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# APPLIED RESEARCH LABORATORY



## Final Report

# COMPUTER AUTOMATION of ULTRASONIC TESTING

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**GENERAL DYNAMICS**
*Convair Aerospace Division*
*Fort Worth Operation*

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# COMPUTER AUTOMATION OF ULTRASONIC TESTING

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# FOREWORD

This final report was prepared by the Convair Aerospace Division of General Dynamics under Contract No. NAS8-28652, Computer Automation of Ultrasonic Testing, for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Quality and Reliability Assurance Laboratory, Analytical Operations Division, with Melvin C. McIlwain as Project Manager.

Personnel involved in the execution of this program are (a) CAD/FWO: Dr. B. G. W. Yee (Program Manager), E. E. Kerlin, A. H. Gardner, D. Dunmyer, T. G. Wells, J. A. Regalbuto, A. R. Robinson, J. S. Kunselamn, T. C. Walker; and (b) NASA/MSFC: Mel McIlwain (Program Monitor) and H. Newberry.

# ABSTRACT

This final report describes a prototype computer-automated ultrasonic system developed for the inspection of weldments. This system can be operated in three modes: manual, automatic, and computer-controlled. In the computer-controlled mode, the system will automatically acquire, process, analyze, store, and display ultrasonic inspection data in real-time. Flaw size (in cross-section), location (depth), and type (porosity-like or crack-like) can be automatically discerned and displayed. At the end of the inspection, the results and the pertinent parameters of the inspection are recorded on paper copies and in permanent storage in computer disk files for future comparison.

The system can operate selectively in the ultrasonic reflection (compressional wave), shear wave, or Delta-Scan method for weld inspection. Delta-Scan and reflection inspection results on ½-in. thick 2219-T87 Al welds are presented. The real-time displays of inspection results are at a selected threshold level. However, during the post-inspection analysis, the results can be displayed at any desired level to facilitate the discrimination of critical flaws.

A Digital Equipment Corp. general-purpose PDP 11/45 computer system consisting of the following major components was used: 20K memory, 2 Decpack Disk-Cartridge Data Storage (2.4-million words), 8 channels of analog-to-digital, 4 channels of digital-to-analog, 5 channels of digital-to-digital, high-speed paper tape reader and punch, and special-purpose counters. The display units used are Tektronix 4002A computer interface terminal with a Tektronix 4610 hardcopy unit.

The ultrasonic unit is based on an Automation Industries UM 771 reflectoscope with gates, logic circuitry, and programmable computer gain control added as needed by General Dynamics. The scanner was built under a separate contract by SPACO, Inc., of Huntsville, Alabama, to scan an effective area of 11.5 x 27-in. The scanner is driven with digital stepping motors for an effective speed range of 0.1 to 10 in./sec in either axis and index in the alternate axis from 0.010 to 0.200 in. in increments of 0.010 in.

The Delta-Scan transducer head assembly can be rotated from 0 to 90 deg. This allows the sound energy to enter the specimen from parallel to normal to the weld line. The software corrects the display for the change in relative location of the receiving transducer.

Another feature of the system is the computer-controlled Delta-Scan transmitting angle to permit sound propagation inside the metal to vary from approximately 40 to 90 deg. This feature can produce nearly equal energy density throughout the thickness of the part to be inspected for parts with varying thickness.

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# I. INTRODUCTION

The increasing demand for rapid and reliable inspection of fabricated articles such as welded pressure vessels and structural members of the Space Shuttle, necessitates the expansion and automation of nondestructive evaluation (NDE) techniques and systems. Currently, the technique most in need of and amenable to automation is ultrasonic testing. While many laboratory investigations have shown ultrasonics to be superior to other NDE techniques for detecting tight flaws such as fatigue cracks and lack of fusion in weldments, the inspection technique is still not widely accepted for routine inspections. The two major reasons for this lack of acceptance are (1) the complicated signal analysis which must be performed by the inspector to interpret defect responses and (2) the test records provided by the inspection are not sufficiently detailed to determine quality of the inspection upon subsequent review. These shortcomings can only be overcome by the development of an automated test system which would perform the test, interpret the defect responses, and produce detailed test records which could be reviewed at any time to determine the quality of the inspection. Such an automated system would provide a cost savings in terms of manpower and provide higher accuracy and dynamic range for the test.

This program was initiated with the aim to increase the reliability of welds inspections, and, at the same time, to reduce the cost of inspection. While computer-automated ultrasonic inspection might not be the final answer to many inspection problems, when applied judiciously, it could reduce cost without compromising quality when large numbers of components with similar geometry are inspected.

The original objectives of this program to develop a Computer-controlled Ultrasonic Inspection System have been met. The system operates in a near-real-time environment, analyzes the sensor data for indications of anomalies, records the flaw anomalies on disk, and generates flaw data displays and records.

The system operates primarily in the reflection and Delta-Scan mode, and has been programmed to operate in the shear wave mode. Both the amplitude-gate and advanced signal counting methods are employed with the Delta-Scan for flaw detection.

This is the final report on the prototype development contract. The system was delivered to NASA during May 1974 for evaluation and operation.

The report is organized to provide the reader with ready access to the information desired. Section II presents an overview of the system and shows a block diagram of the components. Section III presents the standard ultrasonic equipment bought and special interface items built. Section IV discusses the X-Y Mechanical Scanner System and components. Section V discusses the computer, display, and some computer interface items. Section VI gives an overview of the software. Section VII presents results from system operation and shows representative test data from Delta-Scan and reflection mode testing on test panels supplied by NASA.

The program was performed in phases with a report generated at the completion of each. Phase A was the Technology Survey and Preliminary Design and is reported in Ref. 1. Phase B was to design and build the interface hardware to connect the UM 771 reflectoscope, X-Y scanner, and Delta head motor drive to the PDP 11/45 computer system (Ref. 2). Standard ultrasonics and computer components were utilized and the special interface items were custom designed by Convair Aerospace. A special X-Y scanner was provided by NASA for incorporation into the system.

Phase C of the contract was to develop special software for the system. The software was developed concurrently with the hardware, but is documented in a separate report, Ref. 3. The program operates in a real-time environment, analyzes the sensor data for indications of anomalies, records flaw anomalies on disk, and generates flaw data displays and reports.

An Operating and Maintenance Manual has been prepared and is listed as Ref. 4. A complete set of wiring diagrams for the interface components and connection cables is on file at NASA.

## II. DESCRIPTION OF SYSTEM

The prototype computer-automated ultrasonic inspection system utilizes a PDP 11/45 general-purpose computer for real-time control, data acquisition, data processing, data recording, and data display for ultrasonic inspection of flaws in aluminum welds. The system can operate selectively in reflection, shear wave, and Delta-Scan modes. Both the amplitude-gate and advanced signal-counting methods are employed with the Delta-Scan for flaw detection. The thickness of the component under inspection is monitored continuously, and this information used to control the angle of incidence for the transmitting transducer of the Delta-Scan to provide uniform sensitivity for components of different thicknesses.

The computer will analyze incoming ultrasonic signals for indications of anomalies. Any indication with an amplitude above a predetermined threshold level will be recorded as a flaw, and the X-Y coordinate where the indication occurred will also be recorded along with other pertinent parameters. The computer also controls the sensitivity setting on the ultrasonic equipment to compensate for transducer variations, equipment variations, and far-field effects. This operation not only provides equal sensitivity for detection of flaws located at different depths of the computer, it will also minimize calibration and setup time. The computer also monitors the liquid coupling between the transducers and the component under inspection. Inspection will commence only if the computer decides that the sound energy is adequately coupled into the component.

The prototype system utilizes standard ultrasonics and DEC computer components along with special interface items custom designed by Convair Aerospace. These components have been integrated and the computer software developed to fulfill the objectives of the contract for automatic scanning of aluminum welds. The X-Y scanner will operate in manual, automatic, or computer modes. The manual and automatic modes are primarily used during setup and calibration. When connected to the PDP 11/45 computer and set in computer mode, the initiation of each scan and scanning speed are controlled by the computer. The amount of index used during inspection is thumb-wheel controlled from the front panel of the control console. The X and Y scan limits are controlled by adjustable limit switches mounted on the scanner frame.

The display of the flaw signals on the Tektronix memory scope with a $8\frac{1}{2}$ x $6\frac{1}{2}$-in. screen is in real-time. Flaw amplitudes of twenty percent (20%) of the reference signals are displayed at the corresponding X-Y coordinates. The real-time displays are one-third actual size. However, in post mortem analysis, the display can enlarge the scale with the maximum expansion ratio of 4 to 1. Also, the display can be for any percentage of the reference signal.

Figure 2-1 is a block diagram of the prototype system. The system is roughly made up of four subsystems: the ultrasonic unit; the mechanical scanner, its control console, and the ultrasonic head assembly; the computer and the electromechanical interface components; and the display and hard copier unit. Figure 2-2 is a picture of the PDP 11/45 computer and its peripheral components and the Tektronix Model 4002A display with the 4601 hard copier. Figure 2-3 is a picture of the ultrasonic unit and the X-Y mechanical scanner with its control console. The detail operation and progress made on these subsystems as well as computer software development will be described in Sections III, IV, V, and VI of this report. Section VII presents the results of system operation and evaluation at General Dynamics.

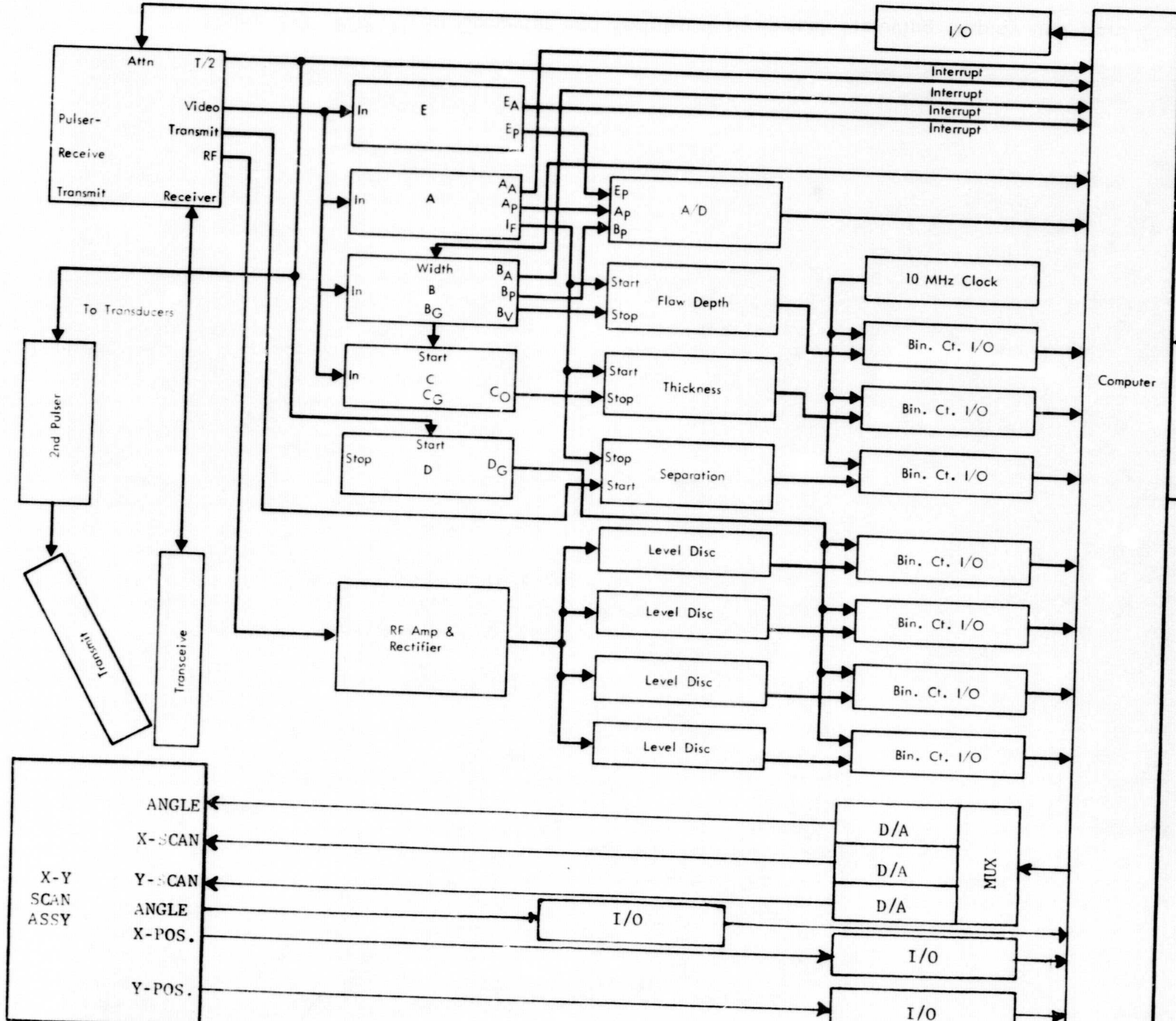


Figure 2-1 System Block Diagram

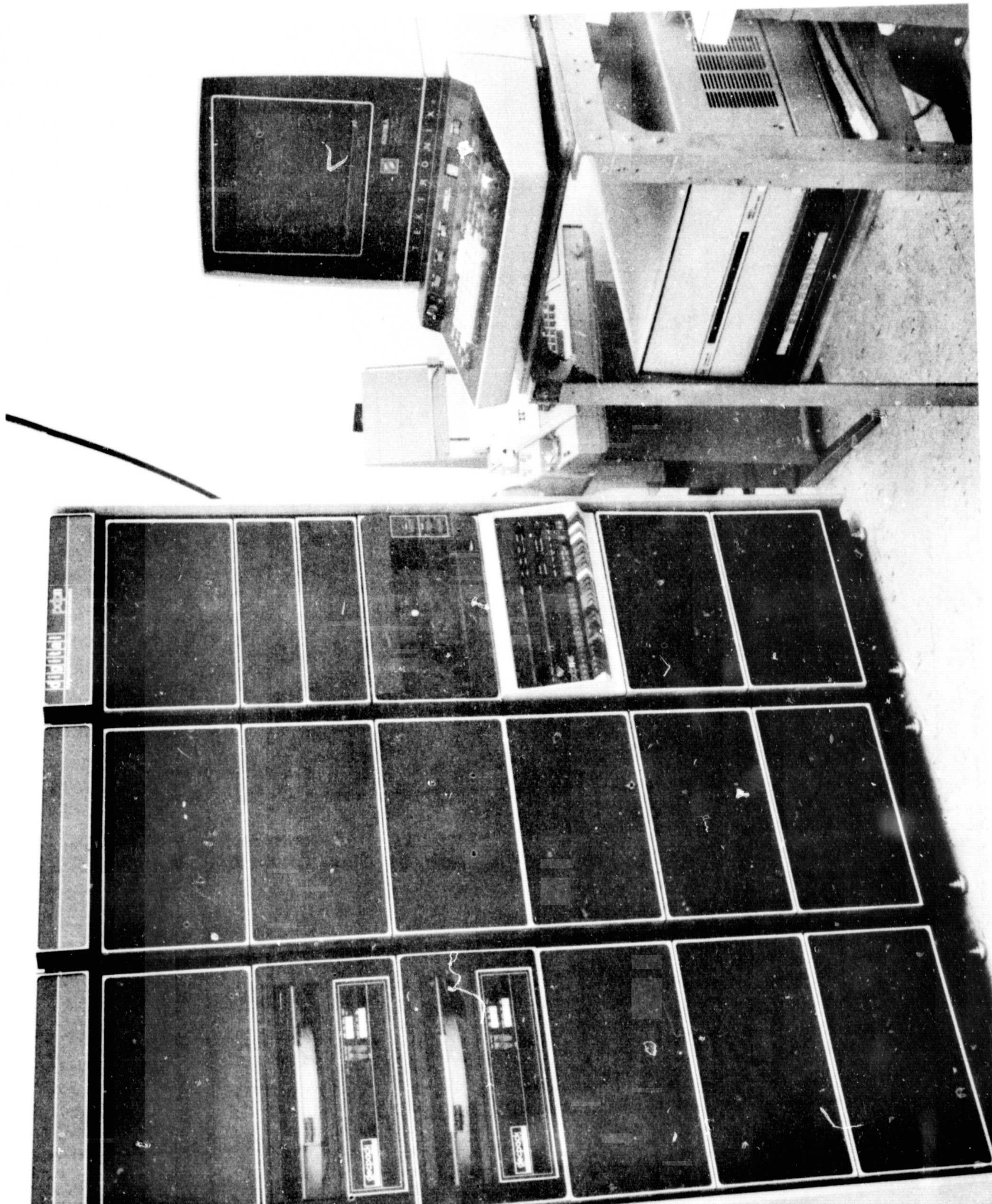

Figure 2-2 PDP 11/45 Computer and Peripheral Equipment Including Display and Hard Copier

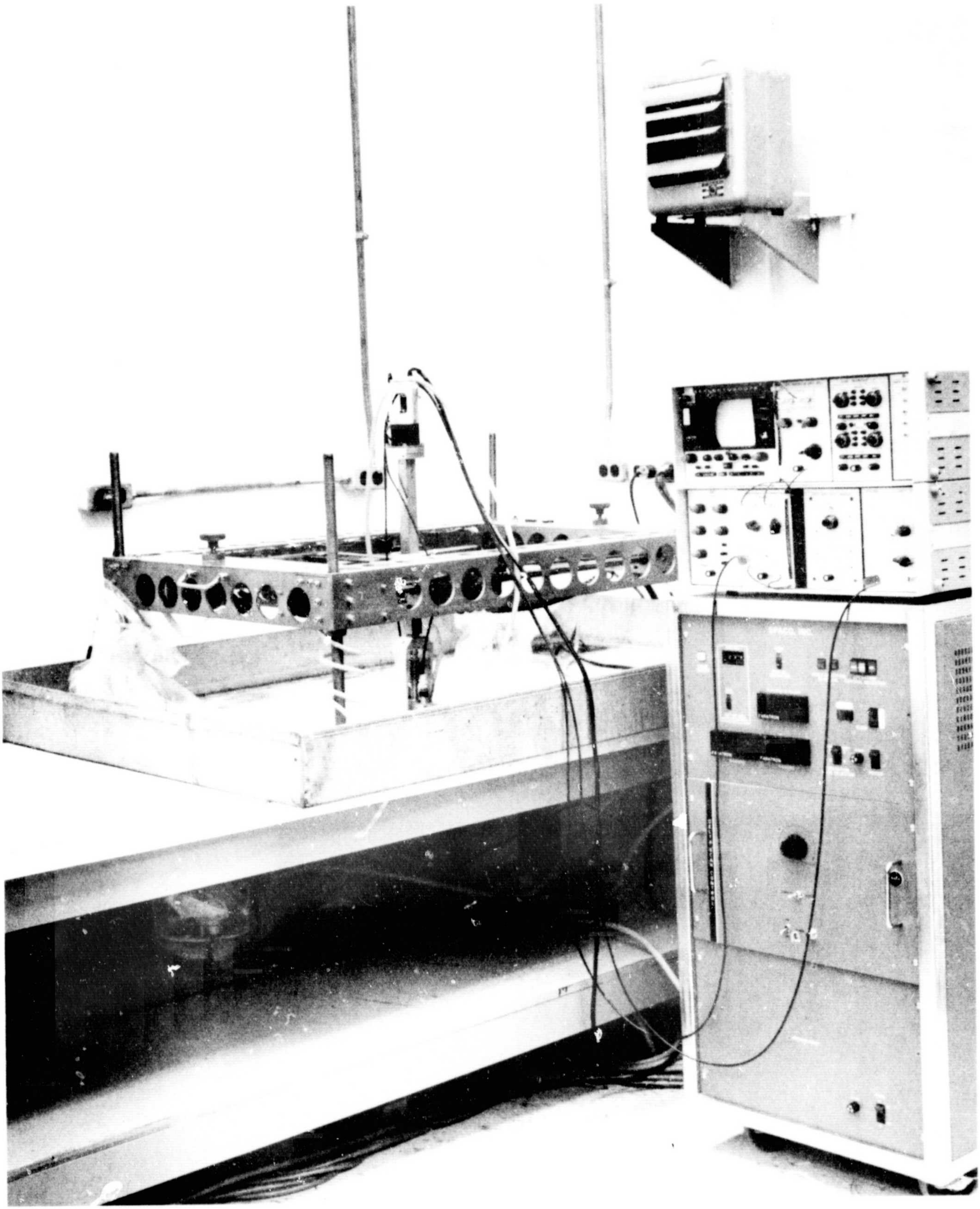

Figure 2-3 X-Y Scanner, Control Console, and Reflectoscope

# III. ULTRASONICS

This section describes the ultrasonic equipment and components used to permit both normal and computer-controlled operation in the reflection, Delta-Scan, and shear wave modes. A description of the ultrasonic equipment is presented in Section 3.1, the signal conditioning and timing requirements for computer interfacing are presented in Section 3.2, and the Delta-Scan head transducer assembly is described in Section 3.3.

