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Multifrequency Eddy-Current Inspection of Seam Weld in Steel Sheath

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NOTICE: This document contains information of a preliminary nature. It is subject to revision or correction and therefore does not represent a final report.

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ABSTRACT

Multifrequency eddy-current techniques were used to perform a continuous on-line inspection of the seam weld in the steel jacket for a superconducting cable. The inspection was required to detect both surface and internal weld flaws in the presence of a large, highly conductive central conductor. Raw eddy-current data were recorded on magnetic tape, and test properties such as discontinuity size and weld penetration were determined by mathematically fitting these data to coefficients developed with representative standards. A sophisticated computer-controlled scanning technique was applied, and a unique scanning device was developed to provide full coverage of the weld and heat-affected zone. The techniques used to develop this multifrequency eddy-current examination are described in this report along with the test equipment, test procedures, and computer programs.

INTRODUCTION

The Large Coil Program (LCP), a major program activity of the Fusion Energy Division at the Oak Ridge National Laboratory (ORNL), is developing and testing large coils for use as superconducting magnets in the fusion energy study. Several international companies have been contracted to build large superconducting magnet coils using different designs and materials, but adhering to the same performance specification and envelope requirements. When completed, these coils will be tested at the ORNL Large Coil Test Facility (LCTF).

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As part of the United States Large Coil Program managed by ORNL, Westinghouse and Oxford-Airco have cooperated in the design and fabrication of a large superconducting magnet that used one of the most sophisticated superconductors ever attempted. The wire manufacturing process, for example, involved two extrusions, approximately 20 heat treatments, and over 50 separate wire drawing operations. After the wire was fabricated, it was twisted into a cable containing 486 strands. The cable was wrapped with a thin Inconel foil, then a steel jacket was formed around the conductor and seam welded along its length. This jacket formed a cryogenic vacuum vessel that was required to be helium leak tight at a temperature of 4 K and a pressure of approximately 10 MPa (100 atm).

The most probable area for leaks was the seam weld; therefore, some type of nondestructive test was needed to evaluate the quality of this weld. The size and geometry of the sample and the need to perform the test continuously along the weld on a production line basis made eddy currents the most logical nondestructive testing (NDT) method to try. Studies using conventional eddy-current techniques encountered significant difficulties because of large irregular signals generated by the twisted conductor and other materials present in the cable assembly. The large background signals and the number of significant variables that changed during the test made the examination by conventional eddy-current methods virtually impossible. This problem was brought to the ORNL Nondestructive Testing Development Laboratory, where prior theoretical and experimental studies had resulted in a capability to solve multiparameter problems by use of multifrequency eddy-current techniques. This report describes the application of these techniques to inspect the weld in the steel sheath for the superconductor cable. Although available funds and time limited the amount of development for computer processing of data, a very useful system was developed.

DESCRIPTION OF PROBLEM

The problem as initially defined was to nondestructively inspect the seam weld of the type JBK-75 steel sheath or jacket surrounding a superconducting cable. This steel is an alloy steel that has properties very similar to those of A-286 stainless steel. The cable consisted of 486 strands of wire that had been twisted and wrapped with a thin [approximately 0.05-mm (0.002-in.)] Inconel foil. Each strand of wire consisted of a copper-coated composite of 2869 filaments of 3.5-μm Nb_3Sn. A 1.7-mm-thick (0.067-in.) steel sheet was wrapped around the cable and foil to form a butt joint, which was welded autogenously by a gas tungsten arc technique. The welded steel jacket forms a cryogenic vacuum vessel for the cable. It was required to be helium leak tight at a temperature of 4 K and a pressure of 10 MPa (100 atm). The JBK-75 steel plate was ultrasonically inspected before the sheath was formed;[1] therefore, the obvious area of concern for possible leaks was the seam weld and heat-affected zone.

INSPECTION REQUIREMENTS

The initial requirements were to inspect the seam weld and HAZ for defects or discontinuities that could cause leaks in the sheath. The test had to be performed from the outside surface of the welded sheath and in the presence of the large conducting cable. It also had to be performed at the superconductor cable assembly site (the Oxford-Airco plant in Carteret, New Jersey). Personnel there had to be trained for eddy-current testing, and written procedures were required to describe the necessary steps to perform the examination. The test also had to be performed continuously on the production line as the weld was being made. [One of the assembly requirements for the superconductor cable and sheath was that they be formed continuously for lengths up to 100 m (~328 ft).] The test was required to detect any crack oriented longitudinal to the weld and having a length of 19 mm (0.75 in.) and a depth of 0.82 mm (0.032 in.) and to detect any transverse crack having a depth of 1.62 mm (0.064 in.) and visible on the surface of the sheath. (After the multifrequency eddy-current inspection method was developed and we had determined its capabilities, additional test requirements were added.) The final test requirements were to inspect the weld and heat-affected zone for defects of the size indicated above and to inspect the weld for lack of fusion, lack of penetration, and sag in the weld crown. The test was performed continuously for weld lengths up to 100 m with the weld moving through the inspection station at a rate of 0.6 m/min (~2 ft/min).

The eddy-current inspection station was located as near to the weld station as possible to allow for quick corrections when errors such as insufficient penetration or the weld beam straying off the joint were detected. Even though the sheath and weld were quenched after the weld operation, they still had a temperature above ambient when they reached the eddy-current inspection station. We therefore had to account for material property changes (e.g., electrical conductivity) due to temperature variation during the inspection. Figure 1 shows a block diagram of the major operations and the location of the various stations used to assemble the superconducting cable and sheath. Because the eddy-current system was near the gas tungsten arc welder, we also tested whether the electrical noise generated by the welding operation was picked up by the eddy-current instrumentation or the recorders. No noise problem existed, but we did use an isolation transformer in the main power line for the instrument. Later in the program we had to move the eddy-current inspection farther downstream in the assembly line because of a change in the welding procedure.

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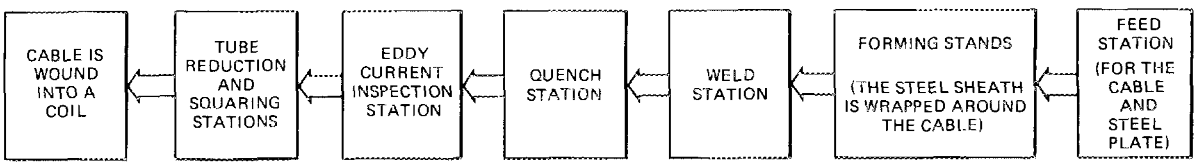

Fig. 1. Block diagram of production assembly line for the superconductor cable and sheath.

The cross section of the cable and sheath at the time of welding was round, having a diameter of about 25 mm (1 in.). The cable and sheath assembly then went through a forming operation that compacted the cable and changed the cross section to a square (21 by 21 mm). Figure 2 shows the cross sections of the two superconductor cable configurations.

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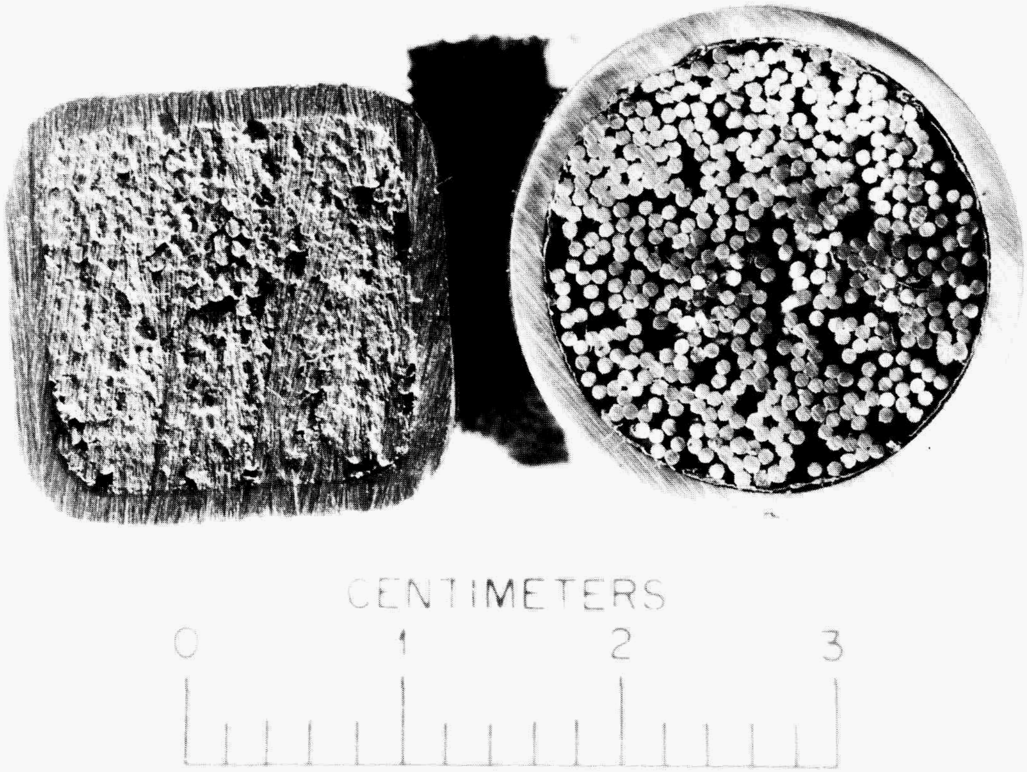

Fig. 2. Cross sections of cable. Left, after forming. Right, as welded.

