary software for the two tape interface subsystems have already been developed by Intel[24, 25] and can be used primarily as subroutines for the main microcomputer system. The software for the system to perform the LIU's labeling and interrogation functions will be described by using flow charts to illustrate the proposed system operation in each mode, each of which requires its own instruction program.

As a precautionary measure against attempts to compromise the sealing system by an unauthorized person, a password (in the form of a user identification code) will be required to gain access to the microcomputer system. This safeguard will be included in the two required programs.

One program will be used to initially identify the seal, form a unique identification message, label the seal and store this information in the non-volatile memory. The sequence of actions that must be performed to accomplish this operation is illustrated in the system flow chart of Figure 3.20.

Once the LIU is energized, the user will input the required password. The labeling mode is then selected by manually depressing the labeling mode selection key. This action enables the particular EPROM that contains the labeling program to be used by the main CPU. The first instruction bytes will initialize the overall system by clearing the RAM, accumulators, reset counters, and prepare the system to accept the manual input of the seal serial number. The seal serial number is used by the microcomputer to initialize the generation of the 50 digit random number. The seal serial number and the generated random number are then stored in the RAM.

A signal from the main CPU is sent to activate the two tape interface subsystems. The CPU notifies the user when the LIU is ready to transcribe the identity message onto the magnetic tape of the seal. The user will use the SID to interface with the seal and write the message onto the tape. When the message is terminated, the LIU will notify the user with an end of message signal. The user will then rewind the tape. The LIU must then instruct the SID to clear its memory in order to prevent an unauthorized duplication of the same message onto another tape.

The user will input the reading on the seal's mechanical counter into the LIU. This will be used during verification inspections to detect unauthorized access to the seal tape. The message to be stored in the LIU's digital cassette contains the seal serial number, a

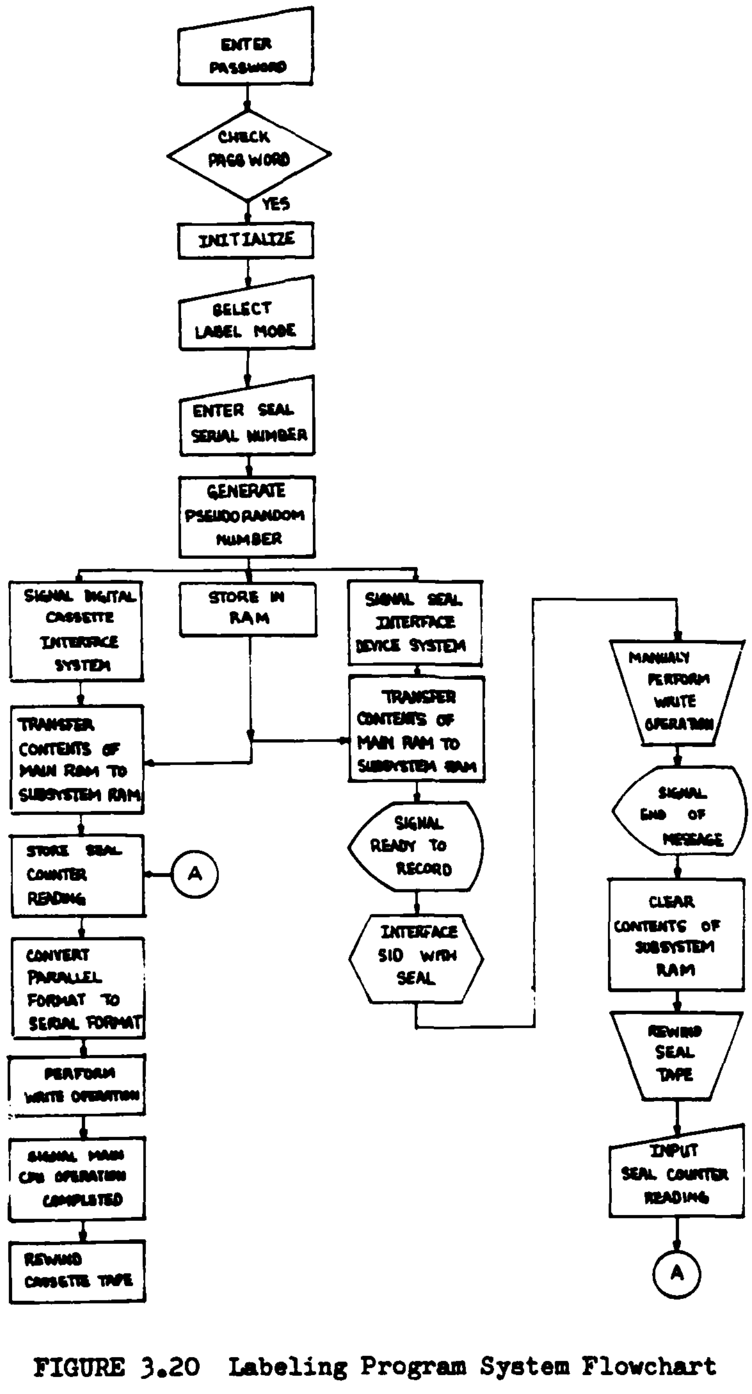


FIGURE 3.20 Labeling Program System Flowchart

randomly generated identification number and the seal counter reading.

The second program of the LIU will be used to interrogate the seal during periodic seal validation inspections. This operation will validate the integrity of the seal by validating the seal serial number, the seal message and the seal counter reading. The sequence of actions that must be performed in this operation is illustrated in the system flow chart of Figure 3.21.

As before, the user is required to first input his or her password after energizing the LIU. The interrogation program is then selected by depressing the interrogation mode selection key, and the system is initialized. The seal serial number is then entered using the keyboard. This causes the LIU's main CPU to signal the digital cassette subsystem to search for the data block that contains the identification message for the indicated seal using the seal serial number as the flag. Since this operation is controlled by a complete microcomputer system, the main CPU can simultaneously signal the seal interface CPU to prepare to accept the seal message. The user is notified when data transfer from the seal can commence. The SID is interfaced to the seal and "reads" the identification message into the SID's RAM. When the entire message is read, the user is then notified to enter the seal counter reading into the LIU.

The SID performs the necessary decoding and decrypts the message into two segments. When the main CPU receives completion signals from the digital cassette and the tape interface subsystems, it will transfer the contents of the two RAMs into its RAM and begin the process of byte by byte comparison. Discrepancies will be signaled to the user to