## 3.1 Ultrasonic Equipment and Components

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

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

The above system was purchased for the contract and received in February 1973, and a detailed check of the system circuits was performed and found to operate satisfactorily after some modification. A photograph of the UM 771 Reflectoscope and Special-Function Chassis is shown in Figure 3-1.

### 3.1.1 UM 771 Display Chassis

This unit contains the cathode-ray display tube, 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 is 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 are:

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

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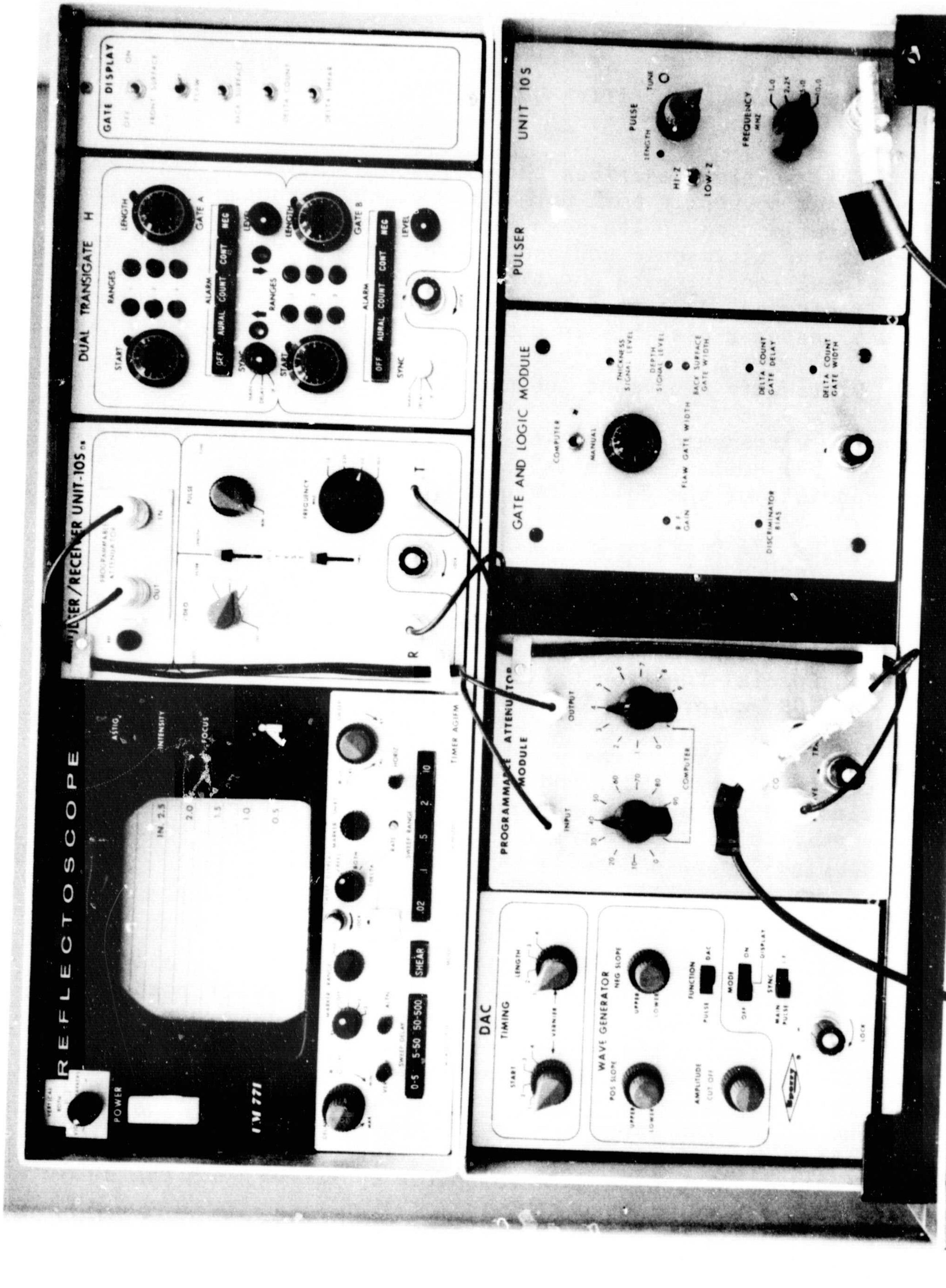



Figure 3-1 Ultrasonic Test Unit for Computer Automated System

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

3.1.2 Type 10S db Pulser-Receiver

This unit is used for the reflection mode pulser and the system receiver.

The pulser/receiver has been modified as listed below:

- An emitter follower has been added to feed the r.f. signal at the base of transistor Q308 through a 50-ohm co-axial cable to the r.f. amplifier in the Delta-Scan counting circuit.
- The original attenuator in the pulser/receiver was removed and co-axial connectors added to connect the programmable attenuator in its place. This permits computer control of the receiver gain.

3.1.3 Type AGIFM Timer

This unit was described in paragraph 3.1.1.

3.1.4 Distance Amplitude Compensation Unit (DAC)

The Distance Amplitude Compensation Module is an unmodified Automation Industries, Inc., module. It is included in the system to provide amplitude compensation for signal attenuation in thick specimens. It is not used in the 1/4-inch and 1/2-inch thick plate scanning system because the change in signal amplitude for 1/2-inch of aluminum is not sufficient to justify its use. The left-hand module position of the special-function chassis is wired to accommodate the DAC only.

### 3.1.5 Dual Type H Transigate

The unit is used for the front surface gate which provides the coupling efficiency data, 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:

- 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.

- 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.

### 3.1.6 Special-Function Chassis

A top view of the special-function chassis is shown in Figure 3-2. It houses the five modular power supplies, the line

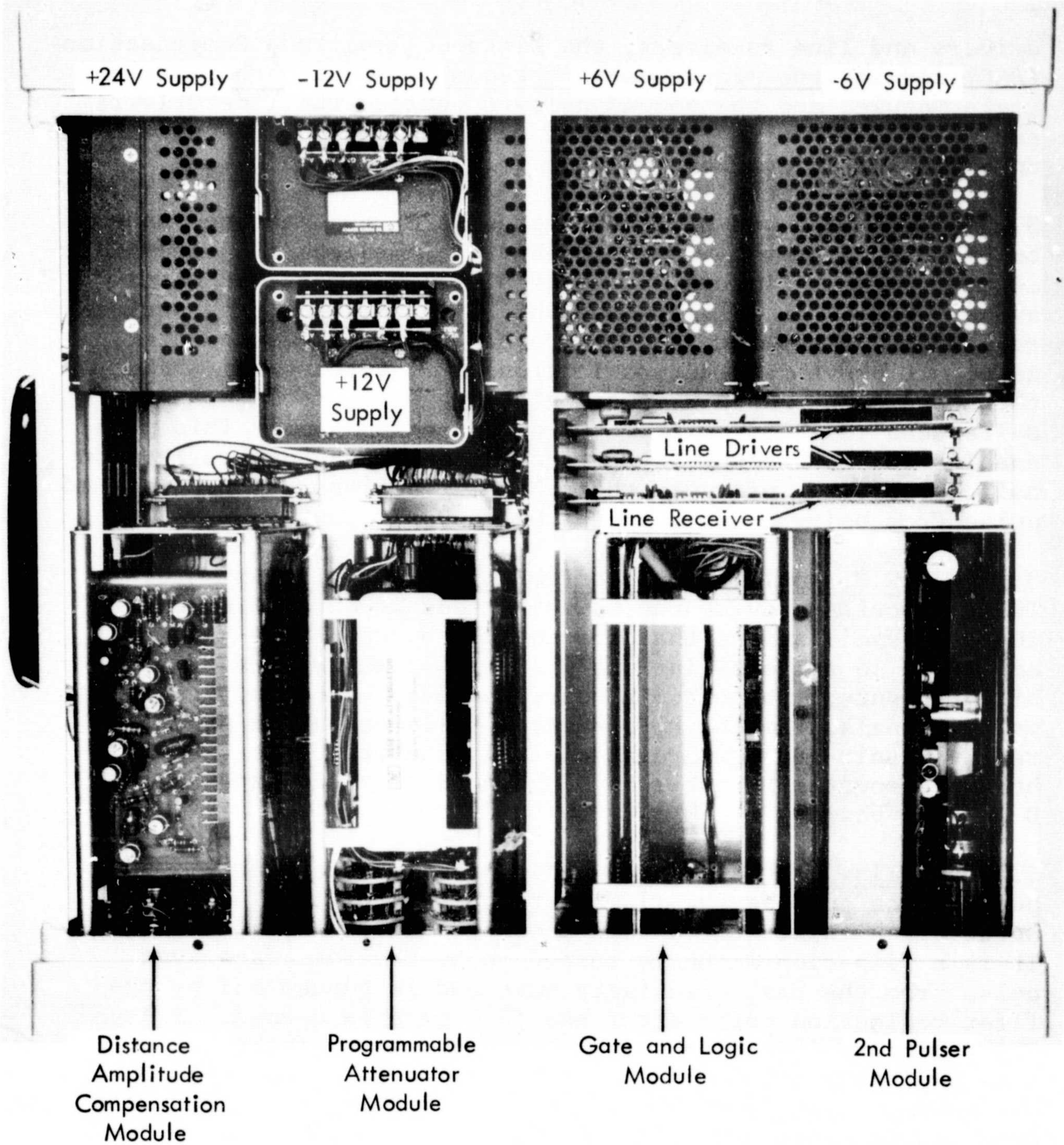



Figure 3-2 Top View of Special-Function Chassis

drivers and line receivers, the Distance Amplitude Compensation (DAC) module, the programmable attenuator module, the Gate and Logic module, and the second pulser module. The line drivers and receivers are to insure that the signals from the ultrasonic unit are sufficient in amplitude for computer processing.

3.1.6.1 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.

3.1.6.2 R.F. Amplifier, Rectifier, and Four Discriminators. These circuits provide the weighing factors on amplitude for the R.F. 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 R.F. emitter follower in the pulser/receiver unit and commercial digital counters. The circuit board is mounted in the same plug-in unit as the gates C and D circuit board.

3.1.6.3 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 is included on the circuit board with gates C and D, part of the Gate and Logic module.

3.1.6.4 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 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. This circuit is on the circuit board with the flaw depth circuit, C gate, and D gate.

3.1.6.5 Programmable Attenuator. This unit is used to replace the manual step attenuator in the ultrasonic pulser/receiver. Figures 3-3 and 3-4 show the front and back views of the completed module. 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 (Figure 3-2). The unit is digitally programmable in 1 db steps from 0 to 99 db. It will connect to the pulser/receiver with coaxial cables.

### 3.1.7 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.

### 3.1.8 10-MHz Clock Pulse Generator and Binary Counters

The clock pulse generator is a Digital Equipment Corp. flip-chip circuit board which plugs into the computer. It supplies 10-MHz pulses to the flaw-depth counter and thickness counter.

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, and four count the Delta-Scan r.f. oscillations from the four amplitude discriminators.

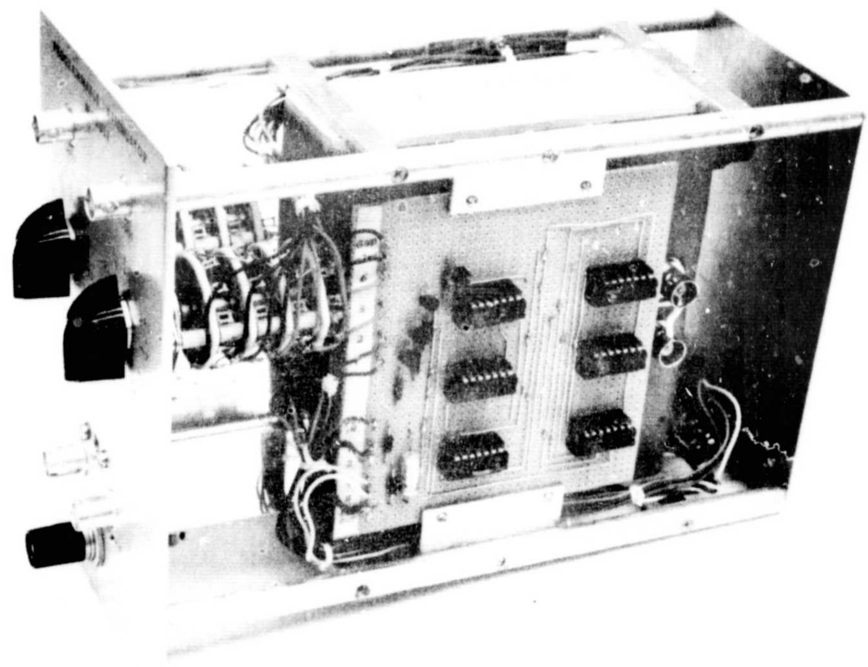


Figure 3-3  Front View of Programmable Attenuator

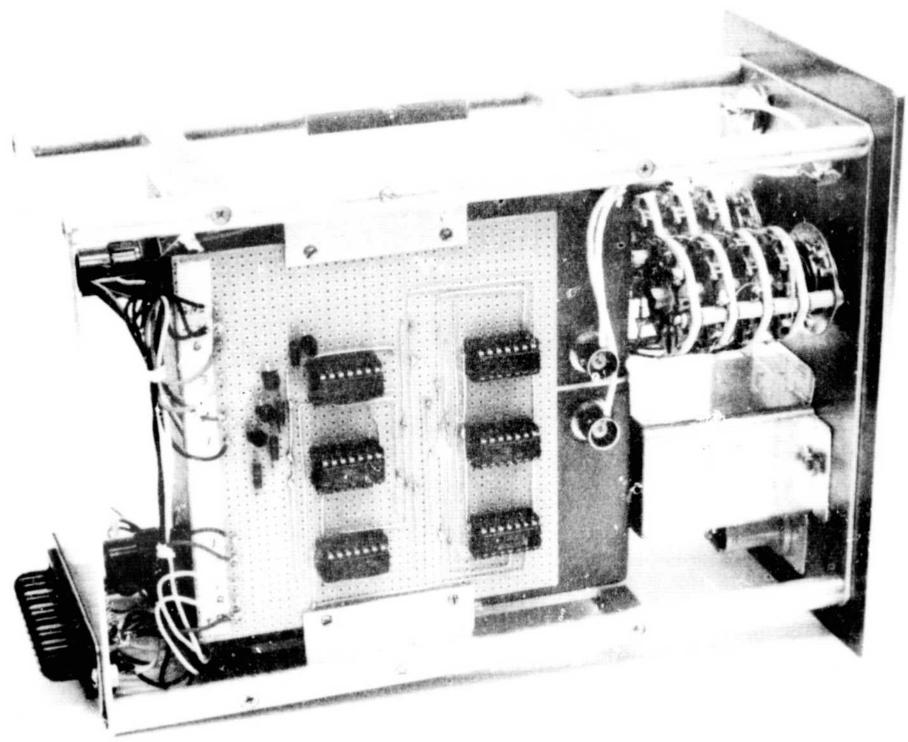


Figure 3-4  Back View of Programmable Attenuator

## 3.2 Computer Interface and Timing Requirements

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 2-1. The system will operate in three modes of inspection: reflection, Delta-Scan, and shear wave.

### 3.2.1 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 3-5.

3.2.1.1 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 3-6. 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 a 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 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.

3.2.1.2 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.

3.2.1.3 Back Surface. The back surface reflection is isolated by gate C which is a logic gate of constant width. This gate