The superconductor cable and sheath had a round cross section when the production line inspection was performed. Subsequent eddy-current inspections were performed on the cable and sheath with the square cross section to relocate and evaluate areas where indications had been obtained during the production test to determine if weld repairs were needed. An electromechanical circuit was developed to automatically mark areas on the superconductor sheath weld where the eddy-current signal exceeded a selected level. The areas that required weld repair were also reinspected to assure that a satisfactory weld repair had been made.

THEORY OF MULTIFREQUENCY EDDY-CURRENT INSPECTION

Many different parameters can influence eddy-current measurements; therefore the unique determination of a given sample property when other properties also vary is usually difficult or impossible unless sufficient data are obtained to eliminate the effects of unwanted variables. In general, at least as many independent eddy-current readings must be made on a given specimen as there are properties whose variation may affect the readings. If sinusoidal eddy currents are used, one can determine no more than two quantities, such as the magnitude and phase, at a given fixed frequency. Therefore, if more than two properties need to be determined, multiple-frequency, pulsed, or swept-frequency eddy currents must be used. Since multifrequency techniques were applied to this particular problem, only that method will be considered in this report. More detailed descriptions of the use of multifrequency eddy-current techniques to solve multiple-property problems have been reported.[2-4]

No more than two pieces of information can be obtained from a given sample with an eddy-current instrument operating at a single frequency, for example, the magnitude and phase of the output voltage. However, many sample properties can affect the readings, and their effects are so interrelated that various combinations of the properties could produce the same pair of instrument readings. Therefore, to distinguish the actual properties from other possible combinations, one must make at least as many independent readings as there are parameters that can vary and affect the readings. This can be done by using magnitude and phase readings at N different fixed frequencies to obtain $2N$ pieces of information.

Assume that N properties, such as conductivity, permeability, lift-off or fill factor, wall thickness, and defects, may affect the readings. Let P_{ij} be an array of properties in which $j = 1, 2, \ldots, N$ gives the particular property or parameter, and $i = 1, 2, \ldots, M$ is the index giving the particular sample. We can write the array as

$$P_{ij} = \begin{pmatrix} P_{11} & P_{12} & \cdots & P_{1N} \\ P_{21} & P_{22} & \cdots & P_{2N} \\ \cdot & \cdot & \cdot & \\ \cdot & \cdot & \cdot & \\ \cdot & \cdot & \cdot & \\ P_{M1} & P_{M2} & \cdots & P_{MN} \end{pmatrix} \qquad (1)$$

Let us also suppose that the set of properties P_{ij} $(j = 1, 2, \ldots, N)$ for the ith sample produces a set of N' independent readings R_{ik} $(k = 1, 2, \ldots, N')$, where $N' \geq N$. We want to obtain a set of formulas such that, for the ith set of properties,

$$\begin{aligned} P_{i1} &\doteq F_1\ (R_{i1}, R_{i2}, \ldots, R_{iN'}) \\ P_{i2} &\doteq F_2\ (R_{i1}, R_{i2}, \ldots, R_{iN'}) \\ &\cdot \\ &\cdot \\ &\cdot \\ P_{iN} &\doteq F_N\ (R_{i1}, R_{i2}, \ldots, R_{iN'})\ , \end{aligned} \tag{2}$$

where $i = 1, 2, \ldots, M$, and the symbol $\doteq$ indicates that the functions $F_1, F_2, \ldots, F_N$ provide only approximations to the corresponding properties. To obtain good approximations we may wish to expand the readings into polynomials, such as

$$P_{ij} \doteq F_j = \sum_{n_1=0}^{N_1} \sum_{n_2=0}^{N_2} \cdots \sum_{n_{N'}=0}^{N_{N'}} C_{jn_1n_2\ldots n_{N'}} R_{i_1}^{n_1} R_{i_2}^{n_2} \ldots R_{iN'}^{n_{N'}}\ , \tag{3}$$

where $N_1, N_2, \ldots, N_{N'}$ are the highest powers of the readings $R_{i_1}, R_{i_2}, \ldots, R_{iN'}$ in the polynomial. To determine all of the coefficients $C_{jn_1n_2} \ldots n_{N'}$ (see above) for the jth property, one must have at least as many sets of readings $(i = 1, 2, \ldots M)$ as there are coefficients to be determined. If M is greater than the number of coefficients to be determined, then a linear least-squares fitting program can be used to determine the set of coefficients to minimize the sum of squares

$$S_j = \sum_{i=1}^{M} (P_{ij} - F_j)^2 \tag{4}$$

for the jth property. This is done by a subroutine in the data-fitting program, which numbers the coefficients consecutively. The first term in the polynomial expansion F_j is the constant $C_{j00\ldots0}$, which is called the "offset." It may be equal to zero.

Once the polynomial coefficients have been determined to calculate a given property with the desired accuracy, they can be used to calculate that property for an unknown sample if the properties of the unknown sample fall within the range of validity of the polynomial expansion. This is assured by fitting the polynomial to a range of variations that is at least as great as that expected for the unknown samples.

Thus, dropping the index i from Eq. (3), we can calculate the property P_j of an unknown sample from the readings R_1, R_2, ..., $R_{N'}$ by the formula

$$P_j \doteq F_j = \sum_{n_1=0}^{N_1} \sum_{n_2=0}^{N_2} \cdots \sum_{n_{N'}=0}^{N_{N'}} C_{jn_1n_2\ldots n_{N'}} R_1^{n_1} R_2^{n_2} \ldots R_{N'}^{n_{N'}} . \quad (5)$$

After examining this formula, it appears that any desired precision can be obtained by making the polynomial large enough, and this is indeed true. If the number of sets of measured properties, M, is equal to the number of sets of linearly independent readings, N', then a unique and exact fit can be obtained for the M values of each property by using only linear terms. However, the function F_j may fluctuate drastically between the fitted points so that intermediate values of the property would not be fitted well.

Furthermore, if each reading R_j is subject to a certain amount of random error, ΔR_j, so that the polynomial becomes

$$F_j = \sum_{n_1=0}^{N_1} \sum_{n_2=0}^{N_2} \cdots \sum_{n_{N'}=0}^{N_{N'}} C_{jn_1n_2\ldots n_{N'}} (R_1 \pm \Delta R_1)^{n_1} (R_2 \pm \Delta R_2)^{n_2} \ldots (R_{N'} \pm \Delta R_{N'})^{n_{N'}} , \quad (6)$$

then we see that the random errors, particularly in the terms involving high powers, may lead to considerable error. The worst possible combination of errors, in which all the errors in the value of the property are in the same direction, will be called the "DRIFT." In the curve-fitting program used to fit the experimental data, the worst possible combination of errors produced by changes of 0.01% in each magnitude and 0.01° in each phase are calculated and printed as the DRIFT, since errors of this amount are characteristic of current eddy-current equipment.

Because most material properties will not oscillate rapidly in a limited range of any given parameter, cubic or higher powers of the readings are rarely necessary or even useful to fit a given property.

Details on the linear least-squares curve-fitting procedure have been given.[2-3] The coefficients $C_{jn_1n_2\ldots n_N}$, in Eq. (3) are determined by a subroutine in the data fitting program used to minimize the sum of squares in Eq. (4).

GENERAL PROCEDURE TO DESIGN A MULTIPLE-PROPERTY EDDY-CURRENT TEST

The overall design of a multiple-property eddy-current test involves two efforts, an analytical study and an experimental study of the given problem. The analytical study is theoretical; it involves only the use of our laboratory minicomputer and appropriate software, and no actual instrument hardware or test standards are required. Appropriate computer programs have been written at ORNL to allow this study. The analytical study can be described in three steps.