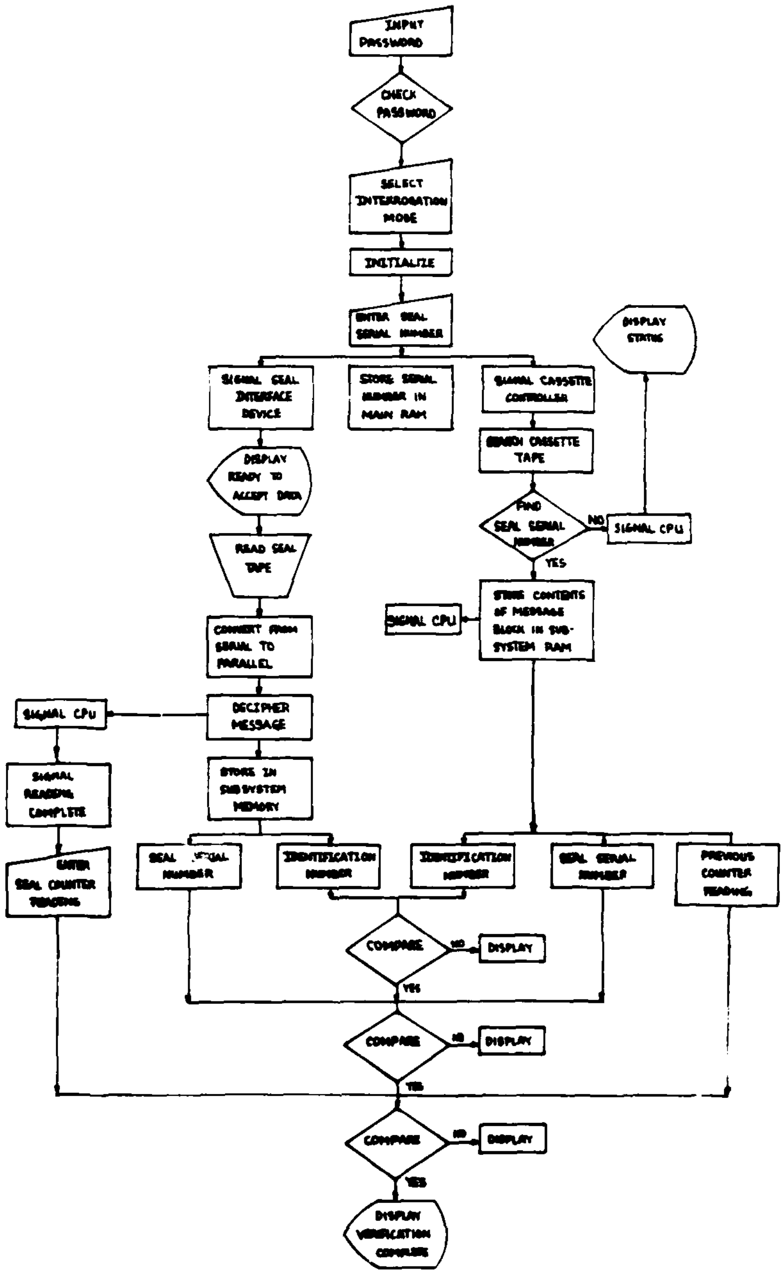


FIGURE 3.21 Interrogation Program System Flowchart

indicate where the discrepancy has occurred. Validation of the complete message and counter reading will also be signaled to the user to indicate the successful completion of the interrogation operation.

CHAPTER 4

DESIGN OF THE MAGNETIC TAPE SEAL

4.1 Preliminary Design Considerations

Figure 4.1 illustrates the first configuration of the magnetic tape seal which was envisioned. A cylindrical shape was selected because it offered a simple and compact design which could be easily molded using plastic molding and bonding techniques. A means to affix the seal was devised using 49 strand stainless steel safing wire[18], similar to that used in the type E seal, and a fastening plug.

To attach the seal, the safing wire would be threaded through the fastening plug, cut to size and crimped using an aluminum cast crimp (see Figure 4.2). The plug would then be inserted into the seal and secured by the expansion of spring loaded pins into slots within the seal.

A strip of 1/2 inch magnetic tape, which would be attached to the interior of the seal, was to be accessible by the use of a specially configured read/write head which fit into a key-slot like opening at the bottom of the seal. To transcribe information onto or from the tape, the read/write head would have been rotated to follow the tape around the seal interior.

The requirement that the tape read/write head can be moved along a stationary tape is a radical departure from the normal practice of moving a magnetic tape across a tape read/write head. Because there was a lack of literature on magnetic recording using this particular technique, the seal was redesigned to accommodate the more conventional recording technique of transporting the tape across a stationary read/