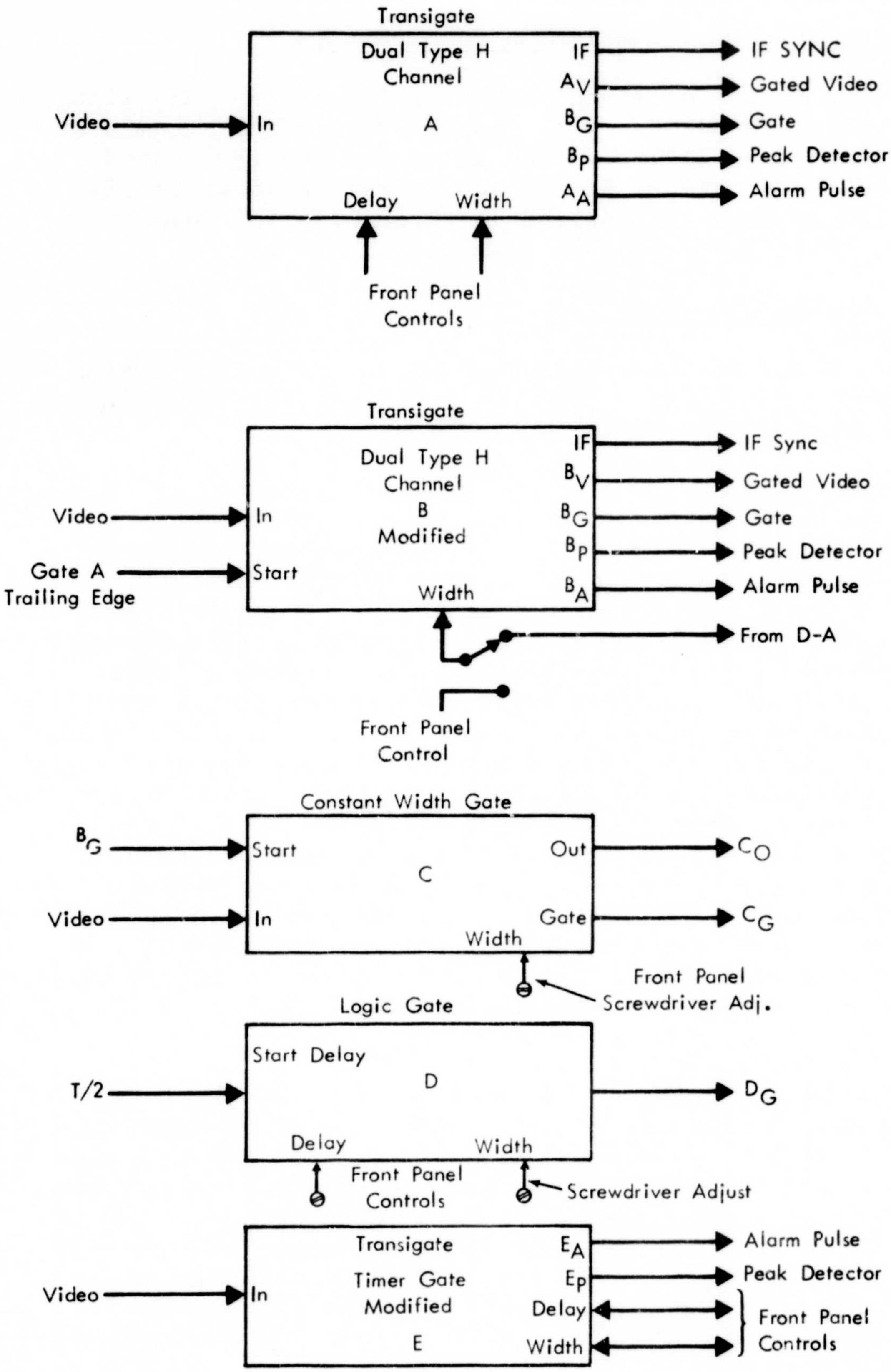



**Figure 3-5 Identification of Signal Abbreviations**

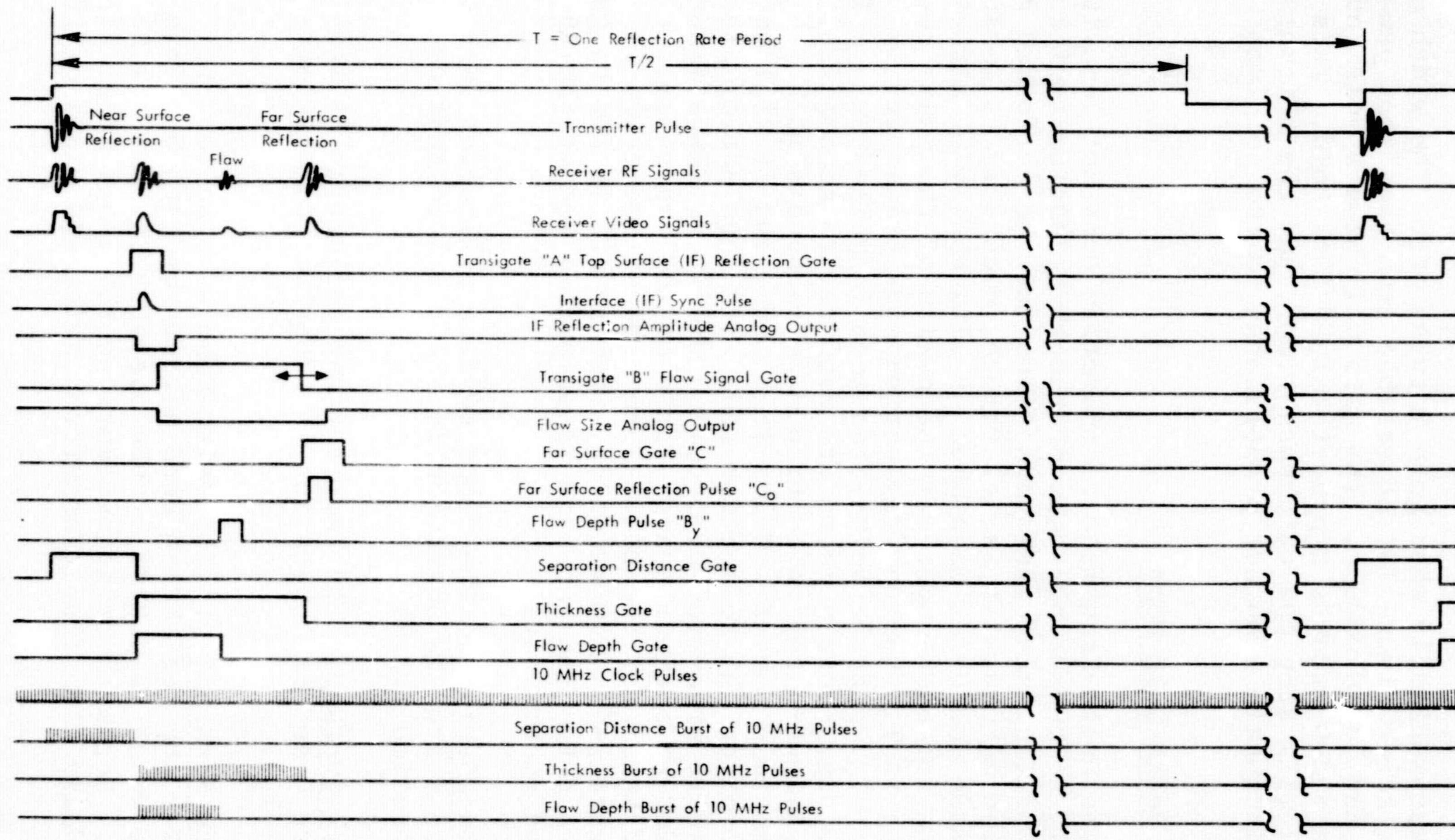



Figure 3-6 Reflection Mode Signal Timing Diagram

is started automatically when gate B turns off. The width of this gate is screwdriver-slot adjustable from the front panel of the gate and logic module. 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.

### 3.2.2 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 $t = T_0$, and the Delta-Scan mode is pulsed at $t = T/2$. Two separate ultrasonic pulsers are required to accomplish this mean. 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 yielded an optimum energy ratio of the two pulses. The timing diagram for the Delta-Scan mode of operation is shown in Figure 3-7. 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.

3.2.2.1 Front Surface. The front surface reflection is isolated by gate A and its operation is identical to that described in Section 3.2.1.1.

3.2.2.2 Back Surface. The back surface reflection is isolated by gate C and its operation is identical to that outlined in 3.1.1.3.

3.2.2.3 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.

3.2.2.4 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

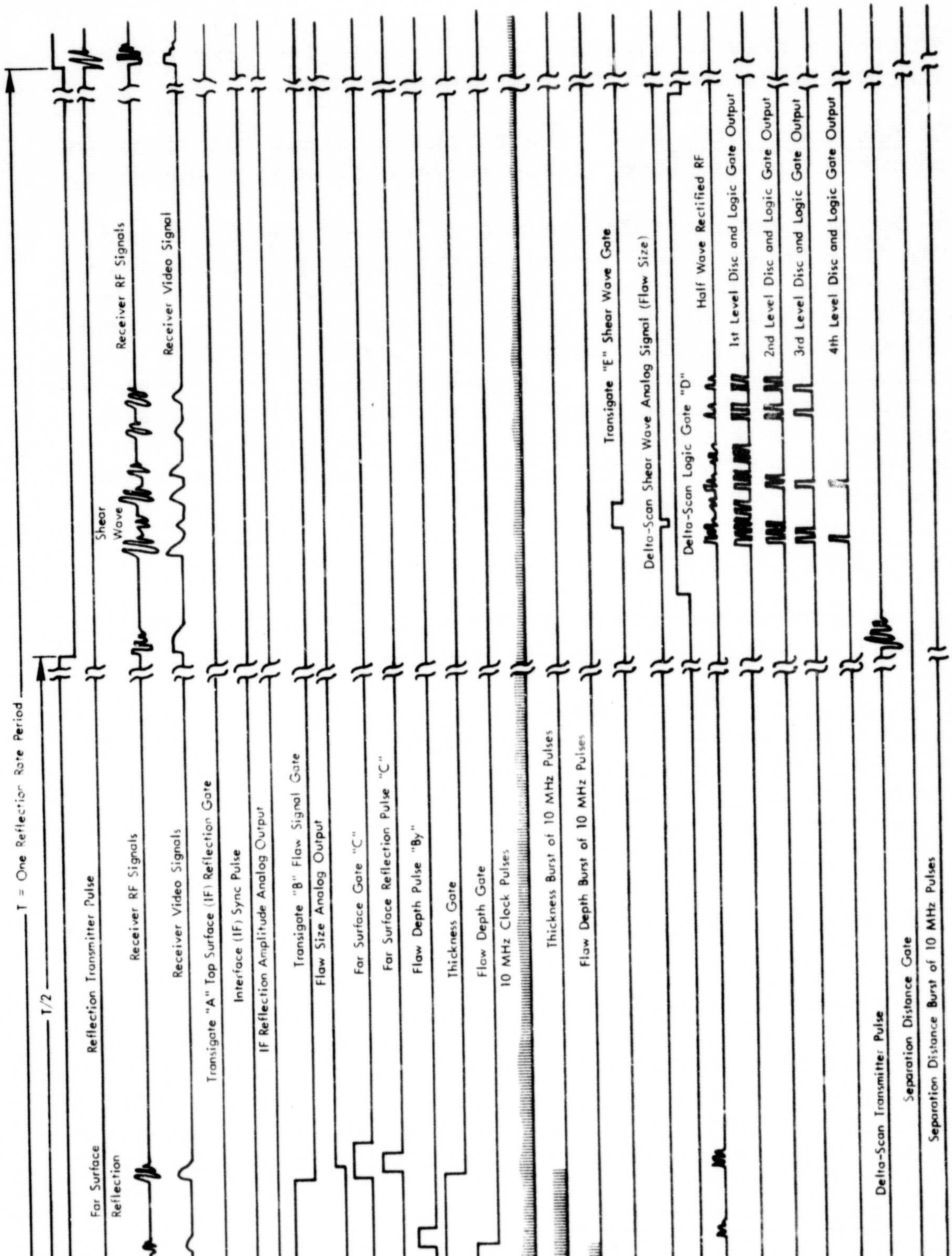



Figure 3-7 Simultaneous Delta-Scan Reflection Mode Signal Timing Diagram

computer that a flaw is present, and the relative size of the flaw is proportional to the peak detector output.

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

3.2.2.6 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 are four discrete values which were 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.

### 3.2.3 Shear Wave Mode

The received video output is fed to gate B. The timing diagram for the shear wave mode is shown in Figure 3-8.

3.2.3.1 Flaw Area. The received signal is isolated by gate B and is set by the operator during calibration. If the peak detector output exceeds a preset threshold, an alarm pulse generates an interrupt to the computer to indicate that a flaw has been encountered. The peak detector output is proportional to the size of the flaw.

## 3.3 Ultrasonic Head Assembly

The primary function of the inspection head for the automated test system is to maintain the ultrasonic transducer (or transducers) in a fixed geometrical relationship with the test article. In the reflection mode, this means that the transmit-receive transducer be kept perpendicular to the surface. The Delta-Scan mode has the additional requirement of varying the sending transducer inclination as a function of thickness.

### 3.3.1 Description of Assembly

The inspection head is mounted to the X-Y scanner by means of a vertical Z-axis shaft supported in a linear ball bushing. The Z-axis shaft and bushing are rectangular in cross section to eliminate rotation of the inspection head around the Z-axis.

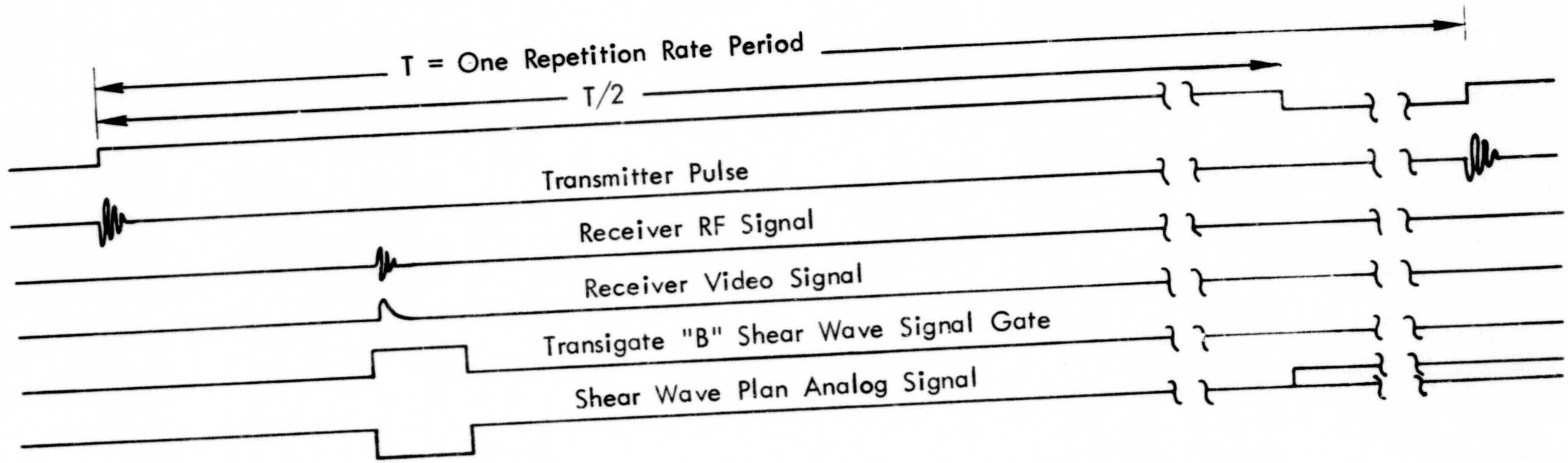



Figure 3-8 Shear Wave Mode Signal Timing Diagram

Figure 3-9 is a picture of the Delta-Scan ultrasonic head assembly installed on the X-Y scanner. A foam rubber boot is attached to the bottom of the transducer assembly. A teflon film is attached to the boot and acts as a wearing surface to contact the test specimen. Small holes perforate the membrane for water flow for coupling. Figure 3-10 is a drawing of the ultrasonic transducer head.

The pulse-echo and Delta-Scan receiving transducers are adjustably mounted within the inspection head. This allows axial alignment along the beam axis.

The head assembly is capable of $\pm 4.5^{\circ}$ tilt and 5.1 centimeters (2 inches) of Z-axis travel minimum. This will accommodate a radius of curvature of 3.6 meters (12 feet). Figure 3-11 is a drawing of the ultrasonic transducer head assembly.

The Delta-Scan head assembly is driven by a stepping motor located at the top of the Z shaft which makes 1 complete revolution to move the transmitting transducer $9^{\circ}$. The stepping motor moves $\pm 180^{\circ}$ to move the transmitting transducer $\pm 4\frac{1}{2}^{\circ}$. A 1-turn, 10-Kohm potentiometer is directly coupled to the stepping motor with a 1:1 gear ratio and $\pm 10$ Vdc is applied across the potentiometer. The output of this potentiometer is fed back to the computer for transducer position information. The thickness measurements will be made by the receiving transducer, eliminating the need for a separate thickness measuring transducer.

### 3.3.2 Operation of Delta-Scan Head

When operating in the Delta-Scan mode, it is desirable to adjust the angle between the transmitting and receiving crystals to receive the maximum reflected energy in the receiving crystal. This maximum sensitivity angle has been experimentally determined to be between 20 and $29^{\circ}$, depending on material thickness. Therefore, an electronic and mechanical system has been developed and built to adjust the angle from either the front panel switch or automatically from the computer. This electronic servo system has been placed in a separate chassis and located in the middle compartment of the scanning system control console.

The Delta-Scan system consists of a stepping motor geared to the ultrasonic transducer, a translator circuit, and a

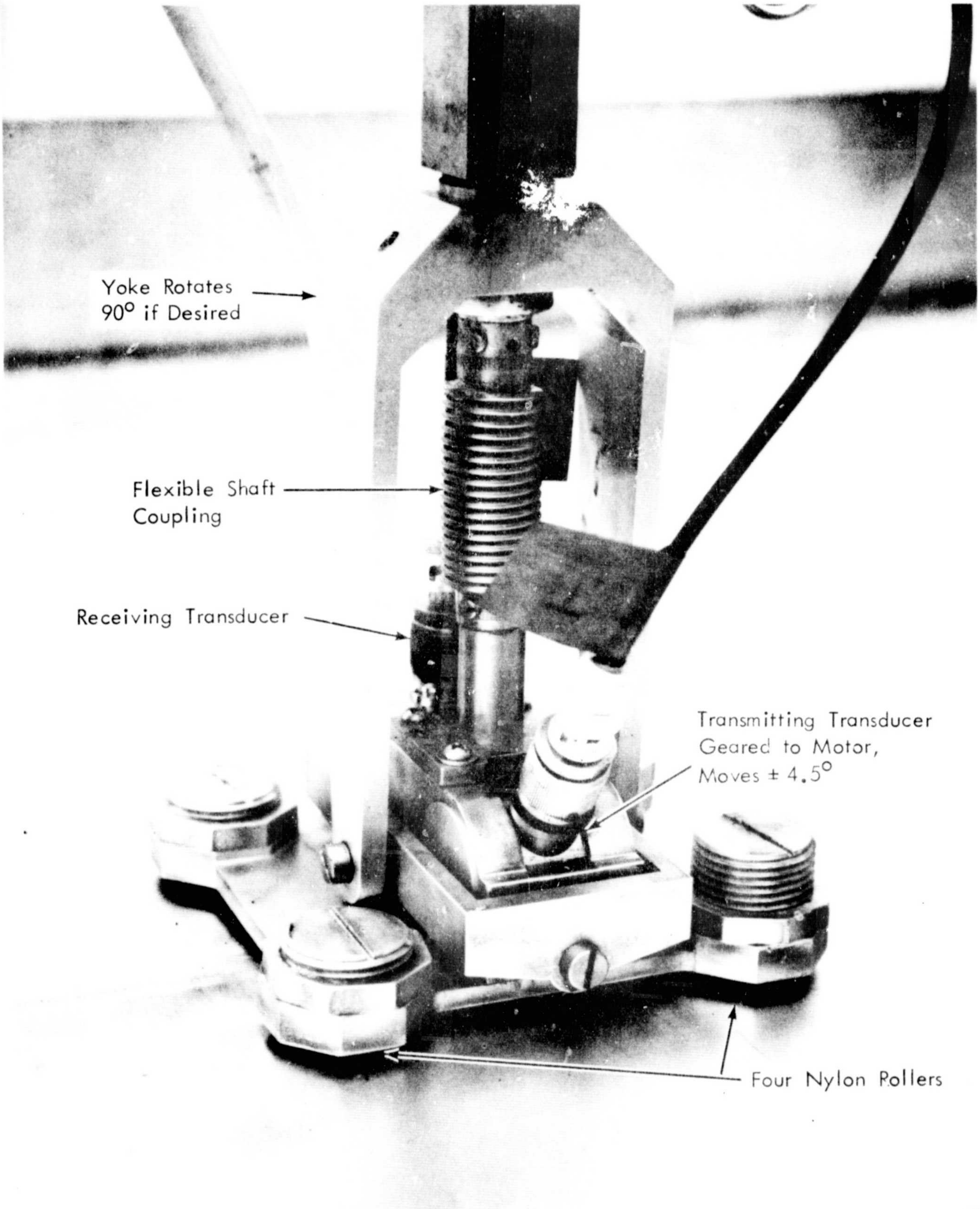



Figure 3-9 Picture of Ultrasonic Delta-Scan Transducer Assembly

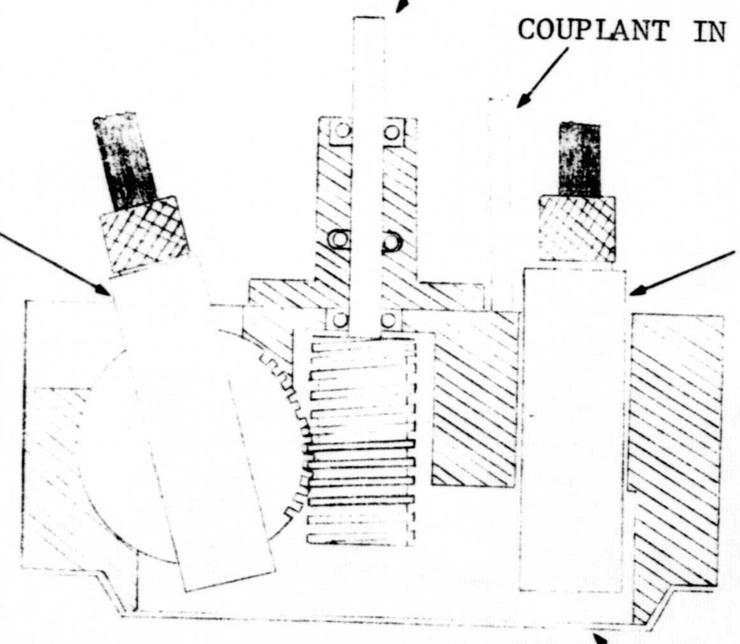



Figure 3-10 Delta-Scan Head with Variable Angle Transmitting Transducer

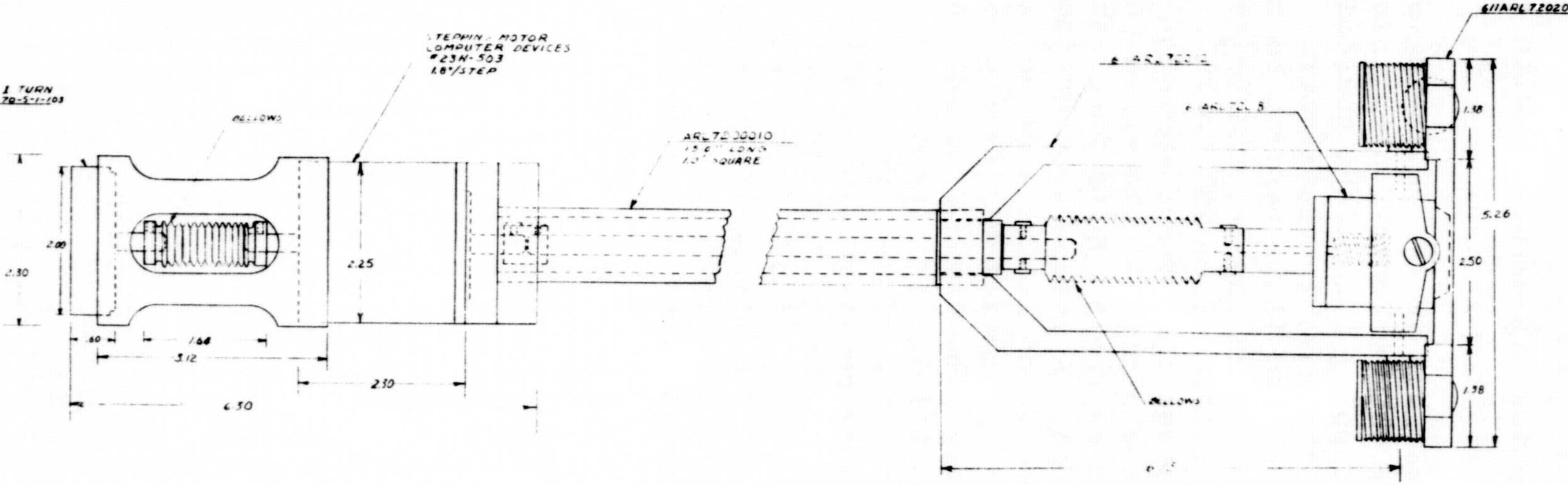



Figure 3-11 Drawing of Ultrasonic Transducer Head Assembly

comparator card. Two power supplies are used, one with +28 Vdc at 2A and one with -28 Vdc at 2A.