1. Eddy-current instrument readings (magnitude and phase) are theoretically calculated with the minicomputer for a number of different frequencies and for a range of values for the test properties that are anticipated to vary.

2. The minicomputer is then used to perform a least-squares fitting of user-selected polynomials (constructed from the theoretically calculated magnitude and phase readings) to obtain the various desired properties.

3. The fit error (how well the chosen polynomial can be used to calculate the specified property) is determined. The drift error is also determined [how much the calculated property will change for small changes in the signal readings (magnitude and phase)].

The above three steps are repeated for different probe designs and frequency combinations until the drift errors are minimized or are acceptable for the given test conditions.

An analytical study is helpful to determine the correct probe design and frequency values to provide optimum test results. The analytical study is not absolutely essential, but it is very useful to determine the feasibility of the examination, and it can be used to predetermine the accuracy for measuring any particular property and the allowable tolerances in the instrumental parameters.

An analytical study was not performed for this particular examination problem because of critical deadlines in the fabrication schedule for the superconductor cable. Essentially we used our experience, engineering judgment, and a few experimental measurements to determine the best combination of frequencies and coil design to use. In fact, the first selected coil design did not meet all the test requirements, and a different coil was selected for the final test.

Once the analytical study has been completed and the coil design and operating frequencies have been selected, the next step in designing a multiple-property eddy-current test is to perform the experimental study as follows.

1. The optimum instrumentation is constructed or assembled from existing modules, and the optimum probe is obtained. The instrument is assembled, it is adjusted to the desired frequencies, and calibration standards that cover the range of expected property variations are obtained. Obtaining a representative set of test samples is one of the most important and most difficult tasks associated with solving any nondestructive examination problem. This particular study was not atypical. The test requirements changed several times before a final solution was obtained, and the changes required new, different, or additional test samples to be fabricated. Rather than belabor these problems in this report, we will discuss only the test samples that were used to obtain the final solution to the problem.

2. The test instrumentation is calibrated, and a set of data (magnitude and phase readings) that represents the concerned property variations is made from the test samples. These data are recorded with a minicomputer, averages and standard deviations are calculated, and the data are stored in the computer's memory.

3. A least-squares fit is made of the selected properties to the polynomials containing the actual magnitude and phase readings recorded in step 2. This is accomplished by use of the minicomputer and the software

developed at ORNL. Various selected polynomials are constructed from the actual experimental readings, and the properties of interest are fit to these polynomials. The fit and drift errors are calculated to determine how well the particular property can be determined.

4. When the optimum or a sufficiently accurate fit is obtained, the coefficients for the polynomial representing the selected property determination are recorded and stored on a programmable read-only memory (PROM) chip. The PROM chip containing the coefficients is placed in the microcomputer circuit for the multiple-frequency eddy-current (MFEC) instrument. Selected properties to be measured can now be calculated from actual magnitude and phase readings by the microcomputer system in the MFEC instrument.

5. The final step is to field test the inspection system on site by examining test samples and other representative samples and calculate the desired properties, to evaluate how well the test system will perform in the actual environment that will be used.

INSTRUMENTATION, EDDY-CURRENT PROBE, AND SCANNING SYSTEM

The three-frequency eddy-current instrument used for this study is shown in Fig. 3. A block diagram of the instrument is shown in Fig. 4. This instrument will simultaneously measure both the magnitude and phase of the eddy-current signal at three different frequencies: 20, 200, and 500 kHz. The eddy-current instrument can record raw data readings and then calculate the specified properties with an internal microcomputer. The instrument can also interface with a larger minicomputer to permit more complicated data analyses, such as least-squares fitting. This instrument was developed at ORNL, and a thorough description has been provided.[5]

The extended module in Fig. 3 contains the NDT-COMP9A microcomputer, the analog-to-digital converter, the digital-to-analog converter, and the transceiver unit. The NDT-COMP9A is a self-contained, eight-bit microcomputer system designed specifically for experiment control and data analysis with the modular eddy-current instrument. The unit has 16 K of

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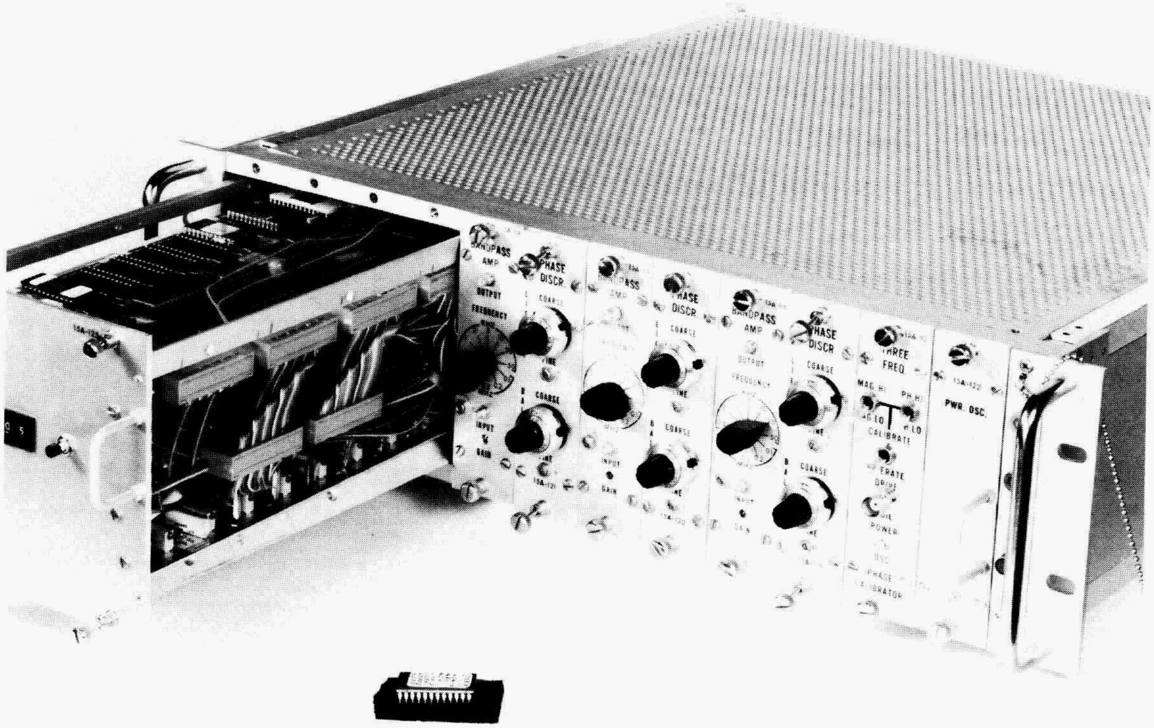

Fig. 3. Three-frequency eddy-current instrument.

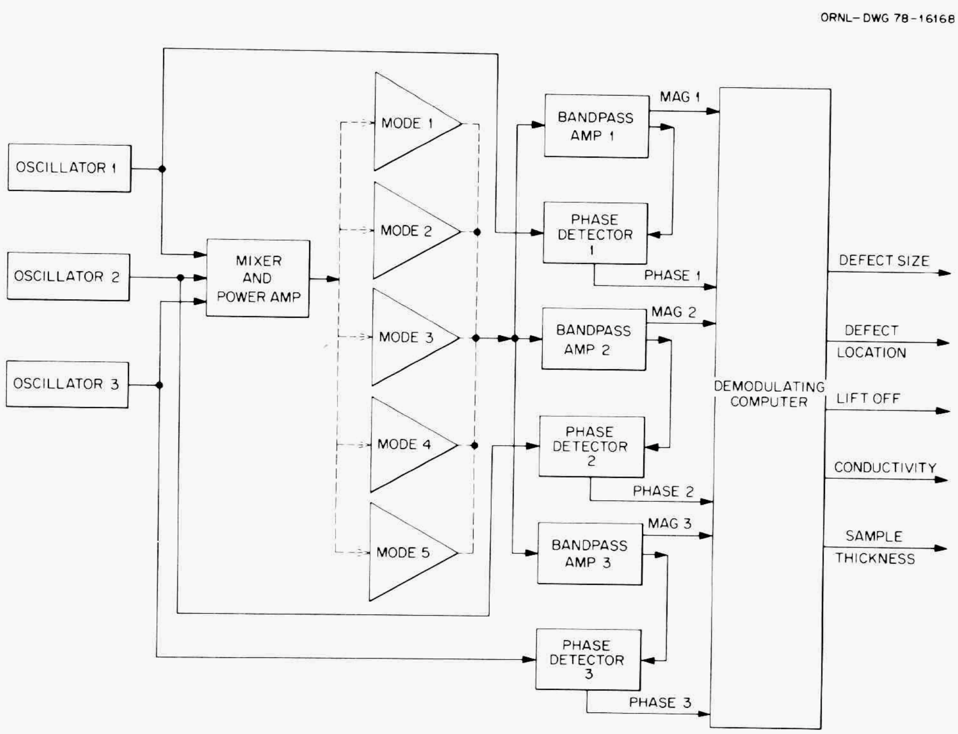

Fig. 4. Block diagram of three-frequency eddy-current instrument.