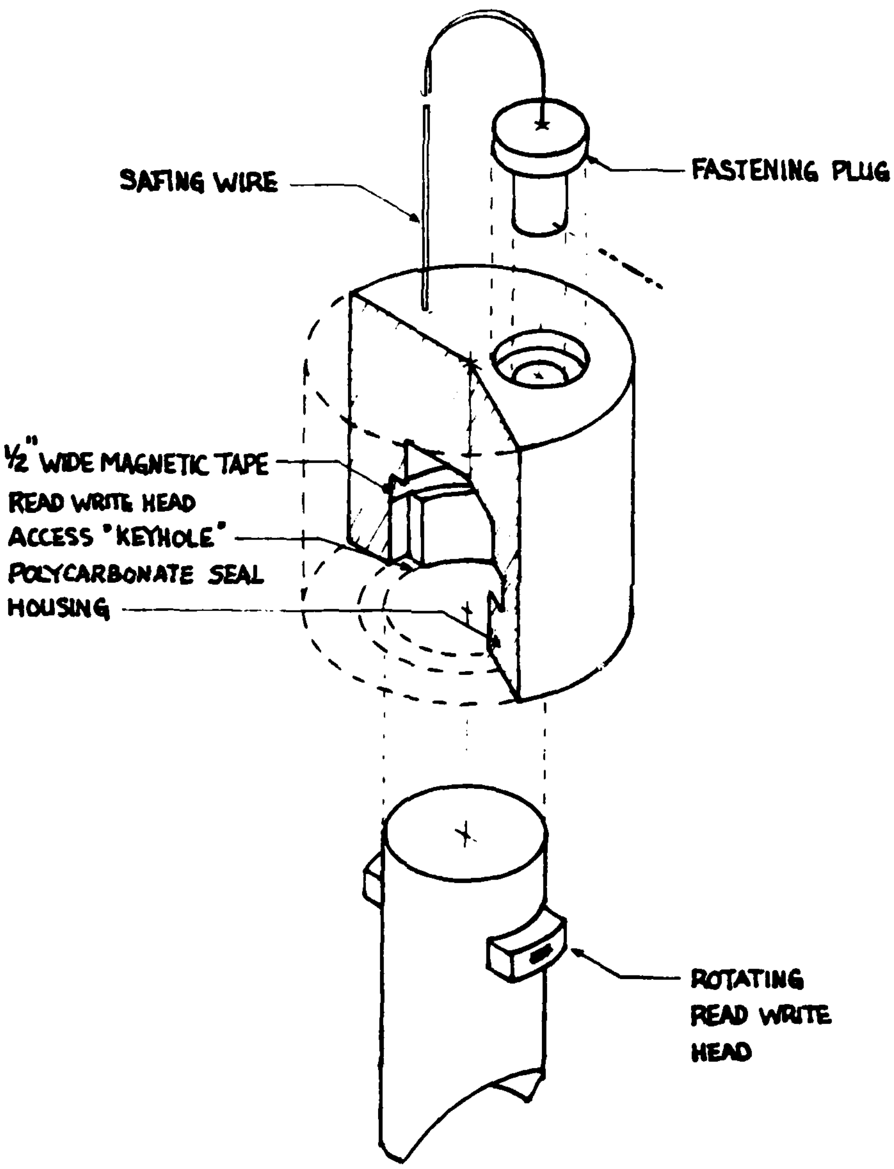


FIGURE 4.1 Conceptual Cylindrical Magnetic Tape Seal

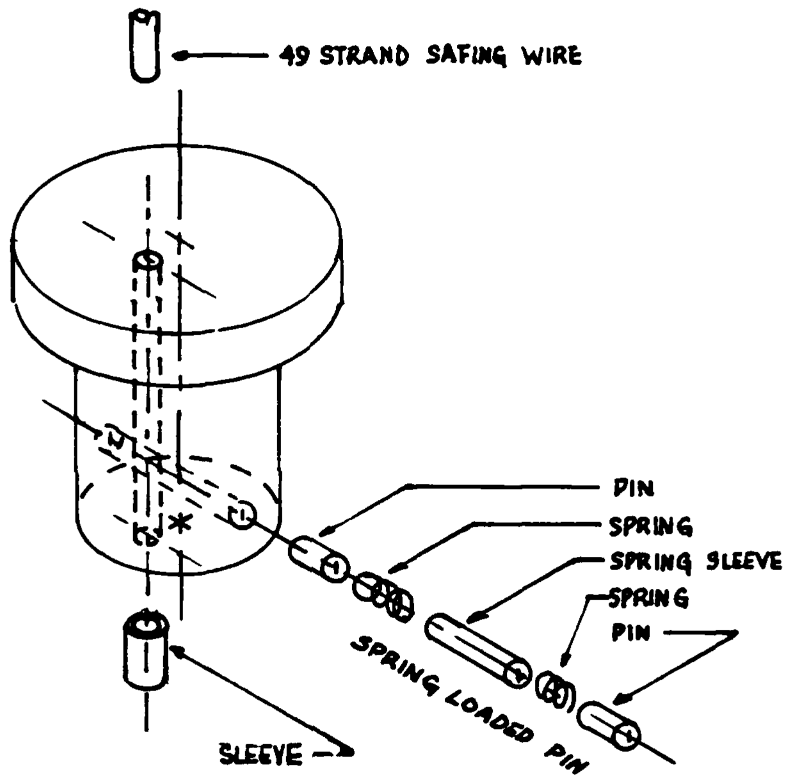


FIGURE 4.2 Conceptual Fastening Plug

write head.

4.2 Seal Design

The experience gained from the first design demonstrated the need to consider more practical recording and playback techniques. In the second iteration, a Phillips-type tape cassette was used as the "building block" around which the seal was designed. This method also allowed for a reasonably-sized seal, albeit one with some trade-offs in seal characteristics (which will become evident later).

Figure 4.3 illustrates the second configuration. The cassette is mounted in a slide assembly which serves two purposes. First, it prevents the cassette from being physically removed from the seal. Second, the assembly is spring mounted such that in the normal position, the cassette is retracted completely within the seal. Reading information onto the cassette tape or retrieving information from it requires moving the slide assembly and cassette forward to a position in which the cassette face protrudes out of the seal and the cassette is in line with the tape transport access holes on the bottom of the external case.

Every such sliding action is registered by a 5-digit mechanical counter inside the seal. Thus the number of times the cassette is moved into position for information transfer to take place is recorded so that it would be possible to detect an unauthorized retrieval of information. This counter also serves to maintain a record of the authorized number of verification checks that have been made on a particular seal.

Two demonstration models of this second configuration were

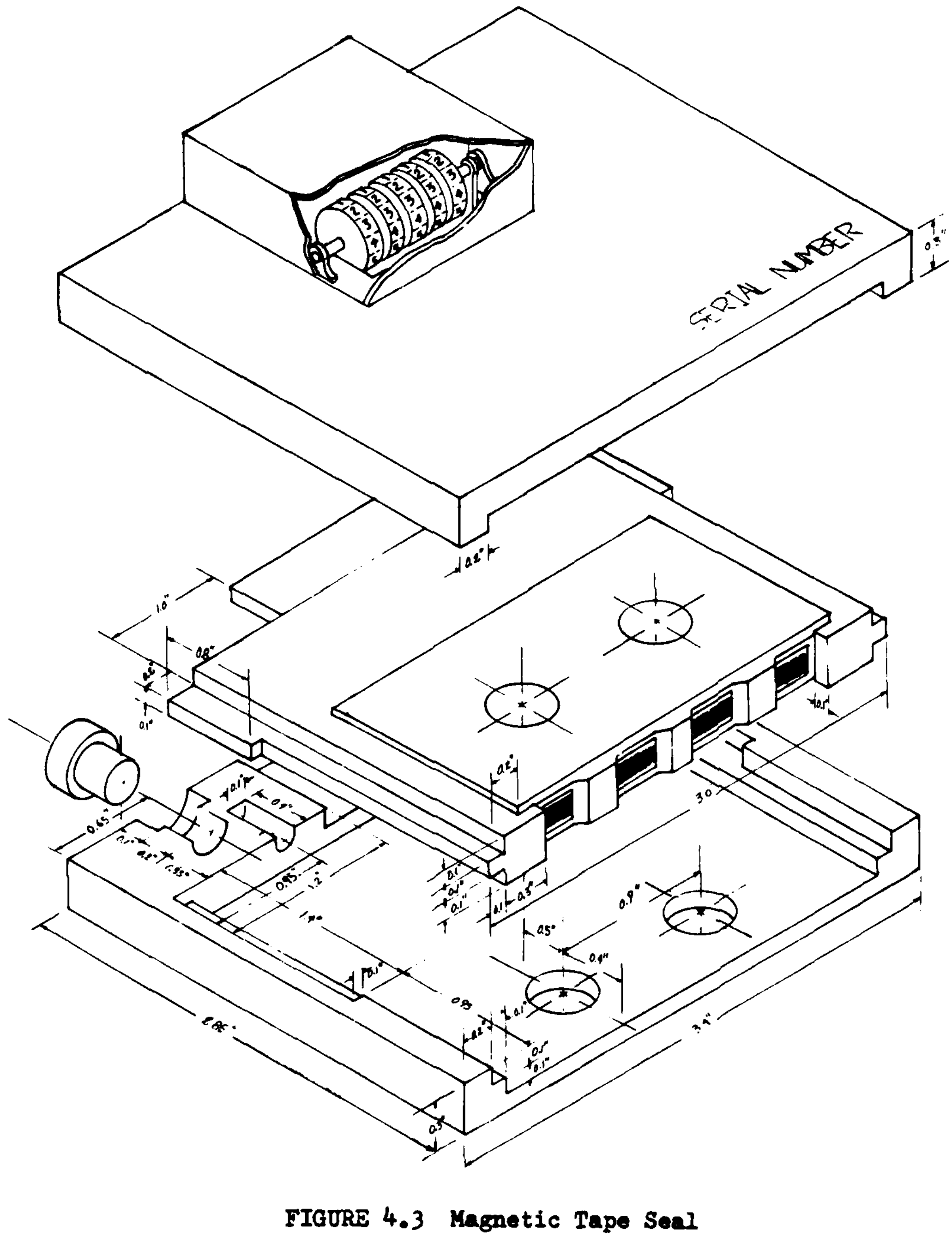


FIGURE 4.3 Magnetic Tape Seal

fabricated in the University of Washington Nuclear Reactor machine shop using plexiglass. The first model shown in Plate I was constructed around a standard size cassette. The cassette shown is a special use endless cassette manufactured by TDK Electronics Co. The tape is configured in an endless loop, similar to that used in tape cartridges, and is available in 5, 15, and 30 second lengths.

A second and smaller model, shown in Plate II, was fabricated using the same techniques; the reduction in size permits the use of a dictation microcassette. The dimensions of both models are presented in Table 4.1 for purposes of comparison of the two models.