The system operation is described in the following paragraph. The system consists of a dc comparator, a translator or stepping motor driver, the stepping motor, the gearhead between the stepping motor, and the movable transducer. If the system is in manual operation, and it is desired to move the transducer from a $20^{o}$ angle to a $29^{o}$ angle, the Delta-Scan transducer angle switch is rotated from $20^{o}$ to $29^{o}$. This switch in turning feeds a dc voltage into the comparator input and the comparator then puts out a string of clockwise pulses to the translator card which drives the stepping motor and transducer to the new $29^{o}$ position. A feedback potentiometer is connected to the stepping motor, and it has a dc voltage applied to it. The wiper of this potentiometer is fed back to the other input of the comparator. The comparator puts out pulses of the proper direction until its two inputs are balanced and then it stops. This is a closed loop servo system and it gets its input in the manual position from a switch and potentiometer on the front panel of the system; and when in the computer position, it gets a dc voltage input from a digital/analog converter in the computer. The computer will know the position the transducer is in from a dc voltage that is being fed to the computer from the potentiometer that rotates with the stepping motor.

# IV. X-Y MECHANICAL SCANNER SYSTEM

This precise mechanical scanning system is composed of two major subassemblies designed to operate in laboratory or moderately severe field environment. The assemblies are described as (1) the Control Console and (2) the X-Y Scanner Assembly. The purpose of this system is to move the ultrasonic transducer assembly in the required sequence over the test area and provide accurate location of concealed flaws (defects) in solid materials nondestructively. The scanner system was provided to General Dynamics by SPACO, Inc., under a separate contract with NASA.

The X-Y scanning system was interfaced with the computer by General Dynamics. The scanner can scan in X and index in Y or vice-versa, and the scan speed and amount of index are adjustable from the console. The scan speed can also be controlled by the computer when in the computer mode. The scanning system, reflectoscope, and display unit are shown in Figure 4-1.

## 4.1 Mechanical Scanner Assembly

The X-Y scanner assembly provides a means for supporting and automatically positioning the ultrasonic transducer platform during the various modes of operation. This action is complemented by readout devices (absolute encoders) which supply "X" and "Y" coordinate data for the console and/or the computer displays. The X axis will scan a 0.6-M length (24-in.) and the Y axis a 0.30-M length (12-in.). The speed of the scan is adjustable from 0.1 to 10 in. per second.

The X-Y scanner will operate in manual or automatic and when connected to the PDP 11/45 computer, the computer will control the drive. The manual and automatic modes of drive are primarily used during setup and calibration. The scanner weighs approximately 34 kilograms (75 lbs) and has four vacuum pads which serve as "feet" to the "legs" which can attach the scanner in any position on any relatively flat surface. The vacuum system is contained in the console and attached to the scanner by 4.6-meter flexible vacuum lines.

The scanner is driven by digital drive motors located on the outer aluminum frame. The bridge is driven directly by rubber timing belts. The platform is driven through a slip bearing on a square shaft that is connected to a timing belt.

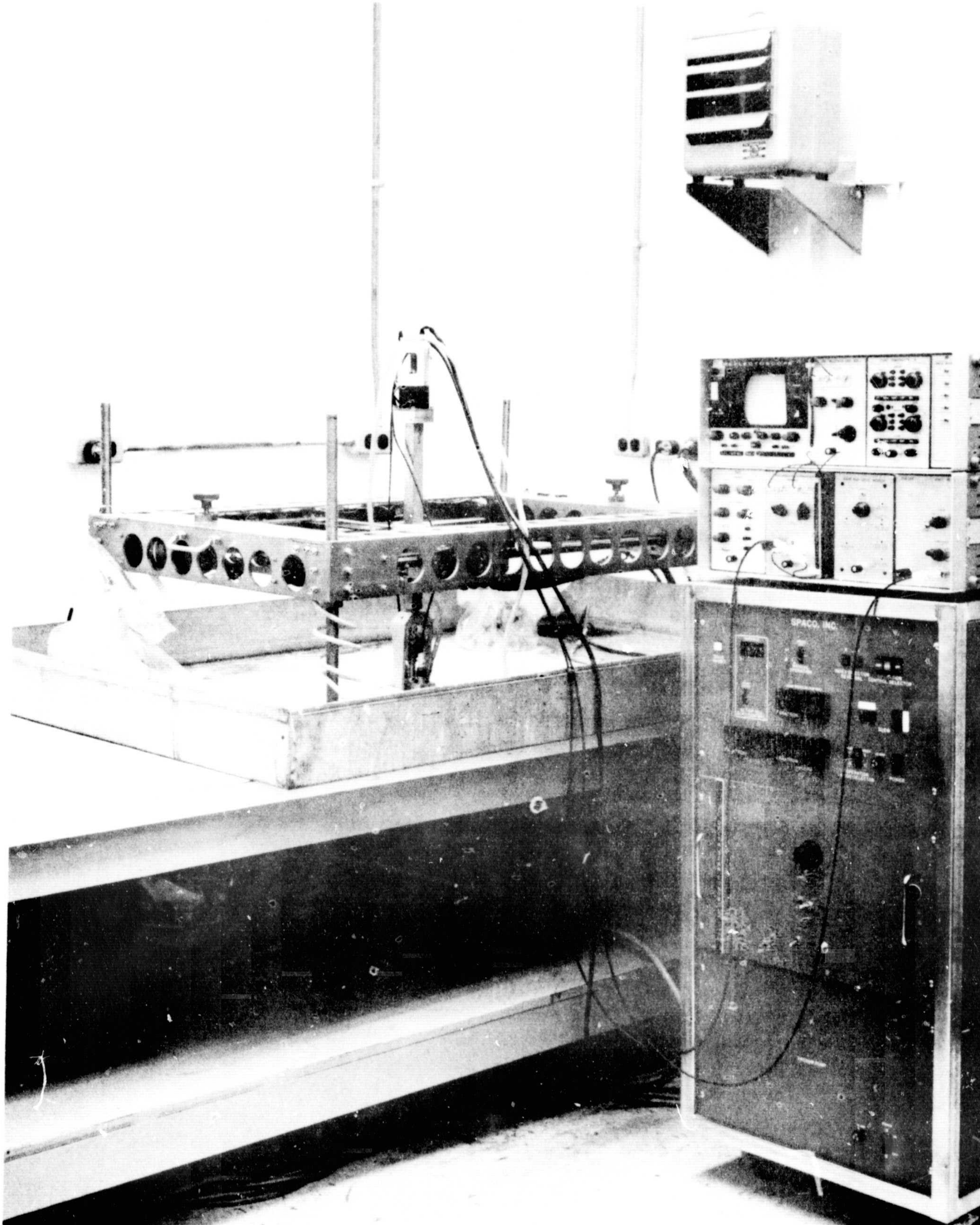


Figure 4-1 X-Y Scanner, Controls, and Ultrasonic Unit

Reversing switches are mounted on the X-Y scanner to control the scan directions and to initiate the indexing. The amount of index is controlled by a variable adjustment potentiometer on the control console. Index increments can be selected from 0 to 0.51 cm (0 to 0.2 in.) in increments of 0.0254 cm (0.010 in.).

## 4.2 Control Console

The Control Console provides a remote control station to operate the X-Y scanner mechanism. During operation, all primary mechanical and electrical connections, as well as functional controls or mode switching, originate at the console. Figure 4-2 is a photograph of the console.

The console cabinet is mounted in large castered wheels which will permit one operator to negotiate the wheeled cabinet over such obstacles as cabling, pipes, shallow trenches, or ledges. Overall height of the console (including the handle and wheels) is approximately 1.34 meters (44 inches) with a depth and width of 54.6 centimeters (21.5 inches). The top cover panel (approximately 48 x 48 centimeters or 19 x 19 inches) provides a platform for the reflectoscope. On the front or operator side, three bolt-on panels conceal three (3) equipment shelves or compartments. The top front panel covers the electronic components (p.c. boards, wiring, power supplies, etc.) for the drive system controls. The center panel covers the electronic component for the Delta-Scan angle drive motor system (Section 3.2). The lower panel covers the vacuum pump compartment. A 10-amp fuse and the Vac Pump "ON" - "OFF" switch are located here, also.

The control panel (approximately 48 x 30 centimeters or 19 x 12 inches) is located on the top front cover of the console cabinet. All operating controls and position or rate dials are located here to facilitate complete, function control by one operator. In the lower, right-hand corner is the primary POWER switch and directly above this is the OPERATION CONTROL SELECTOR switch, providing three (3) independent means of controlling the scan activities. When the COMPuter mode is selected, all scanning control is transferred to the PDP 11/45 computer and only the DPM readout dials are activated on the console control panel. (POWER switch must be "ON" in all modes.)

Selecting either AUTO or MANual mode overrides the computer commands and returns full control to the local operator at the

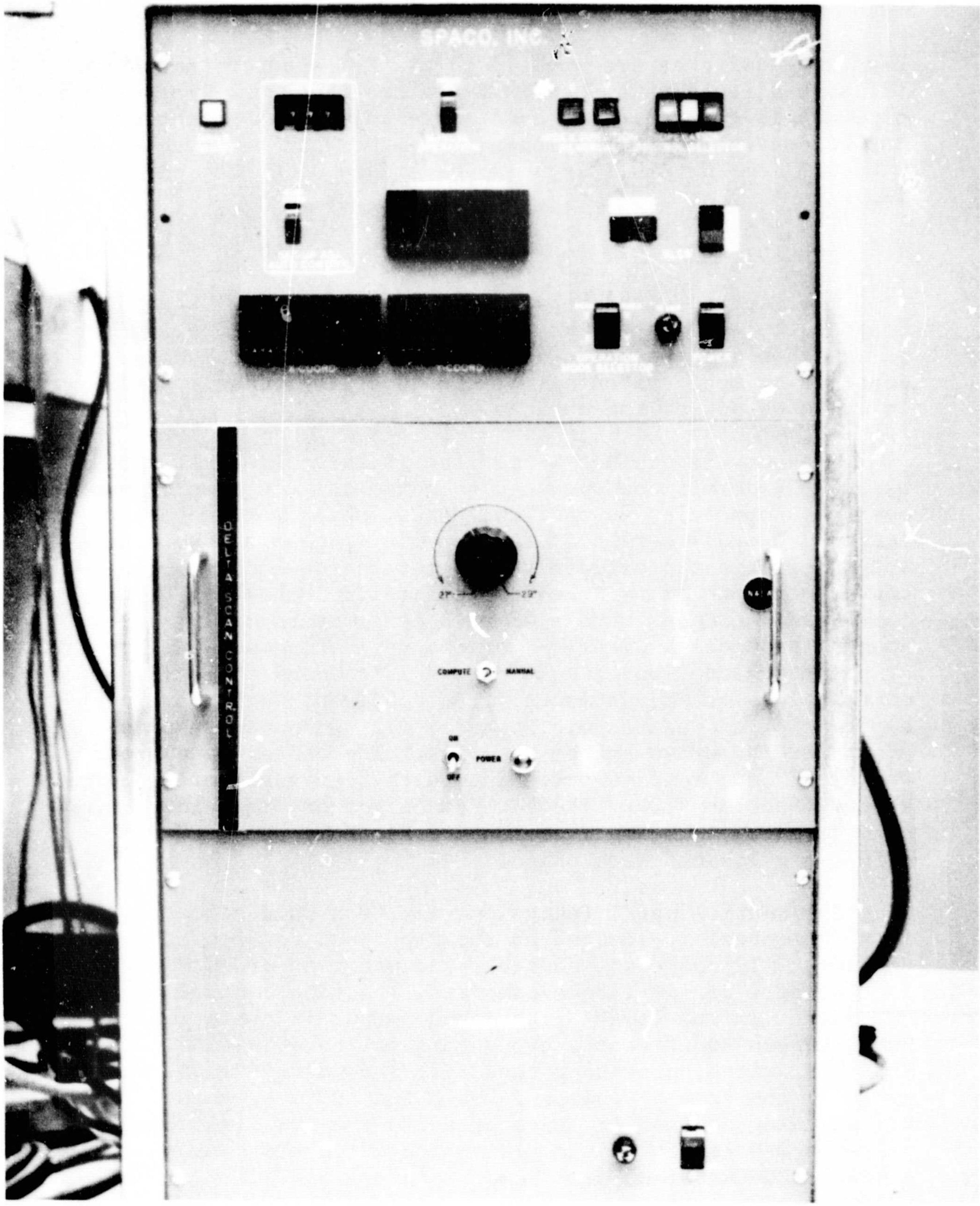



Figure 4-2 Control Console for X-Y Scanner and Delta-Scan Transducer Assembly

console. He can then adjust Scan Rate, Indexing Increments, Reverse Index, or Scan directions. The relative position of the scanner platform is indicated on the X-Y COORD DPMs (left side of the panel). The CONTROL SELECTOR and POWER switches are "lighted" in the activated or selected "ON" position.

When the "AUTO" MODE is selected, drive scan rate and index increments are "set in" at the console and supplied on a continuous basis to the "X"-"Y" drive motors on the scanner. Position data is fed back from the X-Y encoders and displayed as increments of travel representing platform location from a zero ("0"), "X" or "Y" point.

## 4.3 Line Drivers for X-and Y-Position Information

The scanning mechanism contains two encoders, one from the X axis and one for the Y axis position. This position information is fed to the computer through differential line drivers and 35-ft cables. These line drivers were installed by General Dynamics to reduce the signal/noise ratio and to maintain the original rise time of the position pulses that travel through the 35-ft cables. Three line-driver cards were installed in the scanner control chassis. Each card contains 10 differential line drivers.

Limit switch pulses and other control pulses are also fed to the computer through line drivers.

# V. COMPUTER AND DISPLAY SYSTEM

The data acquisition, display, and interfacing devices used and developed for the Computer Automation of Ultrasonic Testing Program are described in this section.

## 5.1 System Configuration

The Digital Equipment Corp. (DEC) PDP 11 model 45 general-purpose computer supplied by NASA is the heart of the system. Figure 5-1 is a block diagram of the final system configuration. Table 5.1 lists the items that make up the system. The system is shown in Figure 2-2. The Phase B Report, Ref. 2, contains a complete description of the Computer System and presents wiring diagrams of the modifications.

### 5.1.1 Central Processor Unit

The Central Processor (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 devices at a maximum rate of 2.5 million 16-bit words per second.

### 5.1.2 Core Memory

The core memory is 16K words of read/write, random access, coincident current memory with an access time of 360 nanoseconds and a cycle time of 900 nanoseconds.

### 5.1.3 MOS Memory

The semiconductor memory section has 4K words of read/write, random access which resides in the upper section of memory (16K to 20K). This configuration was chosen to take advantage of the faster operating speed, 350 nanosecond access time and a cycle time of 450 nanoseconds, in the execution section of memory.

### 5.1.4 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,

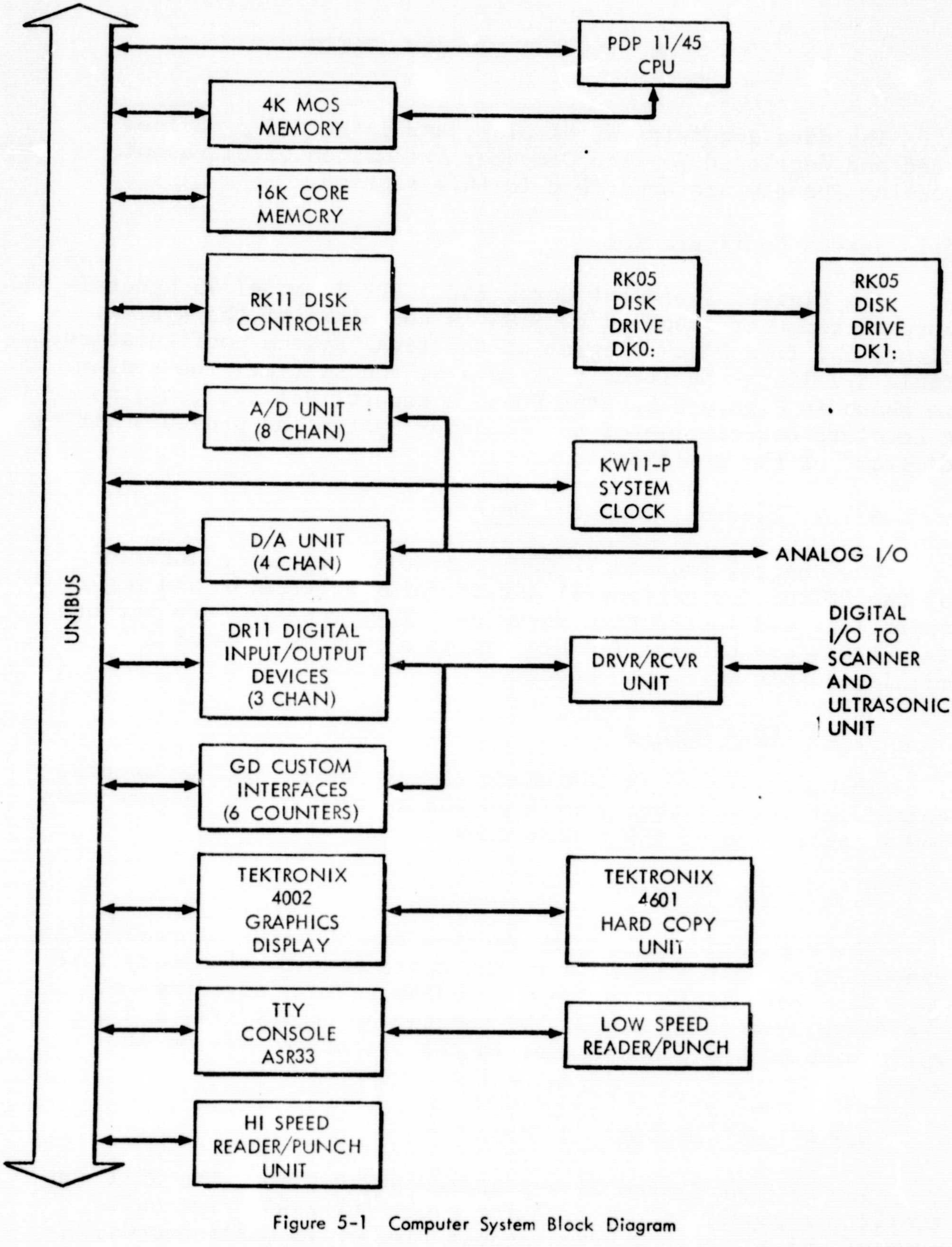



Figure 5-1 Computer System Block Diagram

TABLE 5.1

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 Subsystem (3 Channels) |
| BB11 | 2 | GD Custom Interfaces (Counter Unit and DRVR/RCVR Unit) |
| KW11-P | 1 | Programmable System Clock |
| PC11 | 1 | Hi-Speed Reader/Punch Subsystem |
| 4002A* | 1 | Graphic Display Terminal |
| 4601* | 1 | Hard Copy Device |
| ASR33 | 1 | Teletype Console |