read-only memory and random access memory. It can perform 32-bit, floating-point mathematical operations in hardware and it has a sophisticated input-output structure for instrumentation control. The NDT-COMP9 microcomputer was also developed at ORNL, and details are provided.[6]

A small PROM chip lies in front of the instrument in Fig. 3. This chip has a 2-K byte memory capacity and is used to store the polynomial coefficients (used to determine material property values) in the microcomputer and the program for control of the test, data gathering, and evaluation. The chips are physically located in the top of the microcomputer.

The minicomputer (MODCOMP IV), used for most of the data analyses for tests performed in the laboratory, is shown in Fig. 5. The minicomputer can store and operate on much larger quantities of data. For example, the polynomial coefficients used to develop material properties from the eddy-current readings are developed with the minicomputer and are transferred to the microcomputer by the PROM chips.

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Fig. 5. MODCOMP IV minicomputer.

The eddy-current coil design is selected to be able to detect the types of defects or to measure the properties desired. It must be small enough to provide the sensitivity required by test specifications, yet large enough to provide an area of coverage to allow the test to be performed in the time frame allowed. A flat pancake-type coil having a mean radius of 2.11 mm (0.083 in.) was used for this examination. The eddy-current probe actually contained driver and pickup coils arranged in a reflection mode. Figure 6 shows a simplified circuit diagram for a reflection-type probe. Details concerning reflection coils are reported elsewhere.[7] The eddy-current probe used for this examination can be seen in Fig. 7. (The probe is the cylinder located in the laboratory scanning fixture.) A nominal 25-mm-diam (1-in.) superconductor cable and sheath sample is located under the lower end of the probe. The flat eddy-current coils are located in the end of the eddy-current probe, just above the superconductor sample.

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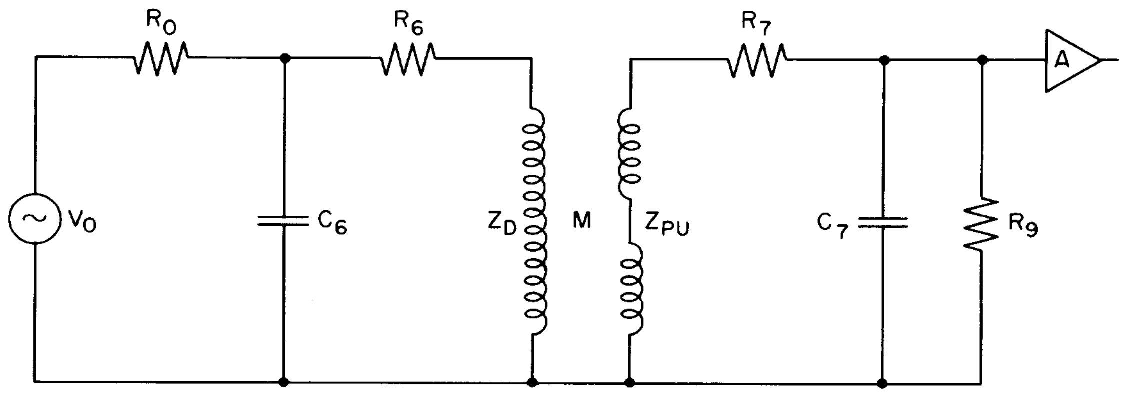

V_0 DRIVING VOLTAGE
R_0 SERIES RESISTANCE IN THE DRIVING CIRCUIT
C_6 SHUNT CAPACITANCE OF THE DRIVING CIRCUIT
R_6 D.C. RESISTANCE OF THE DRIVER COIL
Z_D IMPEDANCE OF THE DRIVER COIL
M MUTUAL IMPEDANCE BETWEEN THE DRIVER AND PICK-UP COILS
Z_{PU} IMPEDANCE OF THE PICK-UP COILS
R_7 D.C. RESISTANCE OF THE PICK-UP COILS
C_7 SHUNT CAPACITANCE OF THE PICK-UP CIRCUIT
R_9 AMPLIFIER INPUT IMPEDANCE

Fig. 6. Simplified circuit diagram for an eddy-current reflection-type probe.

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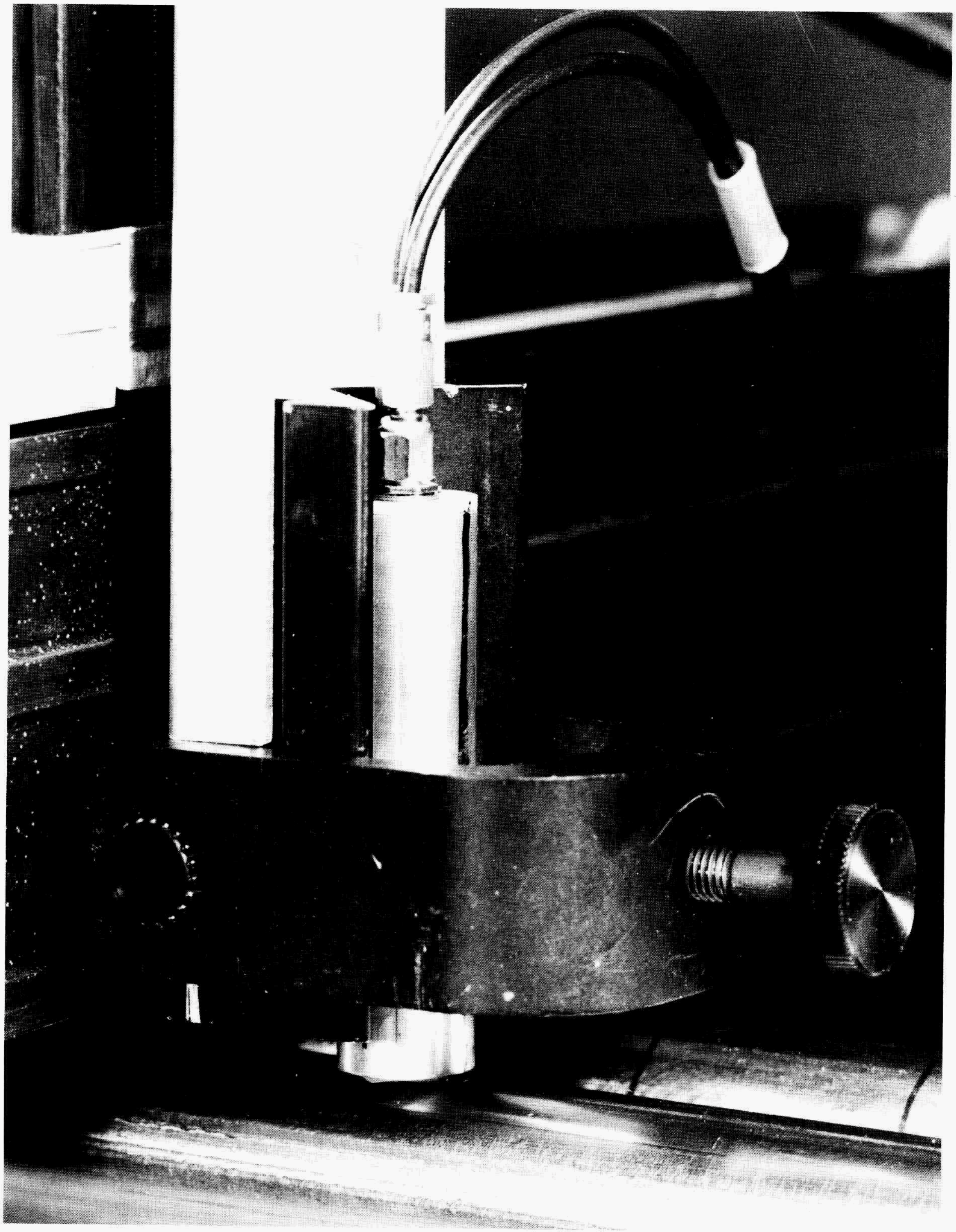

Fig. 7. Eddy-current probe.