The two models were constructed to demonstrate the principles of the design configuration and to investigate various methods of fabricating and mechanically assembling the seal. The seal was envisioned to consist of three parts, the upper housing, the slide assembly with cassette tape and the lower housing, as shown in Plates I and II. Field assembly of the seal was envisioned to be one of snap-fitting the top and bottom housing together to form a complete unit.

The final design iteration of the seal, illustrated in Figure 4.4 incorporates features required for possible fabrication using an injection molding technique. A polycarbonate resin such as LEXAN[32] would be used for the seal housing, the slide assembly and the fastening plug. This material has good impact strength, dimensional stability and is especially suited for injection molding and ultrasonic bonding (see Appendix D).

The injection molding process would require the use of four molds, one each for the top and bottom of the seal housing, one for the slide

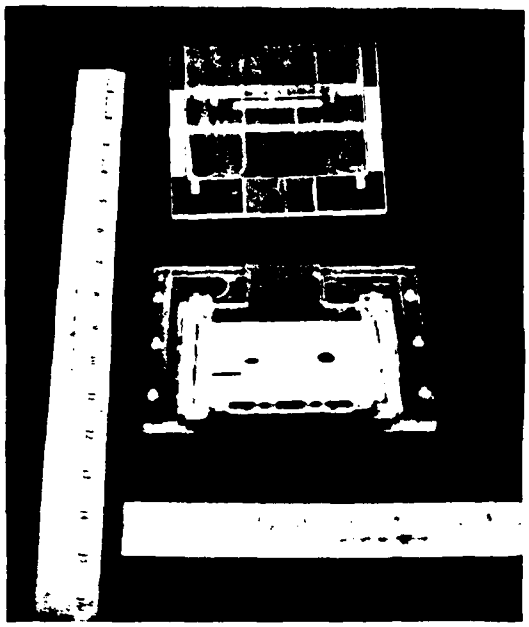


PLATE I Demonstration Model #1

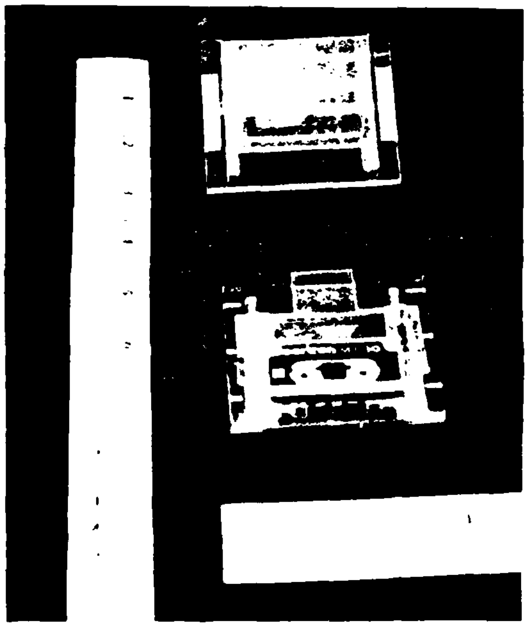


PLATE II Demonstration Model #2

TABLE 4.1 Characteristics of Demonstration Models

	Model #1	Model #2
Material	Plexiglass	Plexiglass
Cassette Type	Special use endless loop cassette (standard size)	Dictation Microcassette
Length	5.5"	3.4"
Width	4.65"	2.8"
Height	0.9"	0.6"

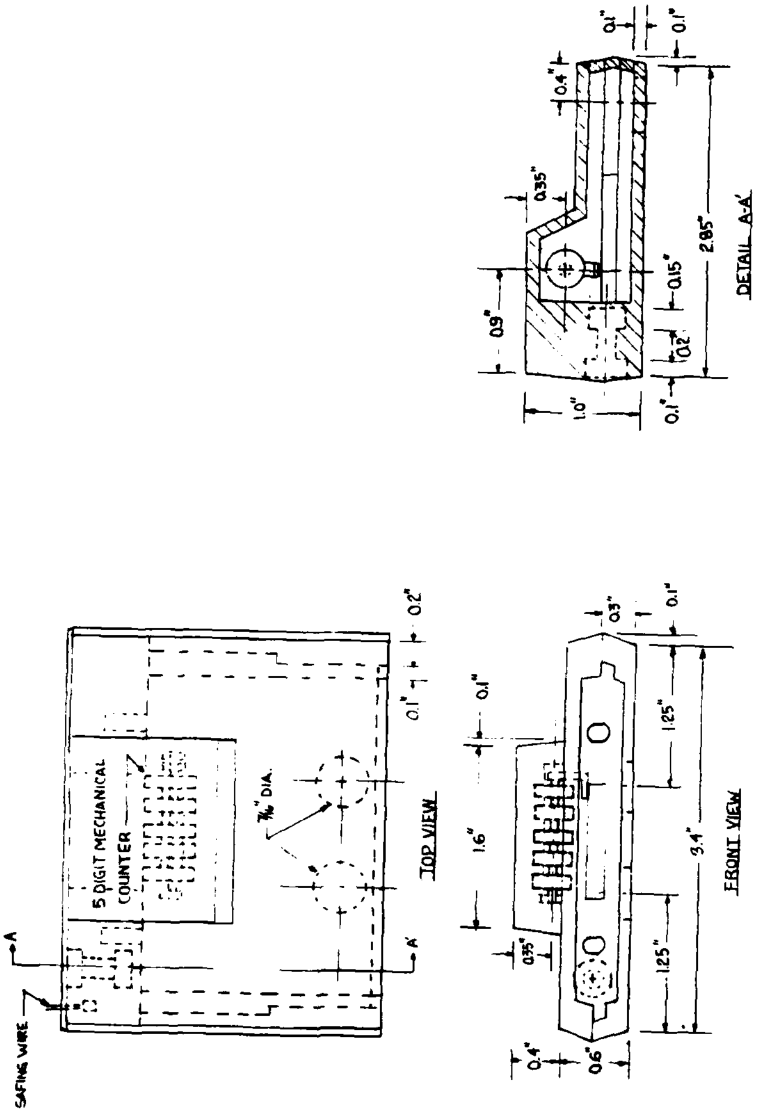


FIGURE 4.4 Redesigned Magnetic Tape Seal

assembly and one for the fastening plug. The bottom half of the seal housing would be injected with one end of the 49-strand safing wire embedded in the part. The seal serial number would be consecutively stamped on the seal shell exterior during the molding process.

Assembly of the seal would require the placement of the mechanical counter, the microcassette tape and the required springs in their respective locations in the seal housing. Then the seal would be ultrasonically bonded together using ultrasonic welding techniques.

To fabricate the injection molded seal, several minor changes in the seal designs shown in Plates I and II would be required. These alterations include:

(a) adding fillets (or radii) to all corners to reduce stress concentration

(b) providing for a tapered reduction of part thickness where necessary to minimize the molded-in stress points, reduce differential shrinking of the parts, and avoid the formation of voids within the part walls

(c) adding draft (or taper) to facilitate removal of parts from the molds

(d) adding provisions to permit ultrasonic welding of the parts.

The fastening plug was also redesigned in this iteration. The spring loaded pin system was replaced by a cantilever lug snap fit pin as shown in Figure 4.5. In this design, the crimped safing wire also acts as a wedge in the snap-fit pin, which would make an undetected removal of the fastening pin difficult.