*Tektronix Part Number

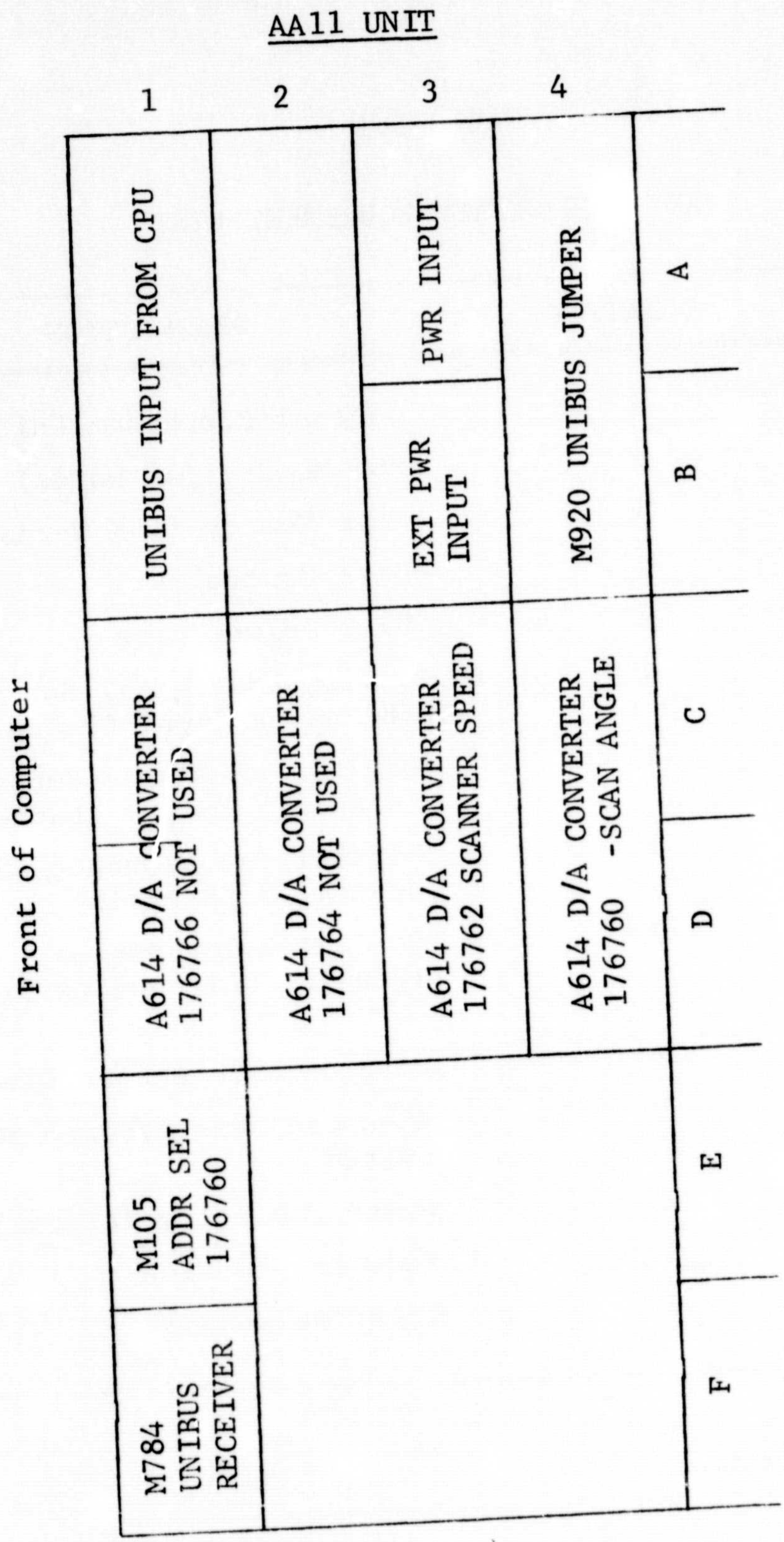



Figure 5-2 Module Layout of Digital-to-Analog System

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) RK05 drive units for a total storage capacity of 2.4 million words.

### 5.1.5 Analog-to-Digital Subsystem

The AD11 is a flexible, multi-channel, analog data acquisition system. This system has an expandable input multiplexer, programmable input range selector, control, and a sample-and-hold amplifier to reduce the conversion aperture to 100 nanoseconds. This is a standard DEC subsystem with expansion to eight analog input channels.

### 5.1.6 Digital-to-Analog Subsystem

The AA11 is a high performance multi-channel digital-to-analog converter. The AA11-D controls four (4) 12-bit digital-to-analog converters which have a maximum update rate of 50 KHz per channel. Figure 5-2 shows the slot allocation for the modules in this system.

### 5.1.7 Digital Input/Output Subsystem

The DD11 peripheral mounting panel is a prewired system unit designed for mounting up to four (4) small peripheral controller interfaces. It is prewired for logic and UNIBUS signals, and for power.

The DR11-A General Device Interface is a 3-module set 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 three (3) DR11-A module sets. The DR-11-A contains three functional sections: a 16-bit buffered output register, a 16-bit data input circuit, and a 2-channel flag and interrupt control. The DR11-A module set contains three physical modules: a M105 Address Selector, a M7821 Interrupt Control, and a M786 General Device Interface with two M927 cable connectors. Figure 5-3 shows the module slot allocations.

### 5.1.8 System Clock

The KW11-P Programmable Real-Time Clock has the following features: four clock rates, program selectable and crystal-controlled clock for accuracy, three modes of operation, two external inputs, and interrupt at the line frequency.

Front of Computer

DD11 UNIT

| | F | E | D–C | B–A |
|---|---|---|---|---|
| 1 | M7821 INTERRUPT CONTROL IV 330 | M105 ADDR SEL 167740 | M786 DEVICE REG INTERFACE NOT USED | M920 UNIBUS JUMPER |
| 2 | M7821 INTERRUPT CONTROL IV 320 | M105 ADDR SEL 167750 | M786 DEVICE REG INTERFACE INPUT: FLAGS OUTPUT: ATTEN | |
| 3 | M7821 INTERRUPT CONTROL IV 310 | M105 ADDR SEL 167760 | M786 DEVICE REG INTERFACE INPUT: YPOSITION OUTPUT: | PWR INPUT (A) |
| 4 | M7821 INTERRUPT CONTROL IV 300 | M105 ADDR SEL 167770 | M786 DEVICE REG INTERFACE INPUT: XPOSITION OUTPUT: N/A | M920 UNIBUS JUMPER |

Figure 5-3 Module Layout of Digital I/O System

5.1.9 Hi-Speed Reader/Punch Subsystem

The PC11 High Speed Reader and Punch is capable of reading 8-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.

5.1.10 System Console

The Teletype ASR-33 is the System Console for this system and is interfaced to the computer through a DL11-A asynchronous transceiver module setup for 100 baud rate.

5.1.11 Graphic Display Terminal

The display device is a Tektronix 4002A CRT unit. The viewing screen is 8-in. by 6-in. and has the capacity of 39 lines by 86 characters per line. For graphic, the unit has a resolution of 1024 addressable points in both X and Y axes. This unit uses a DL11-E interface unit setup for a transfer rate of 9600 baud. The 4002A is a standard Tektronix device and the DL11-E is a standard DEC device.

5.1.12 Hard Copy Unit

The Tektronix 4610 Hard Copy Unit provides a 8½-in. by 11 in. dry, permanent, hard copy of information displayed on the CRT of the Graphic Terminal.

5.1.13 Dual Counter Subsystems

This system is used to obtain pulse length and events count in a form that can be input to the computer. This is done by means of a modified DEC M795 Word Count and Bus Address unit. A dual counter unit consists of a modified M795 unit and a M105 address Selector unit.

5.1.14 Signal Conditioning Unit

All incoming and outgoing signals are routed via twisted pair cables. In order to preserve effective waveshape, all digital signals are transmitted by differential line-drivers and received with differential line-receivers.

## 5.2 Vendor Equipment Modification

Modifications were required to the line-receivers and M795 Word Count and Bus Address units to obtain the desired performance or required operation. The modifications to the line-receivers were required because the leading edge (positive-going) rise time was too great and it was found to be the result of the design of the DM8820A output, a wired OR circuit. The DEC standard M795 Word Count and Bus Address unit was modified to operate as two synchronous, 16-bit binary counters.

# VI. COMPUTER SOFTWARE

The software provided for this project provides for flexible control of the ultrasonic inspection system. The program operates in a real-time environment, analyzes the sensor data for indications of anomalies, records flaw anomalies on disk, and generates flaw data displays and reports. The file structure utilized for storage of the data allows for the cataloging of the test data, calibration, and test identification information for many test runs in a manner which facilitates retrieval of the information at a later date for display and report purposes. The display and report software allows the user to select any area of the tested specimen that is larger than one square inch and to specify minimum flaw intensity levels in order to selectively report only flaw data which exceeds the selected levels.

The software performs the functions listed below. Detailed descriptions of each of the functions are given in Sections 6.1 through 6.8. A functional flow chart of the program process is given by Figure 6-1.

1. Operator Interface. The program provides interface with the operator to allow him to specify the program function to be performed and to specify test identification and control information.

2. Ultrasonic Equipment Calibration. The software performs calibration of the ultrasonic equipment to a standard calibration specimen containing flaws of known size, position, and depth.

3. Scanner Control. The program operates in a real-time environment to monitor sensor position and control sensor head movement.

4. Data Acquisition. The program operates in a real-time environment to acquire the sensor data pertinent to each scanning mode.

5. Data Processing. The program operates in a real-time environment to analyze the sensor data for anomalies and to record the anomaly data and sensor location on disk.

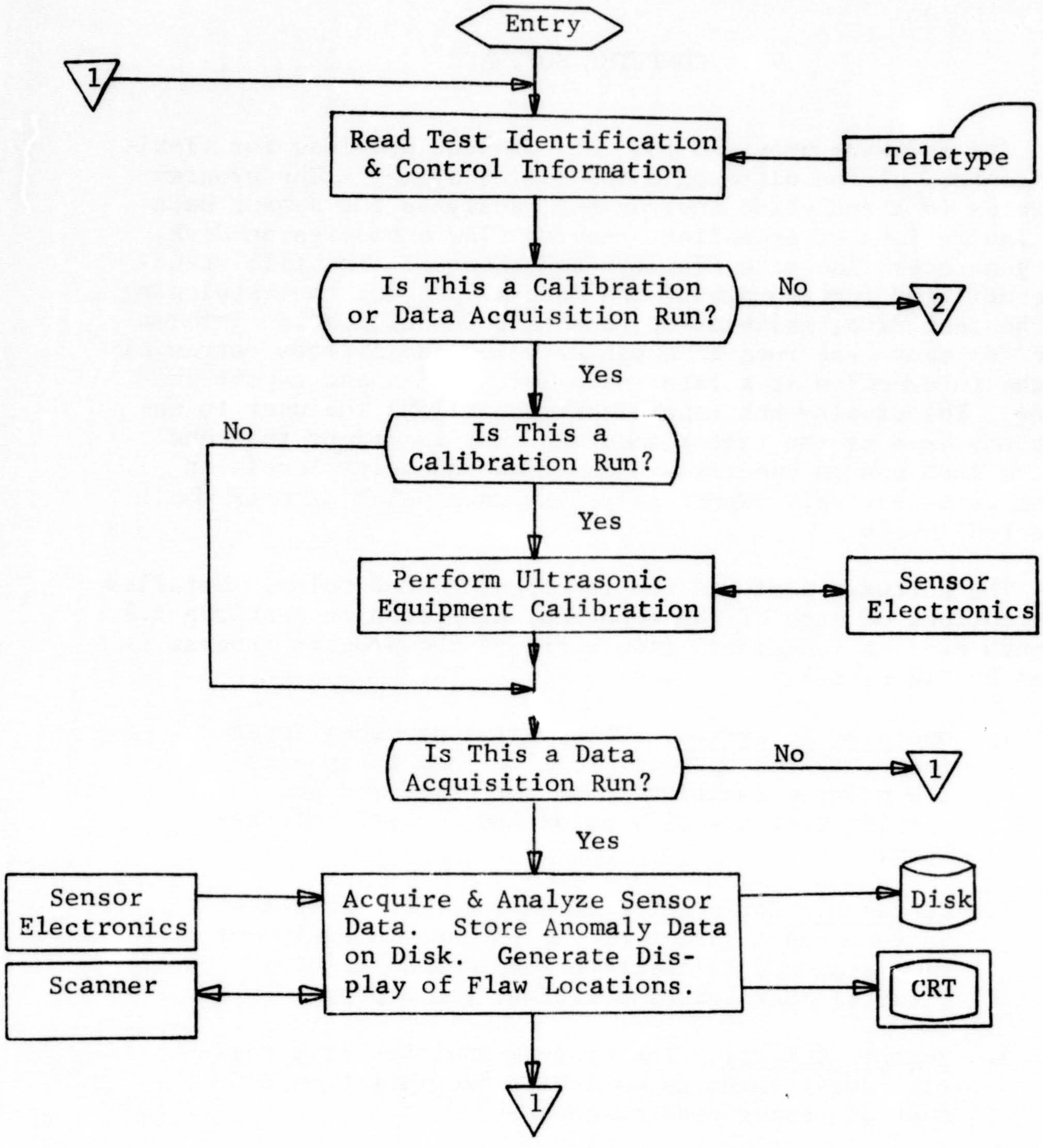



Figure 6-1  NASA Program Processing Flow

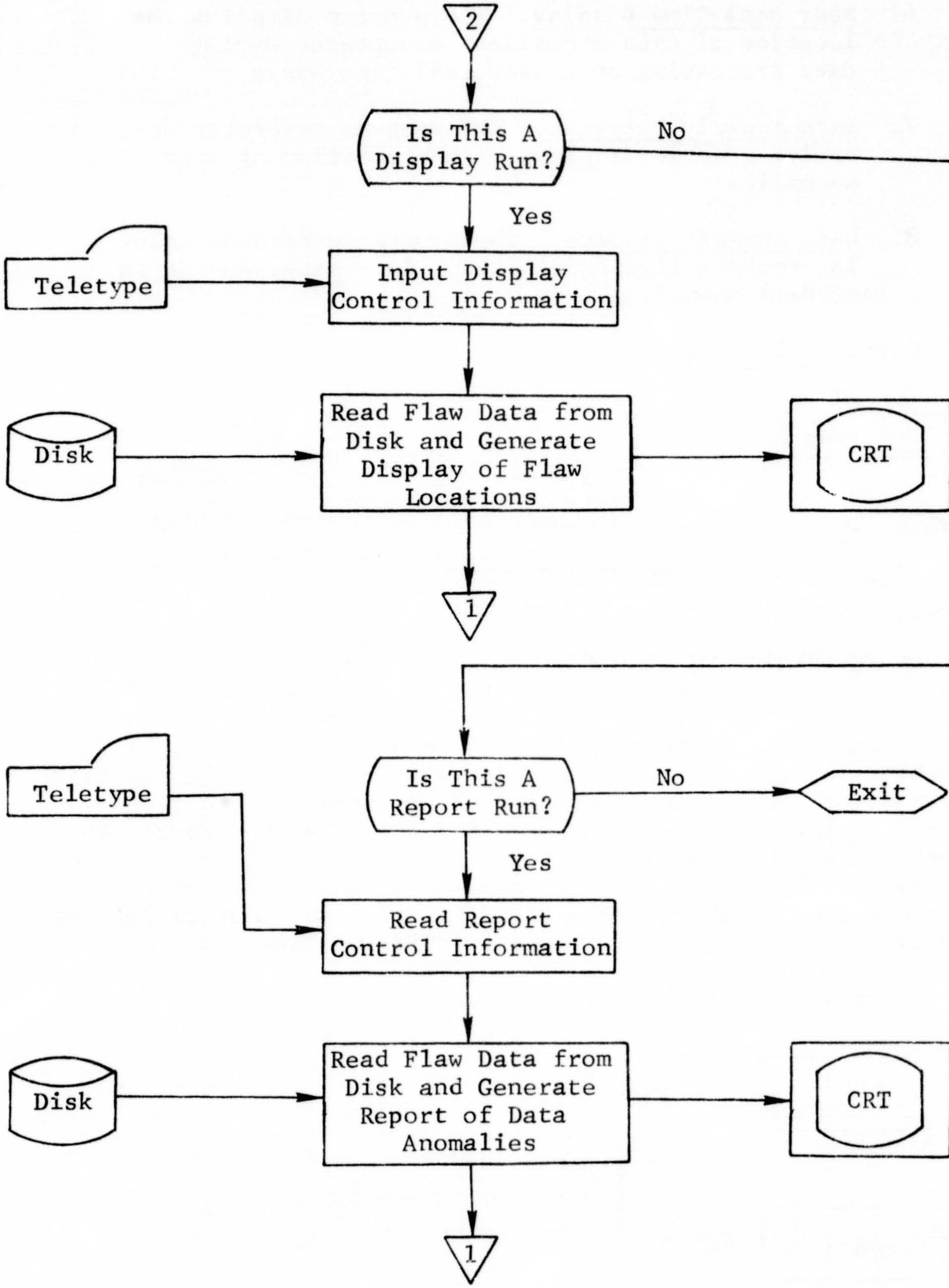


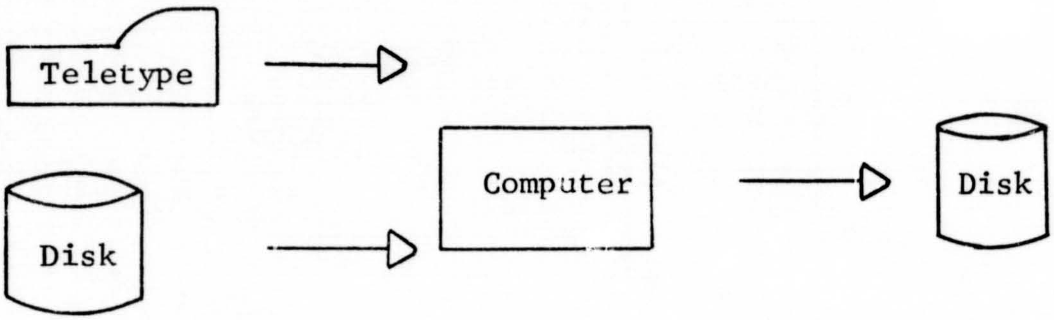

Figure 6-1 (Cont'd)

6. Near Real-Time Display. The program displays the location of data anomalies encountered during data processing on a near real-time basis.

7. Data Anomaly Displays. The program generates detailed graphic displays of the location of data anomalies.

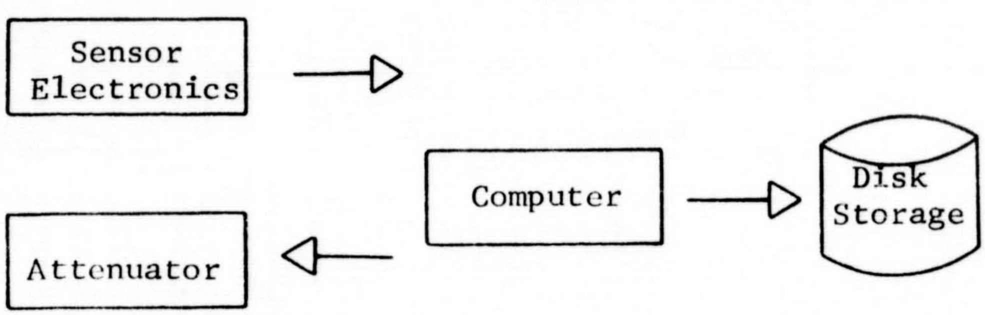
8. Data Anomaly Reports. The program generates tabular reports listing position, intensity, and depth of data anomalies.