The three-axis (xyz) scanning system used to examine the sheath welds in the laboratory is shown in Figs. 8 and 9. The scanning motion can be controlled by the operator using the teletypewriter keyboard (Fig. 10), or the control can be programmed into the computer. The stepping motors that control each axis of motion are driven by voltage pulses, and data are recorded in incremental bytes during scanning.

Figure 11 shows three of the output devices used to record data in the laboratory, a video display, a five-channel strip-chart recorder, and a Versatec printer-plotter. Two other output devices used were the line printer and the magnetic tape recorder shown at the left in Fig. 5.

Figure 12 shows the instrument package that was assembled to perform the tests on site. The components in the cabinet (from top to bottom) are (1) the three-frequency eddy-current instrument, (2) a six-channel strip-chart recorder, (3) a keyboard and video terminal, (4) a power supply and speed control for the scanning drive, (5) a remote control box used with

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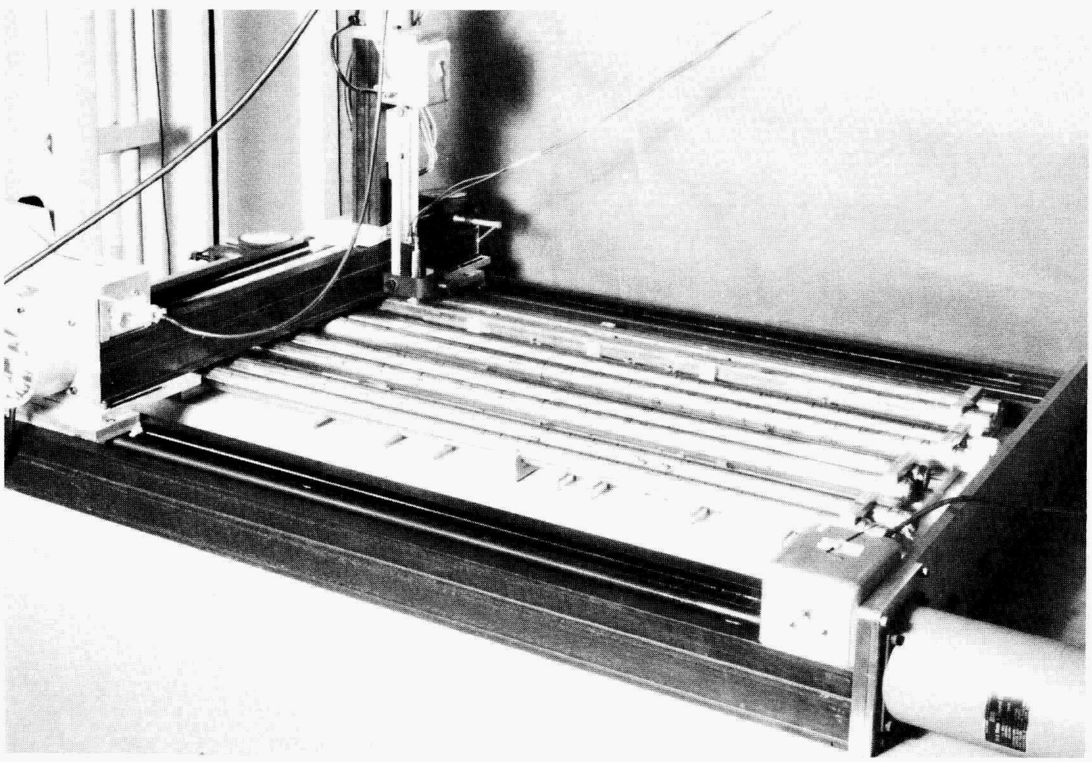

Fig. 8. Three-axis scanning fixture.

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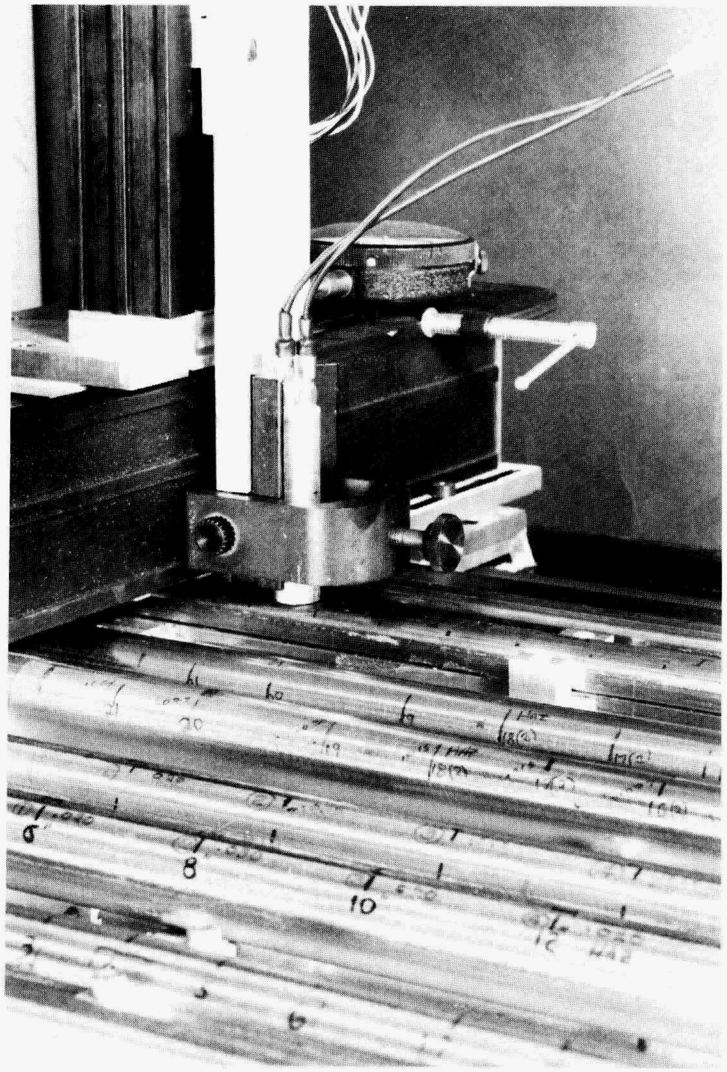

Fig. 9. Close-up of three-axis scanning fixture.

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Fig. 10. Keyboard and video display.

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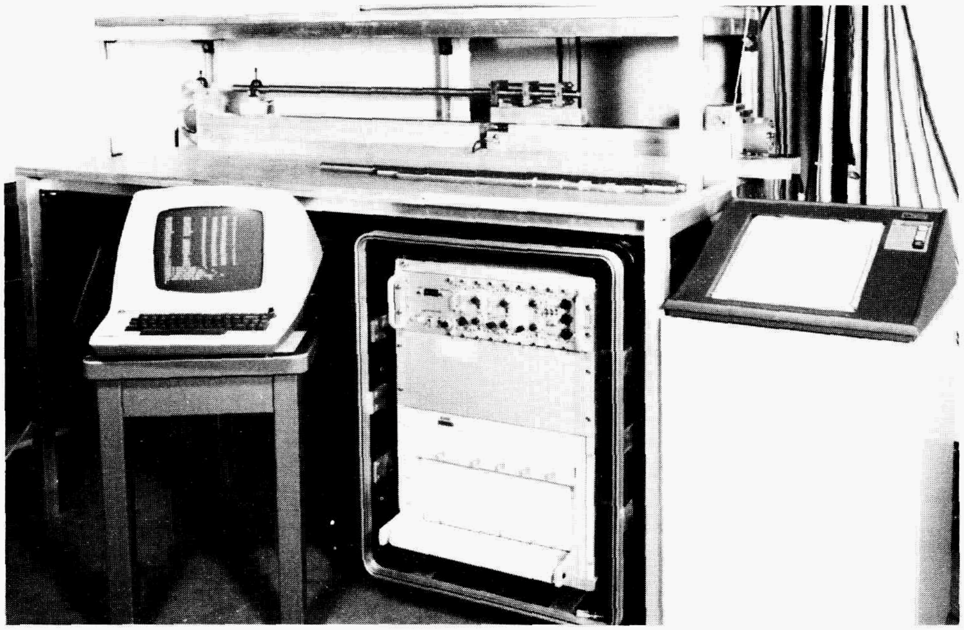

Fig. 11. Output devices (keyboard-video, strip-chart recorder, and Versatec printer-plotter).

the microcomputer to select different test conditions, (6) a magnetic tape recorder and buffer, and (7) a transceiver unit to link the microcomputer and output devices.