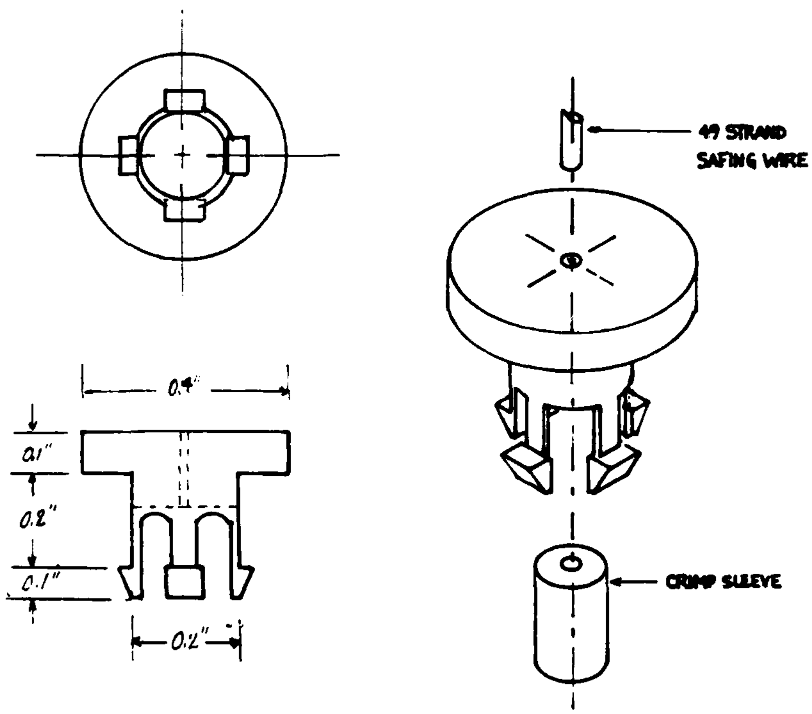


FIGURE 4.5 Redesigned Fastening Plug

4.3 Seal Operation

To apply the magnetic tape seal, the user threads the safing wire through the point of affixation and the fastening plug, cuts the wire to the correct length, and crimps a sleeve onto the wire. The fastening plug is then inverted into the seal housing. Following this, the wire is pulled to wedge the crimp into the fastening plug. The LIU is then used to record the seal identification message onto the magnetic tape as described in section 3.5.

During the validation of a seal's integrity, the inspector must check for signs of physical tampering. A possible order of inspection would be as follows:

(a) Check safing wire to see if it is intact.

(b) Check fastening plug to insure it is not damaged, and that it is securely in place.

(c) Check seal body for cracks, chips and other signs of tampering.

(d) Use LIU to validate the random number label which identifies the seal.

Once the seal is removed from service, the seal must be destroyed to prevent reuse of its parts by an intruder or diverter. Strict accountability of seal history must be maintained by the user organization to minimize seal substitution or forgery.

CHAPTER 5

SYSTEM ECONOMICS

5.1 Economic Considerations

At this stage of development, some "ball-park" estimates are necessary to determine the feasibility for production of the seal based on the present design configuration. The cost estimates of the sealing system were determined by considering the seal and the LIU support system separately. This approach was particularly appropriate because of the different non-recurring development and production costs that would be incurred for each of the two components.

5.2 Seal Cost Estimates

The manufacture of the magnetic tape seal by injection molding will incur certain fixed costs that must be added on to the cost of labor and material for each individual seal. Table 5.1 summarizes the estimated cost of manufacture (in 1980 dollars) of the seal design presented in Chapter 4 based on the shoprate of the John Fluke Manufacturing Company Inc.[33]

A non-recurring cost of approximately $18,000 for molding cost, mold set up cost, and tooling for ultrasonic welding is to be amortized over the total number of seals produced. A production cost of $0.60 per seal is projected for the injection molding process alone, and a total of $6.65 per seal for miscellaneous parts and assembly completes the cost estimates for the seal.

To determine a manufacturing cost estimate for a seal, one can apply the relationship:

TABLE 5.1 Seal Manufacture Cost Estimates[a]

A. PARTS COST	MOLDING COST[b] (±20%)			PRODUCTION COST (±20%)		
	Tool Design ($)	Mold Base and Material ($)	Labor and Burden ($)	Shop Rate ($)	Material[c] ($)	Mold Set up[d] (hours)
Housing[e]	1,250	3,650	10,900	0.12/part[f]	0.07/part	2-3
Cassette Slider[g]	450	1,275	3,800	0.09/part[h]	0.05/part	1-2
Fastening Pin[i]	200	550	1,775	0.06/part[f]	0.02/part	1-2
TOTAL	1,900	5,475	16,475			

Notes:
(a) Cost estimates provided by M. Haapala[33]
(b) To be amortized over total number of parts to be produced
(c) Polycarbonate resin (LEXAN)
(d) Cost of mold set up approximately $30/hr, to be amortized over total number of parts to be produced
(e) Two cavity mold to be used. Both halves of the housing will be molded simultaneously
(f) Based on a production rate of 120 parts/hr
(g) Single cavity mold
(h) Based on a production rate of 90 parts/hr
(i) Two cavity mold

TABLE 5.1 Seal Manufacture Cost Estimates (cont.)

B. OTHER COST		
49-Strand Safing Wire	\$0.10/ft	2 ft required
LEAD Crimp Sleeve	\$0.05 ea	1 required
Microcassette Tape	\$1.15 ea	1 required
Springs	\$0.05 ea	2 required
5 Digit Mechanical Counter	\$5.00 ea	1 required
Bonding Cost		
Ultrasonic Welding	\$0.20/seal	
Tooling for Welding Horns and Fixtures[a]	\$1,500.00	

Note: (a) To be amortized over total number of seals to be produced

$$\text{Estimated Manufacturing Cost (\$)} = \frac{\text{Non-recurring cost}}{\text{Total number of units produced}} + \text{production cost per seal} + \text{parts and labor cost per seal} \qquad (5.1)$$

Using a production run of 5,000 seals, a per unit cost of approximately $12.00 ± 20% is projected.

5.3 Support System Cost Estimates

The cost of the LIU seal support system is more difficult to determine. The selection of off-the-shelf subsystems for the microcomputer system with developed software will circumvent the need for extensive engineering design and development. Non-recurring development costs will be incurred for the development of the main instruction programs, the fabrication of the seal interface device and prototype debugging. Unfortunately, at this time, it is not possible to accurately assess the resources and time required to accomplish these tasks and to assign a dollar value for estimated development cost.

The cost to assemble a bench top prototype of the LIU's microcomputer system can be obtained from the component parts and prices detailed in Appendix E; the results are summarized for each subsystem in Table 5.2.

The cost of system software development and seal interface device fabrication is estimated to be approximately $20,000. This amount is to be amortized over the total number of units to be produced. This estimate is based on a software development time of approximately six months[34] at approximately $150/ man-day and a seal interface device prototype fabrication cost of approximately $2,000.

TABLE 5.2 Parts Cost of LIU Prototype

Subsystem	Cost ($) *
Main CPU	436
Seal Interface	294
Power	149
Miscellaneous	43
TOTAL	$912

Note: * Rounded off to whole dollars

5.4 Economic Summary

The magnetic seal system costs can be misleading and care must be exercised in their interpretation. The amortized amount will, of course, vary with the total number of units of the seal and the support system produced. Obviously the more produced, the lower the per unit cost. Additionally, the software development estimate is, at best, a guess.