## 6.1 Operator Interface



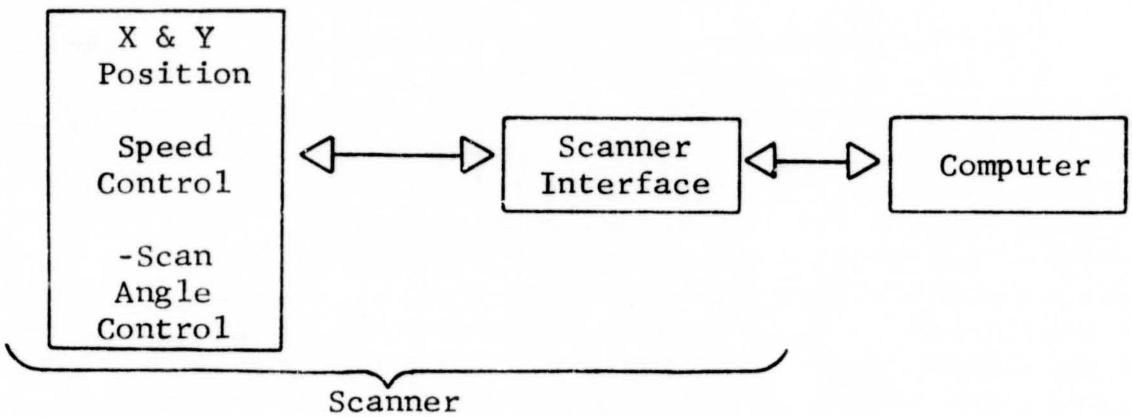

At the beginning of each run of the program, the operator inputs via the teletype to define the program function to be performed. He may request that ultrasonic equipment calibration be performed, that a test specimen be scanned for flaws, or that a tabular report or detailed display of flaw data stored on disk be generated. Specimen identification information and test identification and control information must also be input. The operator may input this information through the teletype, or he may selectively update such information as was stored on disk for a previous test run. The identification and control information is then cataloged and stored on disk for later retrieval.

## 6.2 Ultrasonic Equipment Calibration



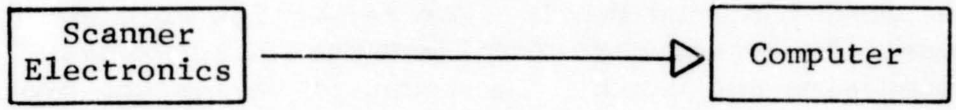
For each mode of scanning, the data acquisition system is calibrated to a standard calibration specimen containing flaws of known size, position, and depth. For reflection mode and shear wave mode, the sensor head is placed over a known flaw of predetermined size and depth. The computer varies the programmable attenuator until the flaw amplitude is correct for that flaw size and depth. In the Delta-Scan mode, the programmable attenuator is set as described above. Values from the four counters (signal counting) are read and stored. The sensor is moved to a non-flaw area of the calibration specimen and values from the four counters are again read and stored. The values read in over the flaw and the values read in over the flaw-free area are corrected using weighting factors input by the operator and then used to compute a Delta-count threshold level. The calibration information is stored on disk for subsequent retrieval.

## 6.3 Scanner Control



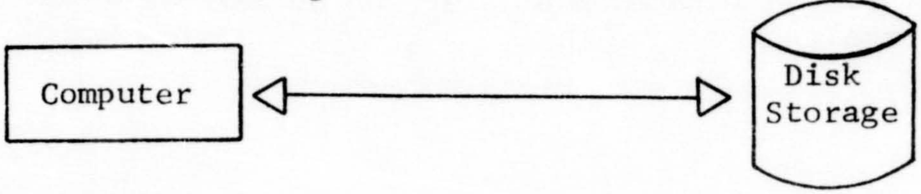

The software provides control of the scanner system by transmitting analog signals to start the scanner at the beginning of a scan cycle, to drive the scanner at the desired speed, and to stop the scanner at the end of a scan cycle. The X and Y bridge positions of the sensor head are monitored during a test run. For Delta-Scan mode of operation, an angle control signal is output to the Delta-Scan transducer angle of incidence motor in response to specimen thickness measurements.

6.4 Data Acquisition



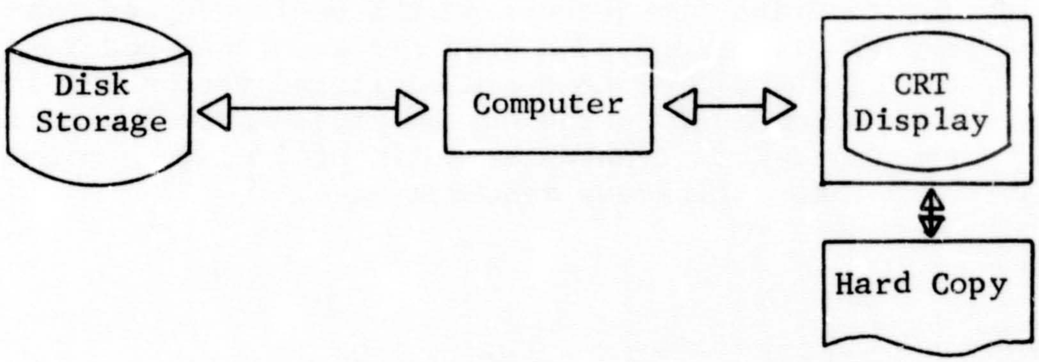

Sensor data is input from the sensor electronics for each scanning mode. Reflection mode and shear wave mode sensor data (flaw depth and flaw size) are input only upon a flaw indication. Delta-Scan sensor data (specimen thickness, flaw depth, flaw size, Delta-Scan counters) are input after each pulse. An example of the input command string is shown in Figure 6-2.

6.5 Data Processing




For reflection and shear-wave modes of operation, the flaw depth and flaw size data which were acquired upon a flaw indication are stored on disk. For Delta-Scan mode of operation, the incoming sensor data are analyzed for data anomalies. A corrected sum of the Delta-Scan counters is computed. If this corrected sum exceeds the Delta-Scan count threshold level established by calibration of the sensor electronics, or if a Delta-Scan shear wave flaw indication is present, the data point is considered to be an anomaly. Flaw depth, flaw size, specimen thickness, transducer angle of incidence, and corrected counts are stored on disk when an anomaly is encountered. For all modes of operation, the X and Y sensor head positions at which the anomaly is detected are also stored on disk.

6.6 Near Real-Time Display

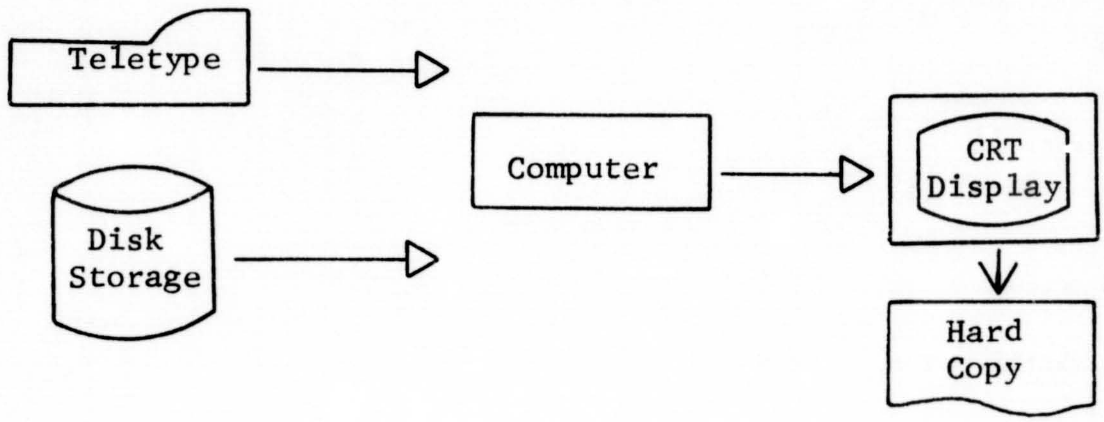


```
RUN MODE = DATA

SCAN MODE = DELTA

PART SERIAL NUMBER : 6A

RUN NUMBER : 12

DO YOU WANT TO SKIP FURTHER INPUTS ? NO

PART NAME : NASA WELD PANEL

SCAN LOCATION : WELD ZONE

SCAN NUMBER : 1

OPERATOR : ELIOT E. KERLIN

TEST FREQUENCY (MHZ) : 5

TRANSDUCER S/N : T120 R18723

TEST MATERIAL TYPE : 2219 AL

TEST SITE : GD/AF\F\RL


DELTA WEIGHTING FACTORS ARE AS FOLLOWS :

WEIGHTING FACTOR 1 :        1
WEIGHTING FACTOR 2 :        2
WEIGHTING FACTOR 3 :       .50
WEIGHTING FACTOR 4 :      100
DELTA WEIGHTING NUMBER CHANGE ? NO

DELTA-COUNT THRESHOLD LEVEL = 20 %
DO YOU WANT TO CHANGE THE THRESHOLD LEVEL ? NO

REFERENCE STANDARD TYPE : ELOX

S
 CAN DIRECTION : X

SCAN SPEED (IN./SEC.) : 1.4

INDEX INCREMENT (MILS) : 50

ROTATION OF TRANSDUCER (DEGREES) : 0

X START POSITION (IN.) : 0

X STOP POSITION (IN.) : 24

Y START POSITION (IN.) : 0

Y STOP POSITION (IN.) : 12

MATERIAL THICKNESS (IN.) : 0.5

IS CALIBATION TO BE DONE ? NO

IS DATA ACQUISITION TO BE DONE ? YES

CLEAR CONTROL SWITCHES
TYPE CARRIAGE RETURN TO BEGIN DATA ACQUISITION
```

Figure 6-2  Operator Input Command String for Taking Data

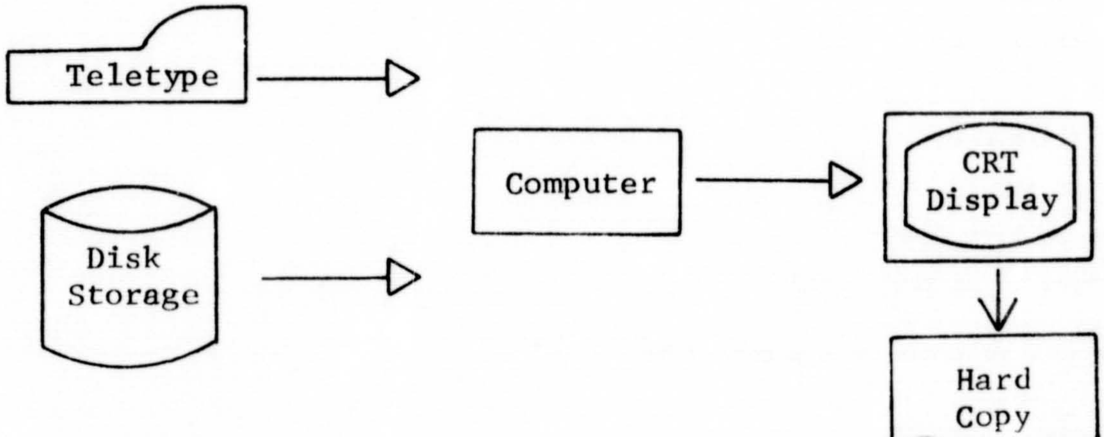
At the end of each scan cycle, the flaw data stored on disk during the scan cycle is retrieved. The X-and Y-position data are quantized and used to generate point plots of the location of data anomalies encountered during the scan. Upon completion of testing of a specimen, a hard copy of the contents of the display is generated.

6.7 Data Anomaly Displays




The operator provides information via the teletype identifying the flaw data to be displayed. This information includes test identification, specimen identification, specimen area to be displayed and minimum flaw intensity level. The flaw data for the selected test is retrieved from disk and analyzed to determine which data points, if any, meet the preselected display criteria. Point plotting of the location of data anomalies which meet the criteria is performed. The display also contains test and specimen identification. Hard copy of the generated display is available on operator request.

6.8 Data Anomaly Reports



The operator provides information via the teletype identifying the flaw data to be displayed. This information includes test identification, specimen identification, specimen area to be displayed, and minimum flaw intensity level. The flaw data for the selected test is retrieved from disk and analyzed to determine which data points, if any, meet the selected report criteria. A report of the flaw data is generated which consists of two sections. The sections are a test identification listing and a tabular listing of the flaw data providing X-, Y-axis position, depth, and intensity. Hard copy of the generated report is available on operator request.

# VII. SYSTEM OPERATION AND RESULTS

The computer system was received by General Dynamics in February 1973 and placed in service within a month. The hardware was completed during the following seven months and the software was completed about four months later. After operation of the hardware and software, some changes were made to both during the next several months.

Section 7.1 presents a summary of the system operation and Section 7.2 presents examples of the type of data obtained with the system. Section 7.3 presents the maintenance that was required by the computer during the year of operation.

## 7.1 System Operation

The system operates primarily in the ultrasonic reflection and Delta-Scan mode and has been programmed to operate in the shear wave mode at any desired angle.

The ultrasonic system was successfully adapted for use with a PDP 11/45 computer system. Gates were added to the UM 771 Reflectoscope system to partition the ultrasonic video signal for analysis. Any indication of anomalies from the incoming ultrasonic signals above a predetermined threshold level is detected by the computer and recorded as a flaw. The X-Y coordinate of the bridge where the indication occurred is also recorded along with other pertinent parameters.

Computer control of the data gives this system a great advangage over the other methods of handling ultrasonic data. With the ultrasonic system repetition rate of 500 pulses per second, a considerable amount of data can be generated and collected. Depending on the grain size and type of weld, some of the data may not be that of a flaw and should not be displayed. The system can analyze the return signal, and based on the signal strength or amplitude and the flaw threshold values, selectively display the desired information for consideration.

The computer also monitors the liquid coupling between the transducers and the weld component under inspection. Inspection will not commence until the computer verifies the sound energy is adequately coupled into the component.

Since the Delta-Scan mode of operation does not measure specimen thickness nor monitor coupling efficiency, these functions are performed by a reflection type of data processing. The transducer normal to the surface (reflection) is pulsed as well as the angular transducer (Delta-Scan). The pulsed or transmitted signals from the two transducers are processed separately by the reflectoscope timing gates. In this manner, the thickness of the test material and depth of a flaw are determined by gates that are turned on by the front-surface reflection signal and turned off by either a flaw or back surface signal. The thickness of the material is used by the computer to control the angle of incidence for the transmitting transducer of the Delta-Scan to provide uniform sensitivity for components of different thicknesses. In the standard reflection mode, the thickness of the test material and depth of a flaw are determined in the same manner.

Disk unit Ø (DKØ) of the disk storage system is used for storage of the PDP-11 Disk Operating System and for storage of the program to perform the ultrasonic inspection functions. All of the test data, calibration and initialization information are stored on disk unit 1 (DK1) in a permanent and retrievable manner. The information can be retrieved for display at any later time after the test. The program also shows the percentage of disk used for each run and for the total space used on DK1. The data are filed by Specimen Serial Number and Run Number.

The Delta-Scan transducer head assembly can be rotated from 0 to 90 deg. This will allow the sound energy to enter the specimen at different angles from the normal to the weld line. The software corrects the display for the change in relative location of the receiving transducer.

A routine has been developed with the display and report mode to aid in data analysis. It will analyze the data and display only the values that are larger than a threshold level. The threshold level being a value that can be set between 0 and 100% of the calibration value.

The system has been developed for an inexperienced computer operator, but experienced level II ultrasonic inspector. The computer hardware and software have been developed to aid in test setup and to check most of the setup operations.

The software functions are described in Section 6. An example of the computer-operator interactions during the command string for taking test data are shown in Figure 7-1. An

```
RUN MODE = DATA

SCAN MODE = DELTA

PART SERIAL NUMBER : 6A

RUN NUMBER : 12

DO YOU WANT TO SKIP FURTHER INPUTS ? NO

PART NAME : NASA WELD PANEL

SCAN LOCATION : WELD ZONE

SCAN NUMBER : 1

OPERATOR : ELIOT E. KERLIN

TEST FREQUENCY (MHZ) : 5

TRANSDUCER S/N : T120 R18723

TEST MATERIAL TYPE : 2219 AL

TEST SITE : GD/AF\F\RL

DELTA WEIGHTING FACTORS ARE AS FOLLOWS :

WEIGHTING FACTOR 1 :        1
WEIGHTING FACTOR 2 :        2
WEIGHTING FACTOR 3 :       50
WEIGHTING FACTOR 4 :      100
DELTA WEIGHTING NUMBER CHANGE ? NO

DELTA-COUNT THRESHOLD LEVEL = 20 %
DO YOU WANT TO CHANGE THE THRESHOLD LEVEL ? NO

REFERENCE STANDARD TYPE : ELOX

S
 CAN DIRECTION : X

SCAN SPEED (IN./SEC.) : 1.4

INDEX INCREMENT (MILS) : 50

ROTATION OF TRANSDUCER (DEGREES) : 0

X START POSITION (IN.) : 0

X STOP POSITION (IN.) : 24

Y START POSITION (IN.) : 0

Y STOP POSITION (IN.) : 12

MATERIAL THICKNESS (IN.) : 0.5

IS CALIBATION TO BE DONE ? NO

IS DATA ACQUISITION TO BE DONE ? YES

CLEAR CONTROL SWITCHES
TYPE CARRIAGE RETURN TO BEGIN DATA ACQUISITION
```

Figure 7-1 Operator Input Command String for Taking Data example of the command string is shown in Figure 7-7 for the DISPLAY sequence. These show the ease of operating the system and displaying the data.

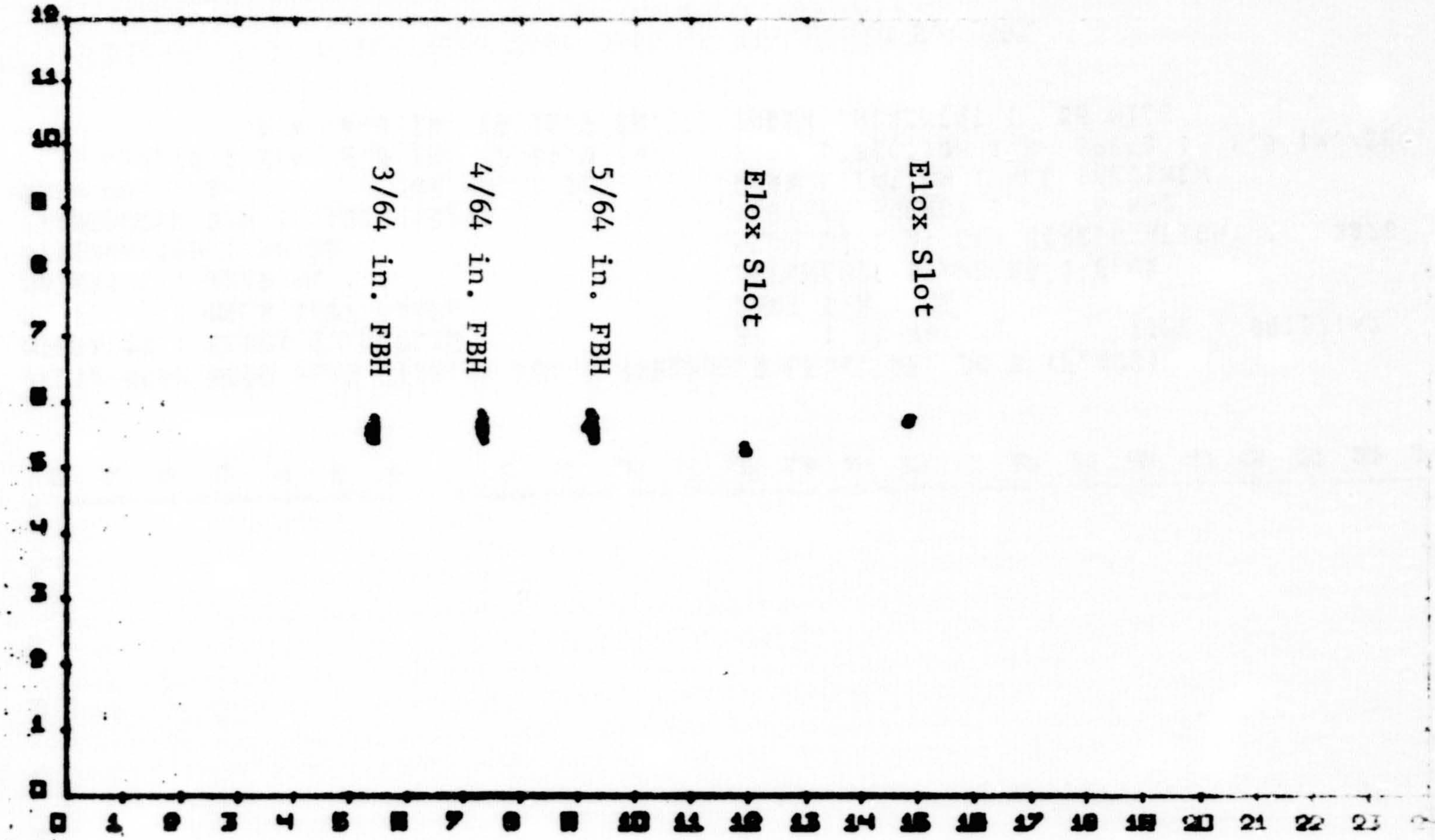
## 7.2 Test Results

The test data are recorded on DEC packs placed on disk drive designated DK1. These packs are interchangeable so the data recorded on a pack can be stored and later retrieved for analysis and display. Examples of test data from two specimens tested will be presented and discussed to show the type of results and data display techniques available with the system. The test plates were welded panels of 0.5-in. thick 2219-H aluminum supplied by NASA.