Figure 13 shows the sheath weld scanner at the test site. This device will be described in more detail later in this report. The marking device, used to identify areas on the sheath weld where significant eddy-current indications were obtained, is oriented about 45° to the scanner.

Two views of a hand-held manually operated scanning device in position on a superconductor cable are shown in Fig. 14. This device was used to accurately relocate the areas where significant indications were obtained and to reinspect local areas where weld repairs were made.

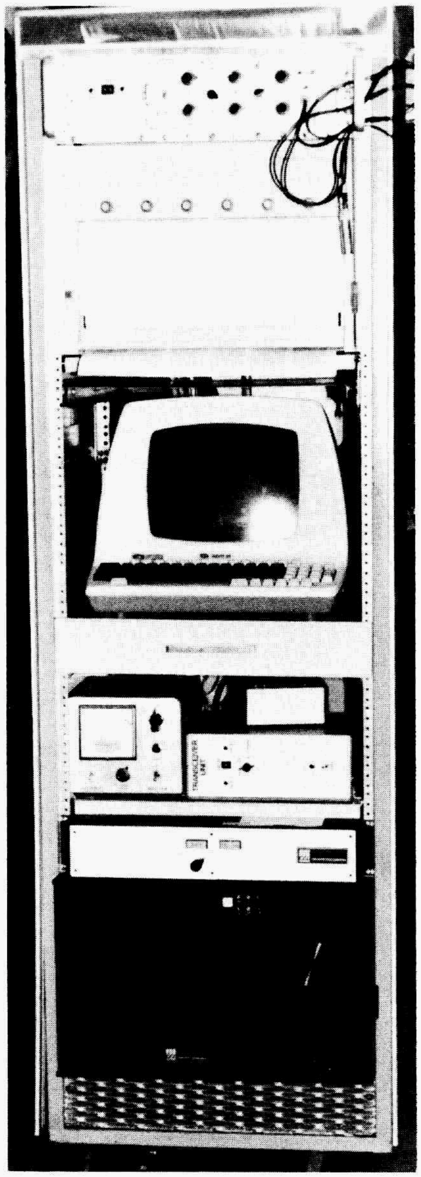

Fig. 12. Field instrument package used at Oxford-Airco.

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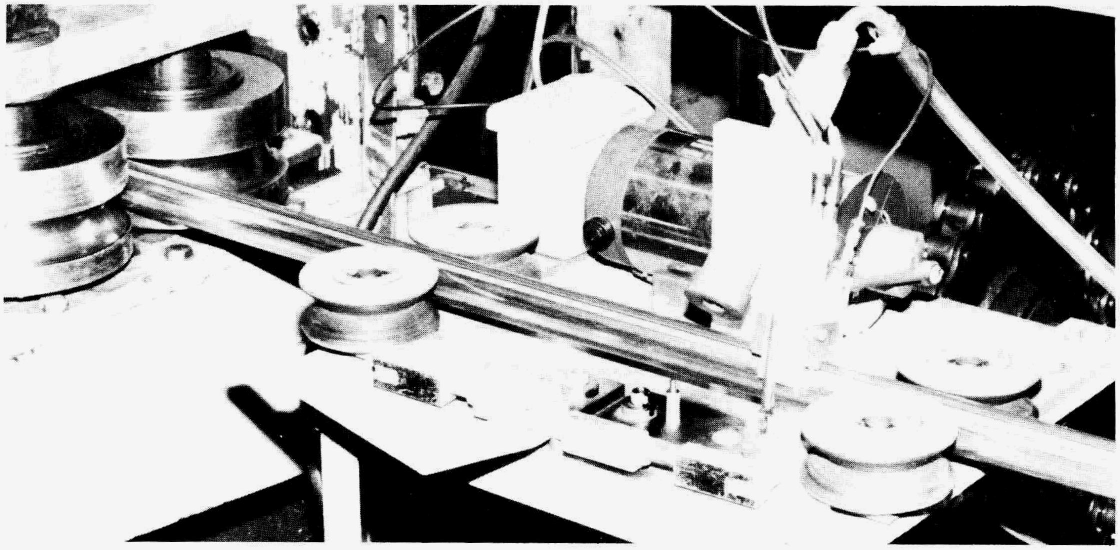

Fig. 13. Sheath weld scanner used at Oxford-Airco.

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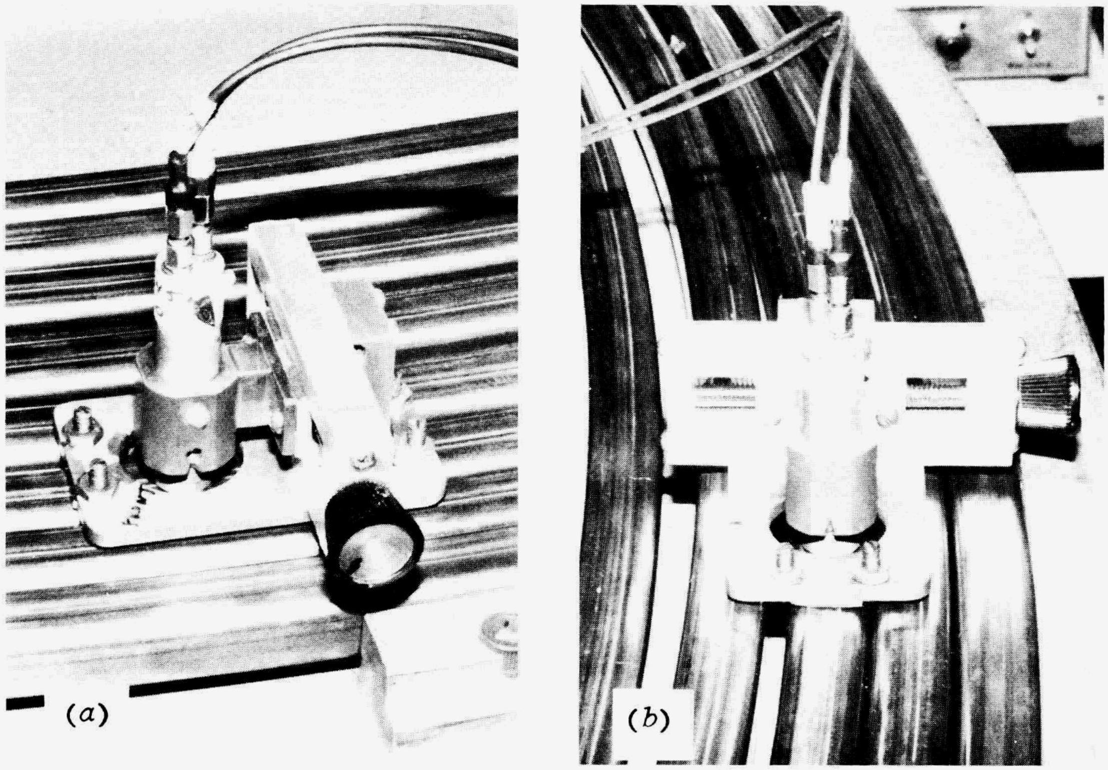

Fig. 14. Two views of the manual scanner used at Oxford-Airco.

TEST SAMPLES

The eight test samples used in this study can be seen in Figs. 8 and 9. Each sample was approximately 0.8 m long (31 in.) and about 25 mm (1 in.) in diameter or thickness. Six samples had a round cross section and two had a square cross section. The two cross sections, illustrated in Figs. 2 and 9, represent different stages in the production of the superconductor cable. The production, on-line eddy-current examination was performed while the cable had a round cross section. The final inspection for weld repairs was performed on the superconductor after it had a square cross section.