Some conclusions concerning the economic feasibility of the magnetic tape seal system can be made by considering the unit cost of other improved seal systems. The fingerprint type E seal can be purchased for $0.40 each and a photographic system (Polaroid MP-4) for around $2,400. When the cost of fingerprinting, verification, storage and handling is added, a final total cost of approximately $20 per seal is reached(16). The passive fiber optic seal is expected to cost between $10 and $15 and the verification reader for this system is expected to cost approximately $5,000 each(16). The cost of an ultrasonic seal is not available, but one can expect that the seal will cost somewhere in the range of $2 to $5 each; the verification system should be quite expensive due to its complexity, but no dollar value is yet available.

The above figures must also be carefully interpreted. The number of units used in the computation of cost estimates are unknown, and a direct comparison cannot be made. However, a general desirable range of approximately $10 to $15 per seal and $5,000 to $6,000 per system support unit should probably be considered reasonable.

The magnetic tape seal cost of $12 ± 20% is certainly in the range of fiberoptic and ultrasonic seals. For the LIU support unit to be economically competitive, a minimum of four units will need to be produced.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Evaluation of the Conceptual Design

The concepts, components and subsystems of the conceptual seal system have been outlined in the previous chapters. Certainly, the design is by no means optimized, and further development undoubtedly will result in modifications to improve the overall system design. What is important, at least in the author's opinion, is that the principal concepts for a magnetic tape seal system have been investigated and assembled in a conceptual design package.

The next step will require funding to improve the design, purchase and assemble a prototype system, develop the necessary system software package and fabricate working models of the seal system for testing and evaluation. Only then will it be possible to adequately compare the performance of the magnetic tape sealing system with the ultrasonic and fiber optic seal systems discussed in Chapter 2.

When evaluating the performance of the magnetic tape sealing system, it would be wise to keep in mind the possible courses of action that can be taken by an adversary to defeat the seal system:

(a) Removal of the applied seal with or without regard to concealing the act of tampering

(b) Removal and substitution of the applied seal with a counterfeit seal to conceal tampering

(c) Compromise of the seal system by access to the equipment and records of the system.

Detection of physical attacks on the seal is accomplished by visual inspection of the seal. The most obvious way to remove the seal is to cut the safing wire. Once this is accomplished, it is difficult to reconnect the wire (by welding or other means) without leaving visible evidence.

Another action that can be taken by an adversary is to remove the fastening plug. The plug is designed to cause damage to the shell of the seal when forcibly removed from the seal, and this damage would serve as a visible means of detection.

The use of chemicals to dissolve parts of the seal was also considered in the design. Chemical attack on the polycarbonate resin will result in irreversible and visible damage to the seal.

The detection of a seal substitution is accomplished by the use of the seal serial number and the randomly generated seal identification message. The comparison of the seal serial number and seal identification message with the record made at the time of seal application will reveal inconsistencies caused by substitution.

The use of the LIU by an adversary to compromise the seal system is made difficult by the incorporation of lockout keys to open and operate the system and by the requirement of a user password to gain entry into the operational programs.

6.2 Recommendations

It is recognized that a conceptual design is, at best, a zeroth-order approximation of a seal system design. In order to reduce development time and cost, the conceptual seal system design strived to link together "off-the-shelf" subsystems and components that are compatible with each other. What remains for further investigation and study is the assembly of a benchtop prototype for testing and evaluation, and further development and improvement of the seal system design.

Based on the economic evaluation presented in section 5.2, the seal system is economically competitive with other improved seal systems being developed, even in its current embryonic form. Further study and iterations to the system may lead to even more favorable economic terms. Certainly this possibility is worth investigation.

The current configuration of the magnetic tape seal device suffers, to some degree, from mechanical complexity and bulk. A more compact and simple design would probably be more rugged and durable, and less susceptible to failure. Perhaps a configuration similar to the original seal device configuration discussed in section 4.1 may be an optimum design, although the difficulties of using a rotating read/write head would need to be resolved. Other configurations might also be suitable, but they would require some innovative and clever designing.

The microcomputer information processing and storage system can also be applied to other seal systems. For example, one should consider a microcomputer system to complement the ultrasonic signature seal system, where the analog output signal can be converted into digital form and permanently stored on magnetic tape. Verification using the microcomputer would eliminate the need for human comparison and reduce overhead expenses for storage of photographs and photographic systems.

Another possibility is to use a microcomputer to query and store digitized ultrasonic signatures and then use a telephonic link to "communicate" with a larger computer at a central location (e.g. NRC or

IAEA Headquarters) to verify the seal's identity. This would enhance the degree of in situ capability to ultrasonic seals.

In summary, the recommended areas for future work include:

(a) Assemble and test the microcomputer system and system software development for use in a magnetic tape seal system.

(b) Develop improved versions of the magnetic tape seal device to reduce seal size, and simplify seal design to enhance seal effectiveness and reduce the unit cost.

(c) Investigate possible applications of portable microcomputer systems to ultrasonic and fiber optic seal systems.

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APPENDIX A

INTERNATIONAL ASPECTS OF NUCLEAR SAFEGUARDS

Non-Nuclear Weapon States (NNWS) party to the Non-Proliferation Treaty (NPT) formally accept the political committment not to divert nuclear materials from peaceful activities to nuclear weapons or nuclear explosive devices[35]. All NNWS are obligated to enter into a safeguards agreement with the International Atomic Energy Agency (IAEA), which was designated under the NPT to establish an International Safeguards Program[36].

The IAEA Safeguards Agreement requires the State to establish and maintain a State's System of Accountability and Control of Nuclear Material (SSAC)[36]. The SSAC is the national or domestic safeguards program to prevent the diversion of nuclear materials by either criminal or political groups for illegitimate use elsewhere. SSAC's serve two purposes. The first purpose is to maintain nuclear material accountability and provide adequate physical security at the national level. The second purpose is to provide information on the quantity and location of nuclear materials to the IAEA for verification purposes[36].

The IAEA safeguards objective, at the international level, is "to detect the diversion of significant quantities of nuclear materials from peaceful nuclear activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purposes unknown, and the deterrence of such diversion by the risk of early detection"[36]. IAEA Safeguards work is thus primarily one of inspection and verification of SSAC accounting and control activities, to ascertain that there is no diversion of nuclear materials especially by the state for national purposes that are contrary to the provisions of the NPT.

The basic element of IAEA Safeguards is nuclear material accountability with a combination of containment and surveillance (C/S) as complementary measures. Nuclear material accountability is accomplished by material balances and physical inventories by inspectors from the IAEA Safeguards Directorate. Containment and surveillance functions are employed to support material accountancy during verification inspections to ensure non-duplicity of inventory, secure IAEA instrumentation devices and working papers from tampering, and to extend the validity of verified physical inventories of discrete fuel items[37].

APPENDIX B

PSEUDO-RANDOM NUMBER GENERATION

Random digits are digits generated by repeated independent drawings from a set { 0, 1, 2, . . ., 9 } where the probability of selecting any one digit is 0.1. A group of n succesive random digits forms what is known as an n-digit random number[38].

Pseudo-random numbers (PRN) are random numbers generated in a deterministic way. Most common methods start with an initial number, and use this number to generate the second number of the sequence. The second number is used to generate the third and so on. Such processes are usually periodic and care must be exercised to select a method with a reasonably long period.