Figure 7-2 shows a hard copy display of the test results from a scan of a specimen with known defects. The defects, as labeled, are flat-bottom holes and elox slots. This copy is of the test results as recorded during the test scan, and shows all received signals above 0.5 in. on the reflectoscope and before any data analysis had been performed. The input commands shown at the bottom of the figure are those that were input as shown in Figure 7-1. The test data shown in Figure 7-2 are for both the flaw-amplitude and signal-counting data. During the analysis of the test results by the computer in DISPLAY mode, the data are separated for display so that either the flaw amplitude or the signal counting is presented.

Figure 7-3 shows the test data of Figure 7-2 after they have been analyzed by the DISPLAY mode to present the signal amplitude data for a threshold setting of 30%. These are the data points from the test shown in Figure 7-2 that are at least 30% of the calibration value. Figure 7-4 shows the same data after the DISPLAY mode was set at a threshold of 73%.

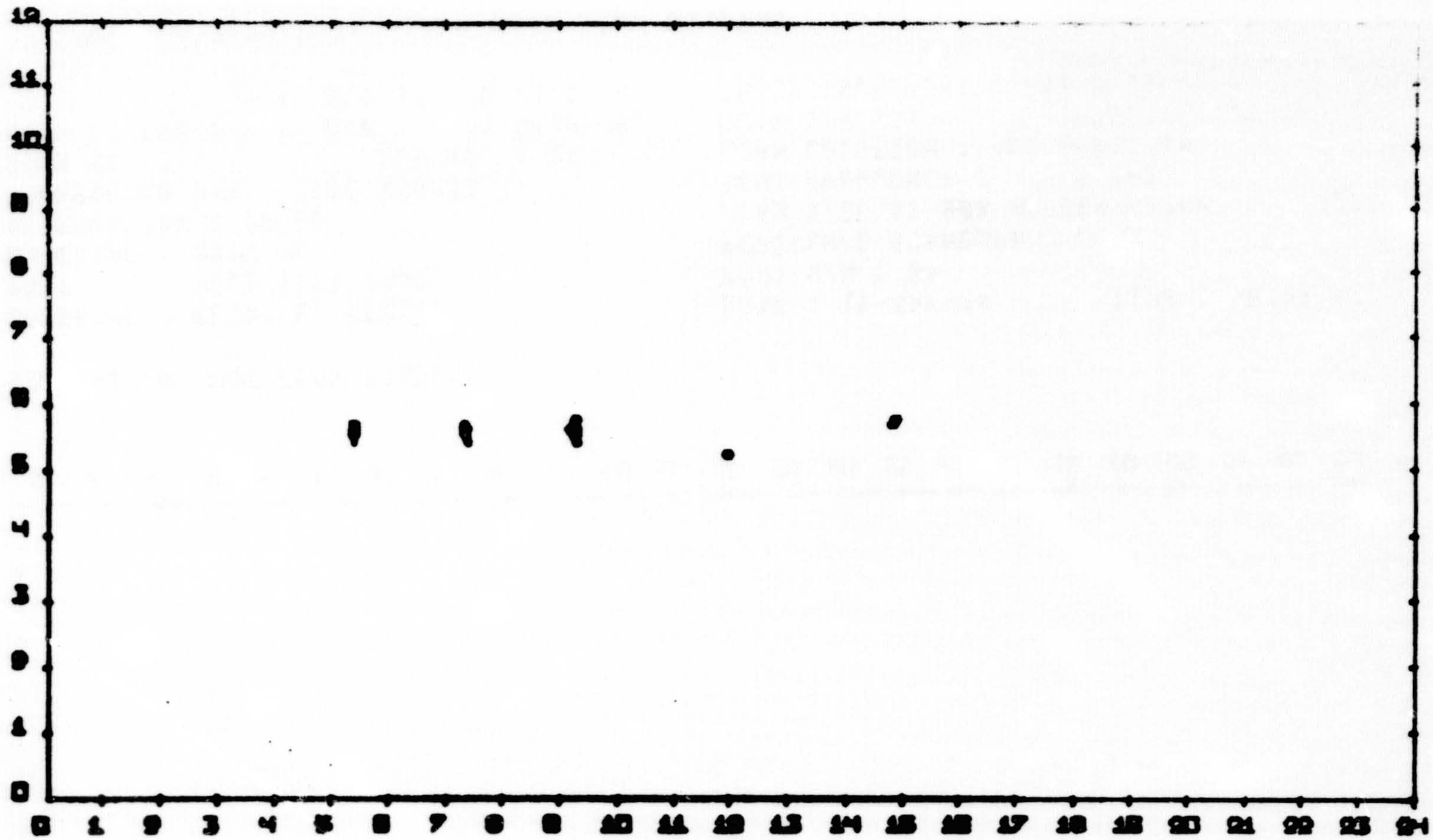
The capability to selectively examine an area of the test data is shown in Figures 7-5 through 7-8. An area of the original scan, shown in Figure 7-2, was selected for expansion and analysis of the flaw-amplitude data. The selected area is between 9 and 10 in. on the X axis and 5 and 6 in. on the Y axis. Figure 7-5 shows all of the flaw-amplitude test data collected in that area with the Delta-Scan mode. Figure 7-6 shows the same area with the test data threshold set at 70%. This shows that the test data was from good strength signals and should be analyzed. An example of the DISPLAY mode command is shown in Figure 7-7.




DELTA-SCAN MODE FLAW DISPLAY

| | |
|---|---|
| OPERATOR : ELIOT E. KERLIN | DATE : 15-MAY-74 TIME : 08:27:47 |
| PART : WELD TEST PANEL | PART S/N : 6A |
| MATERIAL : 2219 AL | REFERENCE STANDARD : ELOX |
| ATTENUATION : 30 DB | FLAW SIZE AT 80% SCREEN HEIGHT : 3278 |
| TRANSDUCER S/N : T120 R10723 | TEST FREQUENCY : 5 MHZ |
| SCAN NO. : 1 RUN NO. : 20 | SCAN LOCATION : ALL SPECIMEN |
| SCAN LIMITS : X = 0.0 IN. TO 24.0 IN. | SCAN DIRECTION : X SPEED : [illegible] |
| Y = 0.0 IN. TO 12.0 IN. | INDEX INCREMENT : 50 MILS |

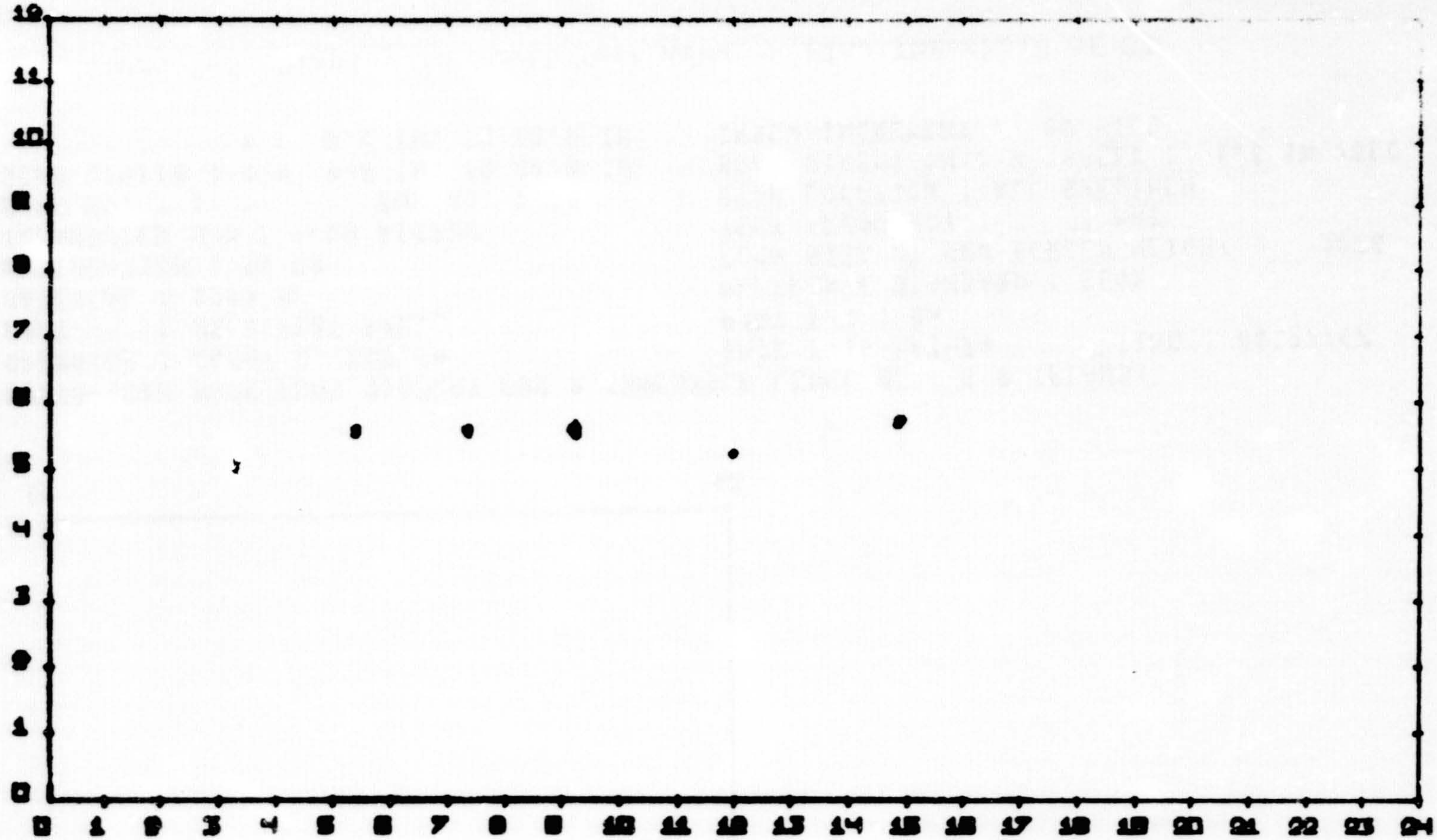
Figure 7-2 Delta-Scan Mode Flaw Display




DELTA-SCAN MODE FLAW DISPLAY FOR A THRESHOLD LEVEL OF 30 % (FLAWS)

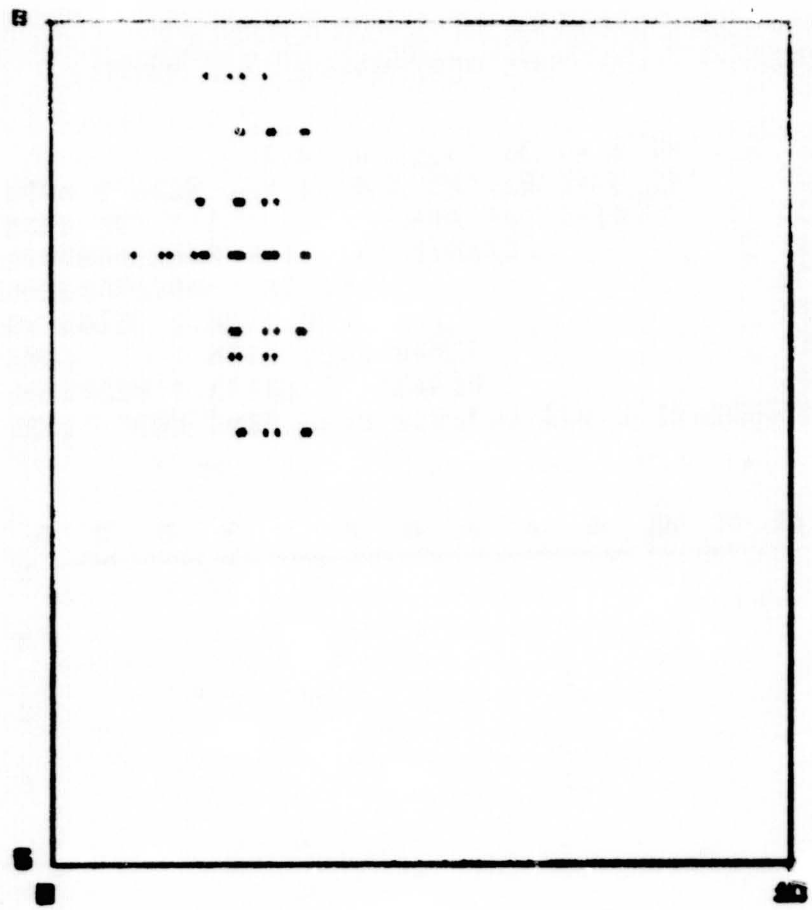
| | |
|---|---|
| OPERATOR : ELIOT E. KERLIN | DATE : 15-MAY-74 TIME : 08:27:47 |
| PART : WELD TEST PANEL | PART S/N : 8A |
| MATERIAL : 2219 AL | REFERENCE STANDARD : ELOX |
| ATTENUATION : 30 DB | FLAW SIZE AT 80% SCREEN HEIGHT : 3276 |
| TRANSDUCER S/N : T120 R18723 | TEST FREQUENCY : 5 MHZ |
| SCAN NO. : 1 RUN NO. : 20 | SCAN LOCATION : ALL SPECIMEN |
| SCAN LIMITS : X = 0.0 IN. TO 24.0 IN. | SCAN DIRECTION : X SPEED : 1.5 IN./SEC. |
| Y = 0.0 IN. TO 12.0 IN. | INDEX INCREMENT : 50 MILS |

Figure 7-3 Delta-Scan Test Data -- Threshold Set 30%



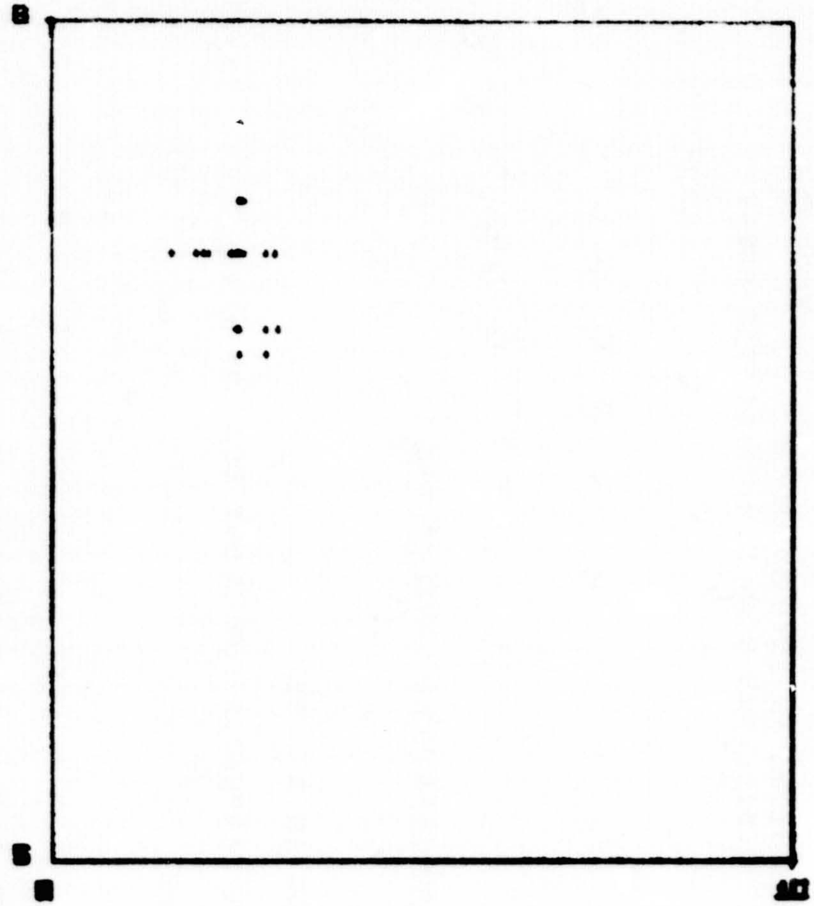

```
DELTA-SCAN MODE FLAW DISPLAY FOR A THRESHOLD LEVEL OF  73 % (FLAWS)
OPERATOR : ELIOT E. KERLIN                DATE : 16-MAY-74       TIME : 08:27:47
PART     : WELD TEST PANEL                PART S/N : 6A
MATERIAL : 2219 AL                        REFERENCE STANDARD : ELOX
ATTENUATION : 30 DB                       FLAW SIZE AT 80% SCREEN HEIGHT :    3276
TRANSDUCER S/N : T120 R10723              TEST FREQUENCY :      5 MHZ
SCAN NO. : 1           RUN NO. : 20       SCAN LOCATION : ALL SPECIMEN
SCAN LIMITS : X =  0.0 IN. TO 24.0 IN.    SCAN DIRECTION : X   SPEED :  1.5 IN./SEC.
              Y =  0.0 IN. TO 12.0 IN.    INDEX INCREMENT :  50 MILS
```

Figure 7-4 Delta-Scan Test Data -- Threshold Set 73%



```
DELTA-SCAN MODE FLAW DISPLAY FOR A THRESHOLD LEVEL OF   0 % (FLAWS)
OPERATOR : ELIOT Z. KERLIN              DATE : 15-MAY-74      TIME : 08:27:47
PART     : WELD TEST PANEL              PART S/N : 6A
MATERIAL : 2219 AL                      REFERENCE STANDARD : ELOX
ATTENUATION : 30 DB                     FLAW SIZE AT 80% SCREEN HEIGHT :    3276
TRANSDUCER S/N : T120 R10723            TEST FREQUENCY :      5 MHZ
SCAN NO. : 1           RUN NO. : 20     SCAN LOCATION : ALL SPECIMEN
SCAN LIMITS : X =  0.0 IN. TO 24.0 IN.  SCAN DIRECTION : X  SPEED :  1.5 IN./SEC.
              Y =  0.0 IN. TO 12.0 IN.  INDEX INCREMENT :  50 MILS
```

Figure 7-5 Display of Small Test Area -- Flaw Threshold of 0%



```
DELTA-SCAN MODE FLAW DISPLAY FOR A THRESHOLD LEVEL OF  7Ø % (FLAWS)
OPERATOR : ELIOT E. KERLIN                 DATE : 15-MAY-74       TIME : Ø8:27:47
PART     : WELD TEST PANEL                 PART S/N : 6A
MATERIAL : 2219 AL                         REFERENCE STANDARD : ELOX
ATTENUATION : 3Ø DB                        FLAW SIZE AT 8Ø% SCREEN HEIGHT :   3276
TRANSDUCER S/N : T12Ø R1Ø723               TEST FREQUENCY :      5 MHZ
SCAN NO. : 1          RUN NO. : 2Ø         SCAN LOCATION : ALL SPECIMEN
SCAN LIMITS : X =  Ø.Ø IN. TO 24.Ø IN.     SCAN DIRECTION : X   SPEED :   1.5 IN./SEC.
              Y =  Ø.Ø IN. TO 12.Ø IN.     INDEX INCREMENT :  5Ø MILS
```