Several different types of manufactured discontinuities, such as longitudinal and transverse notches, holes, and V-grooves, were placed in the weld and heat-affected zones on both the inner and outer surfaces of the steel sheath. Figure 15 shows the locations and orientations of some of the discontinuities. The manufactured discontinuities were selected to produce eddy-current signals similar to those produced by the properties we were trying to measure. The holes and notches were used for defect

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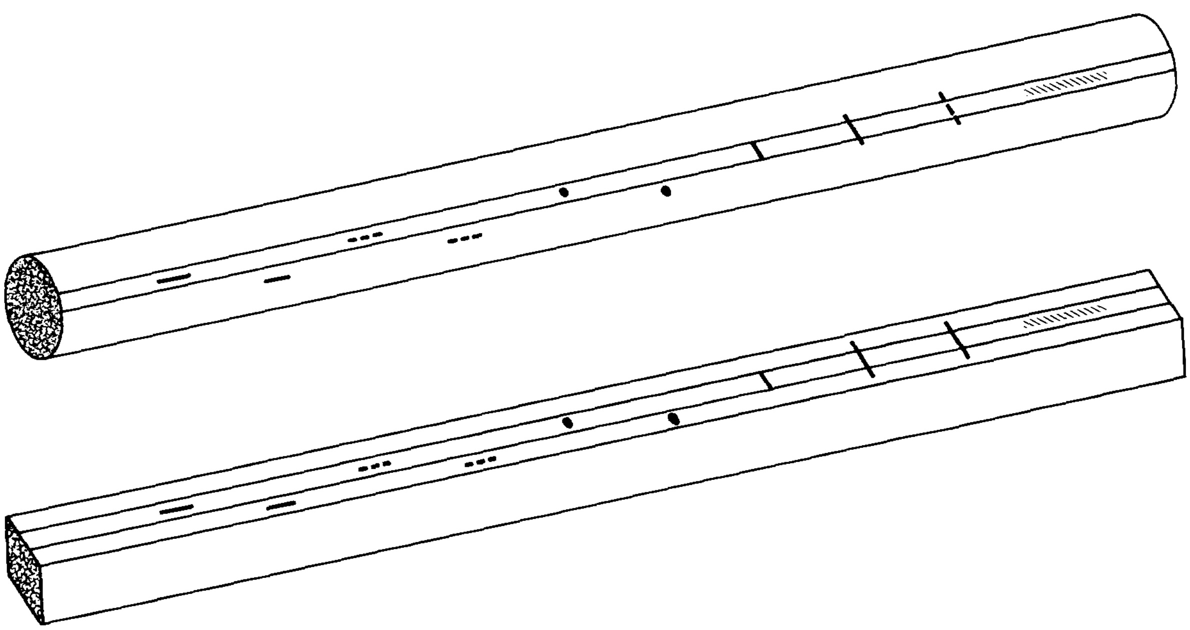

Fig. 15. Locations of manufactured discontinuities in the superconductor sheath weld test samples.

examination. The notches had nominal depths of 0.25, 0.51, and 0.76 mm (0.010, 0.020, and 0.030 in.) and were made by electrodischarge machining. The holes had nominal diameters of 0.18 mm (0.007 in.) and were drilled through the wall. V-grooves were milled in the root area of the weld to simulate lack of weld penetration. The test samples were fabricated in pairs with each pair being essentially identical. Tables 1 through 4 describe the various manufactured discontinuities in the test samples. Samples C and D (Table 4) have a square cross section and represent the final configuration of the superconductor cable. Sample C contained five areas on the weld where weld repairs had been made. Each area was approximately 76 mm (3 in.) long.

A brief identification system was developed for the various manufactured discontinuities in the test samples. This identification was used on data sheets, in computer programs, and in some figures in this report. Examples of discontinuity identities are ILW20, OTZ30, and HW7. Notches have a five-character identification number and holes a three-character number. The first character of a notch identification is either an I or an O, representing the inner or outer surface location of the notch. The second character is an L or T (longitudinal or transverse), and it represents the orientation of the notch with respect to the major axis of the weld. The third character is either W or Z, representing the location of the notch in the weld or in the heat-affected zone. The last two characters are numbers that represent the nominal depth of the notch in 25.4-μm (0.001-in.) increments. The first character of a hole identification is H for hole. The second character is W or Z (weld or heat-affected zone), representing the location of the hole, and the last digit or digits represent the diameter of the hole in 25.4-μm (0.001-in.) increments. All holes were drilled through the sheath (or weld) wall.

We discovered after doing quite a lot of work on the test samples that the material adjacent to the manufactured discontinuities in some of the test samples had become magnetic. These areas were not highly magnetic, and their field strengths could be measured only by using sensitive equipment such as a Hall effect device or an eddy-current instrument. We were mildly surprised because the JBK steel is a high-alloy steel that is

Table 1. Manufactured discontinuities in superconductor sheath weld test samples 1 and 2

Number	Type[a]	Surface	Location	Dimensions [mm (in.)]	
				Length	Depth
1	Longitudinal notch	Inner	Weld	6.35 (0.250)	0.51 (0.020)
2	Longitudinal notch	Inner	Weld	6.35 (0.250)	0.76 (0.030)
3	Transverse notch	Inner	Weld and HAZ	6.35 (0.250)	0.51 (0.020)
4	Longitudinal notch	Inner	HAZ	6.35 (0.250)	0.51 (0.020)
5	Longitudinal notch	Inner	HAZ	6.35 (0.250)	0.76 (0.030)
6	Hole		HAZ	0.18 (0.007)	Through wall
7	Hole		Weld	0.18 (0.007)	Through wall
8	Transverse notch	Inner	Weld and HAZ	6.35 (0.250)	0.76 (0.030)

[a]Transverse notches extend across weld into the heat-affected zone (HAZ).

Table 2. Manufactured discontinuities in superconductor sheath weld test samples 3 and 4

Number	Type	Surface	Location	Dimensions [mm (in.)]	
				Length	Depth
1	V-groove	Inner	Weld	76.2 (3.0)	0.25 (0.010)
2	V-groove	Inner	Weld	76.2 (3.0)	0.51 (0.020)
3	V-groove	Inner	Weld	76.2 (3.0)	0.76 (0.030)
4	Wall thinning	Inner	Weld and HAZ	38.1 (1.5)	15%
5	Wall thinning	Inner	Weld and HAZ	38.1 (1.5)	25%
6	Wall thinning	Inner	Weld and HAZ	38.1 (1.5)	35%

Table 3. Manufactured discontinuities in superconductor sheath weld test samples A and B

Number	Type[a]	Surface[b]	Location	Dimensions [mm (in.)]	
				Length	Depth[b]
1	Longitudinal notch	Inner	Weld	6.35 (0.250)	0.25 (0.010)
2	Longitudinal notch	Inner	Weld	6.35 (0.250)	0.51 (0.020)
3	Longitudinal notch	Inner	Weld	6.35 (0.250)	0.76 (0.030)
4	Transverse notch	Inner	Weld and HAZ	6.35 (0.250)	0.51 (0.020)
5	Hole	T	Weld	1.65 (0.065)	T
6	Hole	Outer	Weld	1.65 (0.065)	1.52 (0.060)
7	Longitudinal notch	Inner	HAZ	6.35 (0.250)	0.25 (0.010)
8	Longitudinal notch	Inner	HAZ	6.35 (0.250)	0.51 (0.020)
9	Longitudinal notch	Inner	HAZ	6.35 (0.250)	0.76 (0.030)
10	Hole	T	HAZ	1.65 (0.065)	T
11	Longitudinal notch	Outer	Weld	6.35 (0.250)	0.25 (0.010)
12	Longitudinal notch	Outer	Weld	6.35 (0.250)	0.51 (0.020)
13	Longitudinal notch	Outer	Weld	6.35 (0.250)	0.76 (0.030)
14	Transverse notch	Outer	Weld and HAZ	6.35 (0.250)	0.51 (0.020)
15	Transverse notch	Both	Weld and HAZ	6.35 (0.250)	0.66 (0.026)
16	Transverse notch	Both	Weld and HAZ	6.35 (0.250)	0.66 (0.026)
17	Longitudinal notch	Both	Weld	6.35 (0.250)	0.38 (0.015)
18	Longitudinal notch	Both	HAZ	6.35 (0.250)	0.38 (0.015)
19	Longitudinal notch	Outer	Weld	19.0 (0.750)	0.76 (0.030)
20	Transverse notch	Outer	Weld and HAZ	12.7 (0.500)	0.61 (0.024)
21	Transverse notch	Outer	Weld and HAZ	3.18 (0.125)	1.63 (0.064)

[a]Transverse notches extend across weld into the heat-affected zone (HAZ).

[b]T = through wall.