A widely used method of PRN generation is the congruence or residue method[38, 39]. In mathematical notation the congruence method is expressed as:

$$C_{n+1} = (\lambda C_n + \mu)(\text{Modulo } P) \quad n = 0, 1, 2, \ldots \tag{B-1}$$

where C_0 is the starting number or "seed", and λ , μ and P are constants. The value of the constants λ, μ, and P used must be carefully tested to insure sufficient randomness of the generated PRNs.

To generate the 50 digit PRN for the seal identification message, a pseudo-random number subroutine will be required. The particular values of λ, μ, and P chosen for this design study are values used in Texas Instruments calculators[40]. These constants are $\lambda = 24298$, $\mu = 99991$ and $P = 199017$, with the limits of the seed C_0 being $0 < C_0 < 199017$. The sequence will have a period equal to P (i.e.

199017).

The seal serial number could be used as the basis for the seed to initiate the sequence except that the ten-digit seal serial number is not within the limits of C_o defined in Eq. B-1. A scheme to select a seed that is in the range $0 < C_o < 199017$ is required. One such scheme is to consider the ten digit seal serial number as a collection of numbers in the form $a_1\ a_2\ a_3 \ldots a_{10}$ where a_i is an individual digit. The seed C_o can then be selected by choosing either every even or odd i such that C_o will be a collection of numbers in the form of either $a_1\ a_3\ a_5\ a_7\ a_9$ or $a_2\ a_4\ a_6\ a_8\ a_{10}$. Either number will consist of 5 digits which will be less than the 6 digit number 199017.

The resultant PRN can be adjusted to be in the range (0, 1) and only the first five significant digits retained. Multiplication of this five digit decimal number by 10^5 would yield a five digit PRN. A total of ten iterations of Eq. B-1 will be required to obtain ten sets of five digits. These will be combined together to form the desired 50-digit PRN. This PRN generation process is illustrated in Figure B-1.

More complex permutations of this process can enhance the PRN generation scheme by clever programming. A possible permutation scheme may be the random ordering of the ten 5 digit PRNs when forming the 50-digit PRN message; other permutations can also be readily devised.

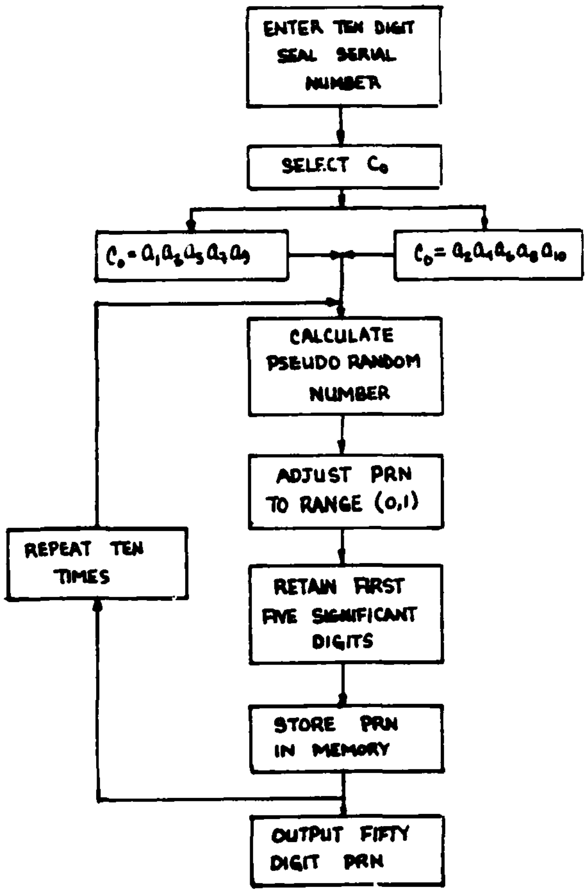

FIGURE B-1 Flow Chart for Pseudo-Random Number Generation

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THE CONCEPTUAL DESIGN OF A MAGNETIC TAPE SEAL SYSTEM.(U)
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APPENDIX C

CONVERSION TABLE BINARY-DECIMAL-HEXADECIMAL

Binary	Decimal	Hexadecimal
00000000	000	00
00000001	001	01
00000010	002	02
00000011	003	03
00000100	004	04
00000101	005	05
00000110	006	06
00000111	007	07
00001000	008	08
00001001	009	09
00001010	010	0A

APPENDIX D

ULTRASONIC WELDING TECHNIQUES

Ultrasonic welding of thermoplastic components offers a fast (cycle time approximately 2-3 seconds), inexpensive (modest labor demands, easily automated) and durable technique for bonding parts with flash free joints. The basic equipment requirements for ultrasonic welding are shown in Figure D-1.

A transducer is used to convert 20 KHz electrical energy into mechanical energy in the form of vibrations. The welding "horn", in intimate contact (under pressure) with one of the components to be welded, transmits the mechanical vibrations through that part to the joint interface. An out-of-phase condition is created at the joint because the other component is firmly fixed. Friction and alternating high frequency stress heat and then melt the touching plastic surfaces to form a homogenous mixture. The pressure is maintained until the joint is solidified in order to form a high strength bond.

Three basic types of joint designs have been developed for use in ultrasonic welding[41-43]. They are the energy director joint, the shear (or interference) joint and the scarf joint. The energy director joint is the most commonly used joint desigr ... .. also the joint selected for use in the magnetic tape se.l device.

In this design, the energy director joint is a projection from one of the mating surfaces of the joint. The projection serves to concentrate the mechanical-vibratory energy onto a small contact area, which speeds up the melting process. Recommended proportions of the projection are illustrated in Figure D-2.

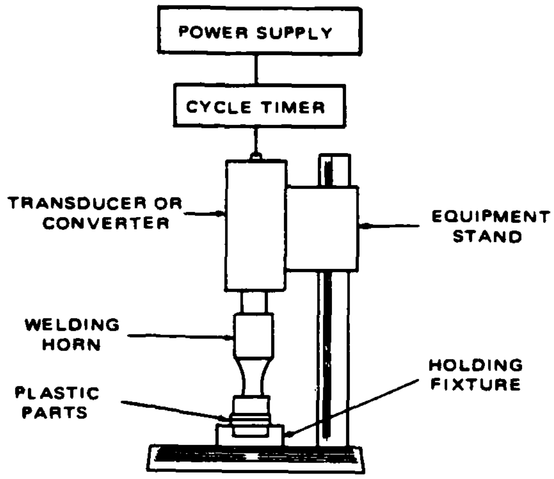

FIGURE D-1 Basic Equipment Requirements for Ultrasonic Welding (From Design Handbook, E.I. Dupont & Co., 141-144, 1972)

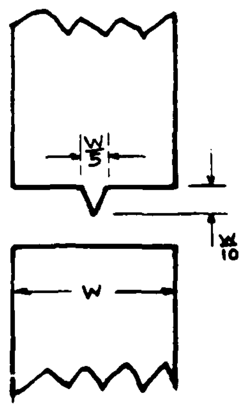

FIGURE D-2 Recommended Joint Proportions for Energy-Director Joint Design (From A Designer's Guide to Ultrasonic Assembly, Plastic Design Forum, 81-86, Nov/Dec 1980)

The energy director projection is to be incorporated in the upper portion of the seal housing and placed around the perimeter. Nominal dimensions of the joint are illustrated in Figure D-3.