Figure 7-6  Display of Small Test Area -- Flaw Threshold of 70%

```
RUN MODE = DISPLAY

SCAN MODE = DELTA

PART SERIAL NUMBER : 6A

RUN NUMBER : 6

DO YOU WANT TO SKIP FURTHER INPUTS ? YES

CLEAR CONTROL SWITCHES

REPORT OF FLAWS IN THE FOLLOWING AREA WILL BE
GENERATED UNLESS REPORT LIMITS ARE INPUT :
X START =  0.000 IN.
X STOP = 24.000 IN.
Y START =  0.000 IN.
Y STOP = 12.000 IN.

DO YOU WANT TO INPUT REPORT LIMITS ? YES

INPUT REPORT START/STOP POSITIONS IN INCHES BELOW
REPORT LIMITS MUST NOT BE OUTSIDE THE SCAN LIMITS LISTED ABOVE

X START : 9

X STOP : 11

Y START : 5

Y STOP : 7

DO YOU WANT TO INPUT A FLAW THRESHOLD LEVEL ? YES

FLAW THRESHOLD LEVEL : 30

INPUT A MINIMUM COUNT LEVEL IN % : 25

INPUT 1 FOR FLAW AMPLITUDE DISPLAY,2 FOR COUNT DISPLAY : 1

DO YOU WANT HARD COPY ? YES
```

Figure 7-7 Operator Input Command String for Display

```
DELTA-SCAN MODE DATA REPORT      15-MAY-74   09:23:22    PAGE   1

PART NAME : WELD TEST PANEL          PART SERIAL NO. : 6A

OPERATOR : ELIOT E. KERLIN           DATE : 15-MAY-74       TIME : 08:27:47

TEST FREQUENCY :      5 MHZ          TRANSDUCER SERIAL NO. : T120 R18723

TEST MATERIAL : 2219 AL              TEST SITE : GD/FW/ARL

NOMINAL THICKNESS OF MATERIAL :  0.50 IN.   TRANSDUCER ROTATION :  0

REFERENCE STANDARD : ELOX                         ATTENUATOR SETTING : 30 DB

DELTA COUNT WEIGHTING FACTORS :     1     2     50    100
LOW COUNT                     :     0     0     0     0 TOTAL :      0
HIGH COUNT                    :     6     4     3     2 TOTAL :    364

DELTA-COUNT THRESHOLD LEVEL    : 20%
REPORT FLAW THRESHOLD LEVEL    : 70%
REPORT COUNT THRESHOLD LEVEL   : 70%

SCAN NO. : 1          RUN NO. : 26        SCAN LOCATION : ALL SPECIMEN

SCAN LIMITS : X =  0.0 IN. TO 24.0 IN.   SCAN DIRECTION : X SPEED :  1.5 IN./SEC.

              Y =  0.0 IN. TO 12.0 IN.   INDEX INCREMENT :  50 MILS

REPORT LIMITS : X =  9.0 IN. TO 10.0 IN.

                Y =  5.0 IN. TO  6.0 IN.
```

Figure 7-8  Report of Small Test Area -- Threshold of 70%

DELTA-SCAN MODE DATA REPORT 15-MAY-74 09:23:22 PAGE 2

| FLAW LOCATION X IN. | FLAW LOCATION Y IN. | CORRECTED COUNTS | FLAW SIZE | TRANSDUCER ANGLE | DEPTH |
|---|---|---|---|---|---|
| 9.250 | 5.871 | 364 | 1093 | 22.5 | 0.626 |
| 9.260 | 5.871 | 466 | 1525 | 23.0 | 0.000 |
| 9.294 | 5.871 | 516 | 1789 | 28.0 | 0.000 |
| 9.294 | 5.871 | 517 | 1986 | 28.0 | 0.657 |
| 9.300 | 5.871 | 618 | 2043 | 22.5 | 0.000 |
| 9.300 | 5.871 | 616 | 1893 | 28.0 | 0.000 |
| 9.342 | 5.871 | 515 | 1594 | 28.0 | 0.000 |
| 9.342 | 5.871 | 414 | 1152 | 28.0 | 0.626 |
| 9.348 | 5.871 | 364 | 539 | 23.0 | 0.657 |
| 9.386 | 5.787 | 314 | 659 | 23.0 | 0.626 |
| 9.208 | 5.787 | 315 | 1349 | 23.0 | 0.626 |
| 9.208 | 5.787 | 367 | 2000 | 23.0 | 0.000 |
| 9.250 | 5.787 | 520 | 2594 | 28.0 | 0.626 |
| 9.252 | 5.787 | 521 | 2706 | 23.0 | 0.000 |
| 9.252 | 5.787 | 522 | 2446 | 28.0 | 0.000 |
| 9.246 | 5.787 | 421 | 2040 | 28.0 | 0.626 |
| 9.248 | 5.787 | 420 | 1444 | 23.0 | 0.000 |
| 9.204 | 5.787 | 288 | 920 | 28.0 | 0.000 |
| 9.162 | 5.721 | 283 | 292 | 28.0 | 0.000 |
| 9.192 | 5.721 | 364 | 553 | 28.0 | 0.000 |
| 9.192 | 5.721 | 264 | 455 | 28.0 | 0.000 |
| 9.204 | 5.721 | 464 | 572 | 23.0 | 0.657 |
| 9.204 | 5.721 | 516 | 3102 | 22.5 | 0.000 |
| 9.248 | 5.721 | 769 | 4007 | 28.0 | 0.000 |
| 9.248 | 5.721 | 768 | 4095 | 28.0 | 0.000 |
| 9.252 | 5.721 | 799 | 4095 | 28.0 | 0.000 |
| 9.252 | 5.721 | 670 | 4095 | 28.0 | 0.626 |
| 9.250 | 5.721 | 669 | 4095 | 22.5 | 0.000 |
| 9.200 | 5.721 | 669 | 4095 | 28.0 | 0.000 |
| 9.200 | 5.721 | 670 | 4095 | 28.0 | 0.626 |
| 9.300 | 5.721 | 569 | 4095 | 23.0 | 0.626 |
| 9.300 | 5.721 | 670 | 3180 | 23.0 | 0.626 |
| 9.342 | 5.721 | 670 | 1839 | 23.0 | 0.000 |

Figure 7-8 (Cont'd)

DELTA-SCAN MODE DATA REPOR[illegible] [illegible] 39:2[illegible]:22 PAGE 3

| FLAW LOCATION X IN. | FLAW LOCATION Y IN. | CORRECTED COUNTS | FLAW SIZE | TRANSDUCER ANGLE | DEPTH |
|---|---|---|---|---|---|
| 9.342 | 5.721 | 366 | 1449 | 28.0 | 0.000 |
| 9.348 | 5.721 | 314 | 732 | 28.0 | 0.000 |
| 9.306 | 5.721 | 312 | 560 | 28.0 | 0.626 |
| 9.294 | 5.721 | 365 | 960 | 23.0 | 0.626 |
| 9.294 | 5.721 | 619 | 855 | 23.0 | 0.626 |
| 9.252 | 5.721 | 518 | 3145 | 23.0 | 0.657 |
| 9.252 | 5.721 | 569 | 4095 | 23.0 | 0.657 |
| 9.246 | 5.721 | 670 | 4095 | 23.0 | 0.657 |
| 9.246 | 5.721 | 668 | 4095 | 22.5 | 0.626 |
| 9.240 | 5.721 | 667 | 4095 | 23.0 | 0.626 |
| 9.240 | 5.721 | 724 | 4095 | 22.5 | 0.657 |
| 9.210 | 5.721 | 675 | 4096 | 22.5 | 0.000 |
| 9.210 | 5.721 | 772 | 4095 | 28.0 | 0.000 |
| 9.192 | 5.721 | 768 | 4096 | 28.0 | 0.000 |
| 9.162 | 5.721 | 567 | 3204 | 28.0 | 0.000 |
| 9.162 | 5.721 | 464 | 1589 | 28.0 | 0.000 |
| 9.150 | 5.721 | 263 | 460 | 28.0 | 0.000 |
| 9.150 | 5.721 | 263 | 454 | 28.0 | 0.000 |
| 9.240 | 5.631 | 468 | 905 | 28.0 | 0.000 |
| 9.240 | 5.631 | 518 | 2106 | 28.0 | 0.000 |
| 9.246 | 5.631 | 619 | 3199 | 28.0 | 0.000 |
| 9.246 | 5.631 | 623 | 3817 | 28.0 | 0.000 |
| 9.252 | 5.631 | 522 | 3990 | 28.0 | 0.000 |
| 9.288 | 5.631 | 469 | 3892 | 28.0 | 0.000 |
| 9.288 | 5.631 | 470 | 3691 | 28.0 | 0.000 |
| 9.306 | 5.631 | 572 | 3364 | 28.0 | 0.000 |
| 9.306 | 5.631 | 823 | 2043 | 28.0 | 0.000 |
| 9.336 | 5.631 | 769 | 2087 | 28.0 | 0.000 |
| 9.336 | 5.631 | 667 | 1450 | 28.0 | 0.000 |
| 9.342 | 5.631 | 413 | 726 | 28.0 | 0.000 |
| 9.300 | 5.601 | 251 | 316 | 22.5 | 0.657 |
| 9.300 | 5.601 | 462 | 1223 | 22.5 | 0.626 |
| 9.288 | 5.601 | 466 | 1775 | 23.0 | 0.626 |

Figure 7-8 (Cont'd)

DELTA-SCAN MODE DATA REPORT [illegible] [illegible] PAGE 4

| FLAW LOCATION X IN. | Y IN. | CORRECTED COUNTS | FLAW SIZE | TRANSDUCER ANGLE | DEPTH |
|---|---|---|---|---|---|
| 9.280 | 5.601 | 516 | 2394 | 23.0 | 0.000 |
| 9.252 | 5.601 | 566 | 2471 | 28.0 | 0.626 |
| 9.252 | 5.601 | 567 | 1907 | 23.0 | 0.657 |
| 9.240 | 5.601 | 517 | 1272 | 23.0 | 0.657 |
| 9.240 | 5.501 | 266 | 506 | 23.0 | 0.626 |
| 9.258 | 5.511 | 366 | 627 | 23.0 | 0.657 |
| 9.280 | 5.511 | 517 | 955 | 23.0 | 0.657 |
| 9.200 | 5.511 | 516 | 1379 | 23.0 | 0.000 |
| 9.306 | 5.511 | 514 | 1703 | 20.0 | 0.626 |
| 9.306 | 5.511 | 514 | 1987 | 22.5 | 0.626 |
| 9.342 | 5.511 | 514 | 1900 | 22.5 | 0.628 |
| 9.342 | 5.511 | 364 | 1616 | 22.5 | 0.626 |
| 9.340 | 5.511 | 362 | 930 | 22.5 | 0.657 |

THERE WERE 79 DETECTABLE SIGNALS

Figure 7-8 (Cont'd)

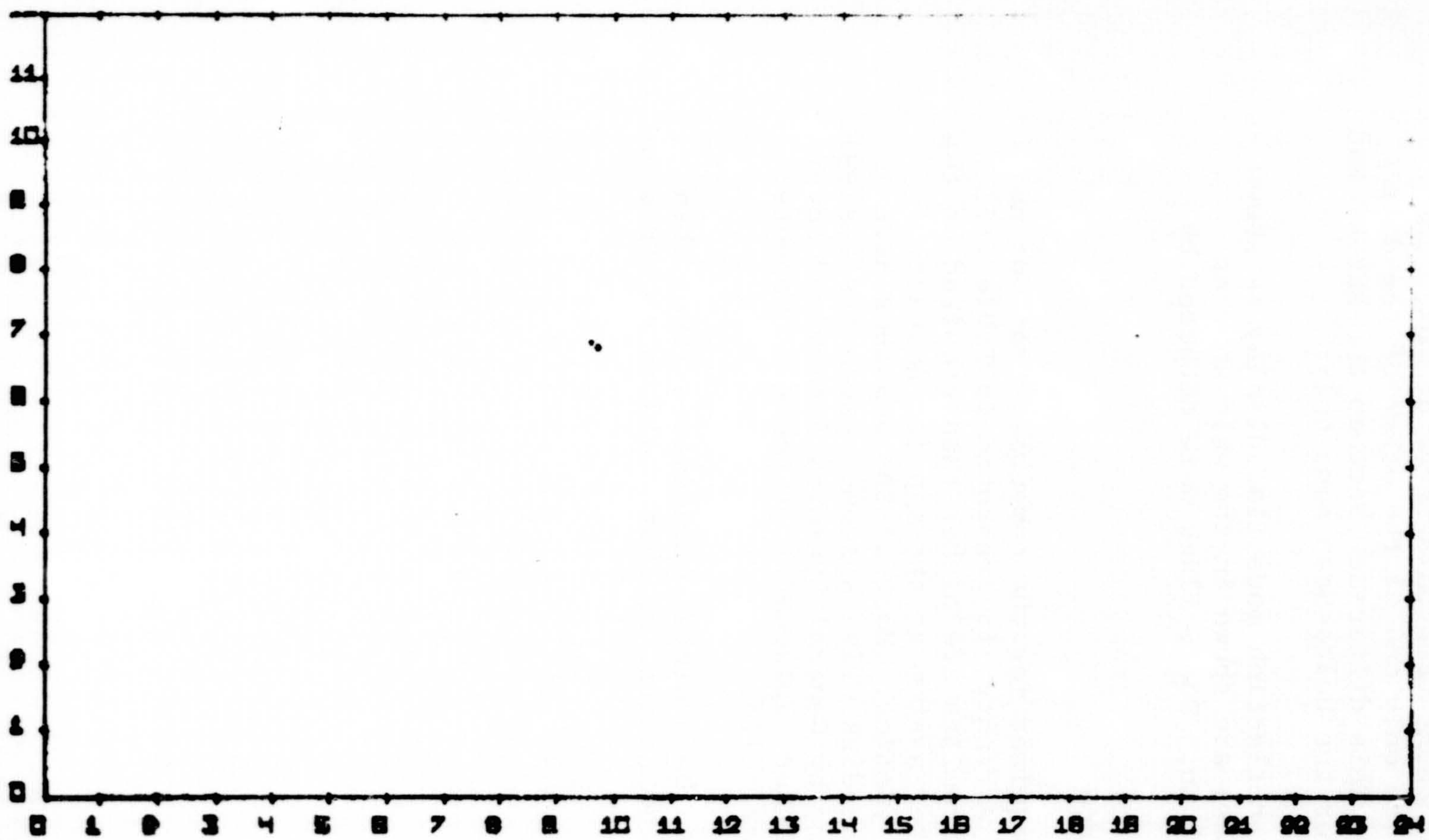
Figure 7-8 shows the REPORT presentation of the same data as presented in Figure 7-6. The values tabulated are for a flaw threshold level or count threshold level of 70%. The DISPLAY procedure selects only one or the other of the data sets for presentation. This difference between the REPORT and DISPLAY procedure is for the Delta-Scan mode only.

An example of the reflection mode flaw display is shown in Figure 7-9. Two flaws are shown in the weld zone at approximately 10 and 19 in. These flaws were detected by X-ray.

## 7.3 Computer Maintenance

The maintenance required for the computer, that was not covered by the 3-month warranty, is presented in Table 7-1. These maintenance requirements are higher than required on the second PDP 11/45 computer system at the Applied Research Laboratory of General Dynamics. Most of the problems have been associated with the disk drive system. Extensive analysis of the system in January by General Dynamics determined several marginal components. After replacement of these components, the system has been very solid.

We consider this to be a higher maintenance level than would be projected in the future, or that would be required on a new system.



```
REFLECTION MODE FLAW DISPLAY FOR A THRESHOLD LEVEL OF   0 %

OPERATOR : ELIOT E. KERLIN                DATE : 19-FEB-74       TIME : 08:18:00
PART     : NASA WELD PANEL                PART S/N : 3A
MATERIAL : 2219                           REFERENCE STANDARD : 4/64 FBH
ATTENUATION : 38 DB                       FLAW SIZE AT 80% SCREEN HEIGHT :   3276
TRANSDUCER S/N : 120                      TEST FREQUENCY :       5 MHZ
SCAN NO. : 1              RUN NO. : 1     SCAN LOCATION : WELD ZONE
SCAN LIMITS : X =  0.0 IN. TO 24.0 IN.    SCAN DIRECTION : X      SPEED :  1 IN./SEC.
              Y =  0.0 IN. TO 12.0 IN.    INDEX INCREMENT :  50 MILS
```

Figure 7-9 Reflection Mode Test Data

Table 7-1

NASA-PDP 11/45 COMPUTER MAINTENANCE
NOT COVERED BY WARRANTY

| Date | Item | Amount |
|---|---|---|
| 07-10-73 | Intermittent Errors on the RK05 Disk Drive | $ 142.40 |
| 07-23-73 | Intermittent Seek Errors in RK05 | 96.00 |
| 07-26-73 | Intermittent Seek Error to Cylinder Ø9 of RK05 | 365.83 |
| 07-31-73 | Intermittent Seek Error with RK05 Disk Disk Drive | 65.00 |
| 08-02-73 | DOS Monitor Won't Operate | 48.00 |
| 08-03-73 | Check System Head Clearance | 80.00 |
| 08-06-73 | Intermittent Problem with Disk Drive | 248.00 |
| 12-10-73 | Memory Module Failed | 294.00 |
| 12-20-73 | Disk Drive Readout | 175.00 |
| | TOTAL | $1,514.23 |

# VIII. CONCLUSIONS AND RECOMMENDATIONS

## 8.1 Conclusions

A Computer-Automated Ultrasonic Inspection System for weldments has been developed. The system operates in a near real-time environment, analyzes the sensor data for indications of anomalies, records the flaw anomalies on disk, and generates flaw data display and records.

The computer handling of the data gives this system a great advantage over the other methods of handling the ultrasonic data, not only the speed in recording the test data but also in the analysis that can be performed during display and reporting. The system is able to analyze and record the test results at a repetition rate of 500 pulses per second.

The hard copy capabilities of the graphic display terminal provide the operator with excellent permanent records, not only in the test document, but enough information is provided for any re-analysis of the records at a later date.

The system was developed for smooth weld joints that were machine-welded and machined smooth. These were the type welds used on the Apollo. During the development of the system, the design of the ultrasonic circuitry was changed to aid the system in handling non-smooth surfaces. The start of the flaw gate was changed from a delay of the main bang to that of the front-surface return signal. This aided in testing the wavy surfaces of specimens that have not been machined completely smooth. This greatly helped in preventing the front surface signal from moving into the flaw gate during reflection mode operation.

## 8.2 Recommendations

It is recommended that more experience be obtained with the system on selected specimens that would be destructively examined. The test should be initiated on specimens that are machined smooth to establish the basic system operation and determine the flaw detection sensitivity. The next set of specimens should have some wavy sections and plate mismatch to evaluate the returned signals characteristics. The sensitivity of the ultrasonics and dynamic range of the computer system are such that the system can be set to evaluate particular geometries of specimen surfaces.

Consideration should also be given to developing a transducer head assembly for non-machined welds. One type of transducer head is a set of shear wave transducers operating simultaneously.

## REFERENCES


1. Yee, B. G. W., et. al., "Automation of Ultrasonic Testing - Phase A Report - Technological Survey and Preliminary Design," on Contract NAS8-28652, Convair Aerospace Report FZM-5964 (1 June 1972).

2. Yee, B. G. W., et. al., "Computer Automation of Ultrasonic Testing - Phase B Report - System Design, Fabrication, and Test," on Contract NAS8-28652, Convair Aerospace Report FZM-6279 (March 1974).

3. Yee, B. G. W., T. G. Wells, and T. C. Walker, "Automation of Ultrasonic Testing - Phase C Report - Software Design," on Contract NAS8-28652, Convair Aerospace Report FZM-6280 (15 March 1974).

4. "System Operation and Maintenance for the Automated Ultrasonic Inspection System," on Contract NAS8-28652, Convair Aerospace Report FZM-6281 (March 1974).