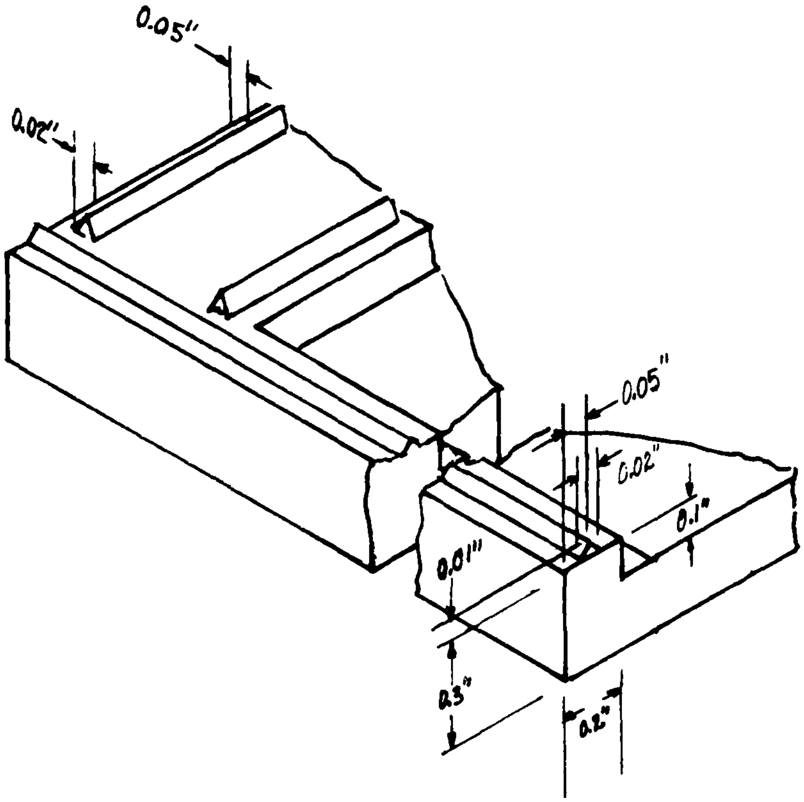

FIGURE D-3 Nominal Dimensions of Energy-Director Joint for Magnetic Tape Seal

APPENDIX E

COMPONENTS LIST FOR THE LIU MICROCOMPUTER SYSTEM

TABLE E-1 Component Parts List

MAIN SYSTEM MICROCOMPUTER	Quantity	Unit Cost*	Total Cost	Supply Voltage	Supply Current	Remarks
Intel 8085 Central Processor	1	18.00	18.00	5v + 5%	170 mA	40 pin configuration
Crystal	1	4.51	4.51			10 MHz
Diode (IN914)	1	0.26	0.26			
Resistors	4	0.13	0.52			
Capacitor	1	0.10	0.10			
Crystal socket	1	1.54	1.54			
Intel 8755A EPROM	2	84.00	168.00	5v + 5%	180 mA	40 pin configuration
Intel 8185 STATIC ROM	1	40.00	40.00	5v + 5%	100 mA	18 pin configuration
Intel 8741A Universal Peripheral Interface 8-bit Microcomputer	1	77.70	77.70	5v : 10%	125 mA	40 pin configuration
Braemar CM-600 Mini-Dek Tape Transporter	1	125.00	125.00	5v + 5%	700 mA	700 mA in rewind mode; typical 250 mA
	SUBTOTAL:		$435.63			

TABLE E-1 Component Parts List (Cont.)

SEAL INTERFACE DEVICE	Quantity	Unit Cost	Total Cost	Supply Voltage	Supply Current	Remarks
Intel 8279 Keyboard and Display Peripheral Interface	1	17.70	17.70	5v ± 5%	120 mA	40 pin configuration
Microswitch 16NW1-1 16 Key Keypad	1	15.00	15.00	5v ± 5%	6-20 mA	
Monsanto MANIA (RED) 7-Segment LED Display	10	1.50	15.00	5v	20 mA	0.3" height
Texas Instruments SN 74154 4-16 Line Decoder/Multiplexer	1	2.20	2.20	5v ± 5%	34 mA	For LED display and LED lamps
Texas Instruments 75491 4 Line LED Driver	1	0.79	0.79	5v ± 5%	1.6 mA	
Texas Instruments 75492 6 Line LED Driver	2	0.89	1.78	5v ± 5%	1.6 mA	
LED Indicator Lamps	5					
Monsanto MV 5252 (Green)	2	0.88	1.76	5v		Verification indicators
Monsanto MV 5302 (Yellow)	2	0.88	1.76	5v		Manual SID input indicators

TABLE E-1 Component Parts List (Cont.)

	Quantity	Unit Cost	Total Cost	Supply Voltage	Supply Current	Remarks
SEAL INTERFACE DEVICE (Cont.)						
Monsanto MV 5752 (Red)	1	0.88	0.88	5v		Non-verification indicators
Intel 8085 Central Processor	1	18.00	18.00	5v + 5%	170 mA	
Crystal	1	4.51	4.51			
Crystal Socket	1	1.54	1.54			
Diode	1	0.26	0.26			
Resistor (+ 5%)	4	0.13	0.52			
Capacitor	1	0.10	0.10			
Intel 8755A EPROM	1	84.00	84.00	5v + 5%	180 mA	
Intel 8156 RAM	1	40.00	40.00	5v + 5%	100 mA	
National Semiconductor LM 324 QUAD OP AMP	1	0.69	0.69			
IN914 Diode	2	0.26	0.52			
Resistors (1/4 watt + 5%)	13	0.13	1.69			
Capacitors	4	0.10	0.40			

TABLE E-1 Component Parts List (Cont.)

	Quantity	Unit Cost	Total Cost	Supply Voltage	Supply Current	Remarks
SEAL INTERFACE DEVICE (Cont.)						
Microcassette Recorder	1	85.00	85.00	3v		Separate power supply
	SUBTOTAL:		$294.12			
POWER SUPPLY						
Transformer 20:1 Center Tap	1	21.49	21.49			
Microswitch with Lamp	1	2.50	2.50			On-off switch
DPDT Toggle Switch	1	2.50	2.50			Battery recharge switch
VM08 Bridge Rectifier	1	1.12	1.12			
Intersil ICL 8211 Integrated Chip	1	2.50	2.50			
LED Indicator Lamp	1	0.88	0.88			
In4001 Diode	2	0.23	0.46			
Eveready N-91 6v Nickel-Cadmium Rechargeable Battery	8	13.75	110.00	6v	9.6 A-Hr	1.2 A-Hr max. drain per battery

TABLE E-1 Component Parts List (Cont.)

	Quantity	Unit Cost	Total Cost	Supply Voltage	Supply Current	Remarks
POWER SUPPLY (Cont.)						
Power Supply 5v 5A	1	115.00	115.00	5v	5A	Optional; required only for development phase
Fuse w/Fuse Holder	1	2.45	2.45			
Resistors (12 watt ± 1%)	5	0.75	3.75			
Capacitor	1	0.10	0.10			
	SUBTOTAL:		$147.75			
MISCELLANEOUS ITEMS						
Vector board, prepunched 17" x 8.5" (L x W)	2	12.90	25.80			
Wire 100' spool	2	6.10	12.20			
Miscellaneous resistors and capacitors			5.00			
	SUBTOTAL:		$43.00			
	TOTAL:		$920.50			

Note: * Unit costs obtained from local distributors based on order quantity of 1-12

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