Table 4. Manufactured discontinuities in superconductor sheath weld test samples C and D

Number	Type[a]	Surface[b]	Location	Dimensions [mm (in.)]	
				Length	Depth[b]
1	Transverse notch	Outer	Weld and HAZ	6.35 (0.250)	0.25 (0.010)
2	Longitudinal notch	Outer	Weld	6.35 (0.250)	0.25 (0.010)
3	Transverse notch	Inner	Weld and HAZ	6.35 (0.250)	0.76 (0.030)
4	Longitudinal notch	Inner	HAZ	6.35 (0.250)	1.02 (0.040)
5	Transverse notch	Outer	Weld and HAZ	6.35 (0.250)	0.51 (0.020)
6	Longitudinal notch	Outer	Weld	6.35 (0.250)	0.51 (0.020)
7	Transverse notch	Inner	Weld and HAZ	6.35 (0.250)	0.51 (0.020)
8	Hole	T	HAZ	0.15 (0.006)	T
9	Longitudinal notch	Inner	Weld	6.35 (0.250)	0.76 (0.030)
10	Longitudinal notch	Inner	Weld	6.35 (0.250)	1.02 (0.040)
11	Longitudinal notch	Outer	HAZ	6.35 (0.250)	0.25 (0.010)
12	Longitudinal notch	Outer	HAZ	6.35 (0.250)	0.51 (0.020)
13	Transverse notch	Inner	Weld and HAZ	6.35 (0.250)	0.51 (0.020)
14	Longitudinal notch	Inner	Weld	6.35 (0.250)	0.51 (0.020)
15	Hole	T	Weld	0.15 (0.006)	T
16	Longitudinal notch	Inner	HAZ	6.35 (0.250)	0.51 (0.020)
17	Longitudinal notch	Inner	HAZ	6.35 (0.250)	0.76 (0.030)
18	V-groove	Inner	Weld	25.4 (1.0)	0.25 (0.010)
19	V-groove	Inner	Weld	25.4 (1.0)	0.51 (0.020)
20	V-groove	Inner	Weld	25.4 (1.0)	0.76 (0.030)

[a]Transverse notches extend across weld into the heat-affected zone (HAZ).

[b]T = through wall.

very similar to the 300-series stainless steels and should have been nonmagnetic. In fact, no magnetic effects could be detected with the typical gaussmeter used in machine shops. The electrodischarge-machining processes used to cut the notches in the weld had apparently changed the metallurgical structure and the properties of the steel in the small areas where discontinuities were located. The result was that the signals the eddy-current instrument received from these discontinuities were a combination of geometrical and magnetic effects. The signals were larger than normal, and the error was due to the magnetic effect. A very light chemical etch of the samples alleviated the magnetic problem, and after etching we reinspected the samples using a saturating magnetic field around the eddy-current probe and the discontinuity being measured. No adverse effects were caused by the problem, except for a short delay in the completion of the program to establish the test, but the sensitivity of the eddy-current inspection could have been adversely affected if we had not discovered the magnetic effects surrounding some of the discontinuities.

CALIBRATION AND TRAINING OF TEST SYSTEM

An experimental study (discussed earlier in the theory section) was performed in the laboratory to train the computer to determine the specified properties from the available magnitude and phase readings. The basic steps required to complete this study were to produce a data file, record a data set, mathematically fit the data, develop mathematical coefficients for the fit, and then store the coefficients for later use. Details of how these steps were performed are discussed in this section of the report.

To produce a representative data set, we fabricated a set of test samples that had known property variations of the type and over the range that we wished to measure. These samples are described in an earlier section of this report. We then arranged them in a three-axis (*xyz*) scanning system so that the necessary measurements could be made to produce the data set. Figures 8 and 9 show the eight test samples assembled in the scanning fixture. Leveling bars can be seen under the samples in the figure. We needed to level the samples so they could be scanned at known, uniform, fixed lift-off values to compensate for the lift-off variations that occurred during the production line inspection. (The large lift-off variations were due primarily to changes in the weld crown reinforcement.) The eddy-current probe was mounted on the z-axis slide, and lift-off variation was controlled with the z-axis motion. The samples were aligned so the x-axis motion scanned the eddy-current probe down the length of the sample along the major weld axis. The y-axis motion moved the probe across the samples and was used to select the area to be scanned (weld or heat-affected zone) and to select the sample to be scanned.

After the samples had been arranged in the scanner, a "scan data file" was produced. A scan data file contains the coordinates of the test samples and the areas on the sample where we wish to record eddy-current readings. (The samples are physically measured, and the resultant data are typed into the computer data file.) This file then supplies the coordinates that the computer uses to direct the scanner to move the eddy-current probe to the areas where readings are recorded. The data file also contains additional information about the properties being measured, such as the dimensions of the manufactured discontinuities, thickness of the samples, and lift-off values. The computer later uses this information to identify or describe the specific properties. The properties evaluated for this study were defect size and location, weld thickness, and lift-off.

The next step in the experimental study was to modify an existing computer program to direct the minicomputer to record a data set from the specific test samples. This program utilized the coordinates and other information provided by the data file just discussed. In general, the modifications to the program were to correct the array sizes for data storage, provide information about the specific eddy-current instrumentation and coil being used, and update the instrument calibration values. Our basic computer program for recording data is referred to as a "READ" program. The name of the program is BIGRDG, and for this particular test the modified version was dubbed "SUPRDG" (superconductor read). A copy of BIGRDG is included in Appendix A. This program controls the scanning system, maintains a calibration check on the eddy-current system, records and averages the data (typically three independent sets of data are recorded), and stores the data on a random access data (RAD) file. The microcomputer in the eddy-current instrument actually records the data readings from analog-to-digital converters, and the readings are then transferred to the minicomputer through a handshake arrangement between the two computers. A computer program called MICMOD controls this operation. A copy of of this program is included in Appendix B. The program was written in machine language and was stored on one of the PROM chips in the microcomputer (see Fig. 3).

It is essential that the eddy-current test system be properly calibrated when these data are recorded. If this step is properly conducted, a representative data set will be obtained, and no further data recording will be required. However, changes in the production procedure (such as changing materials or the welding technique) or changes in the test specifications could necessitate the recording of additional or new data sets.

A data set can consist of a large number of readings of magnitude and phase. These data require a relatively large amount of memory space (typically about 1 megabyte), and they must be stored in an orderly manner for easy retrieval. We can store a data set of this size in our (MODCOMP IV) minicomputer, but it occupies most of the available "free" memory space and therefore limits some of the other capabilities of the computer. Because of this we usually store these large sets of data on a disk or magnetic tape until we are ready to use them.

After we obtained the data set, the next step was to perform a least-squares mathematical fit of the data to select the polynomial that best determines the specified properties from the magnitude and phase readings recorded in the data set. The fitting was done with the minicomputer and a slightly modified version of another computer program called BIGFIT. This program is our basic FITTING software and was also developed at ORNL. A copy of BIGFIT is included in Appendix C. The modified version of the BIGFIT program used for this study was entitled SUPFIT (superconductor fit). This program allows the type of polynomial to be user selected from the computer keyboard. The operator can select linear or nonlinear polynomials of various degrees, with or without offsets, for fitting the data. In addition, he can examine the effects of other parameters on the results by including or excluding these data in the fits. Whenever a mathematical fit is made, the computer calculates the fit error (how well the specified property was determined) and the drift error (how small changes in the magnitude and phase readings will affect the property determination). Once the optimum mathematical fit to the data is established, the computer will calculate the coefficients for the terms in the polynomial that represent that fit. These coefficients are then stored in the minicomputer's memory until we are ready to transfer them to the microcomputer in the eddy-current instrument.

Whenever a satisfactory mathematical fit is obtained, it is usually experimentally evaluated before the coefficients are transferred to the microcomputer. This evaluation is accomplished by scanning the test samples, recording the eddy-current readings, and using the polynomial and associated coefficients to calculate the desired property as the test is being conducted. The computer program that controls this operation is a modified version of the program PLTRDG. A copy of PLTRDG is included in Appendix D. A hard copy of the test results is normally obtained (in the form of a plotted curve or tabular printout) from the Versatec printer-plotter.

For example, Fig. 16 shows a plot of the raw data readings (magnitude and phase) that were recorded for each test frequency as the eddy-current probe was scanned over the sheath weld for a 381-mm (15-in.) length of superconductor test sample 1. The six curves represent the magnitude and phase readings recorded for each of the three frequencies. These are the data recorded in the "data set" just discussed. In this particular case it is difficult to select signals that distinctly relate to the manufactured discontinuities placed in the sheath. Figure 17 is a plot of the data obtained when the same weld was scanned and the selected property of discontinuity size was calculated by the computer from raw data identical with that obtained in Fig. 16. The calculations were made by matching the raw data readings to the appropriate polynomial using coefficients that

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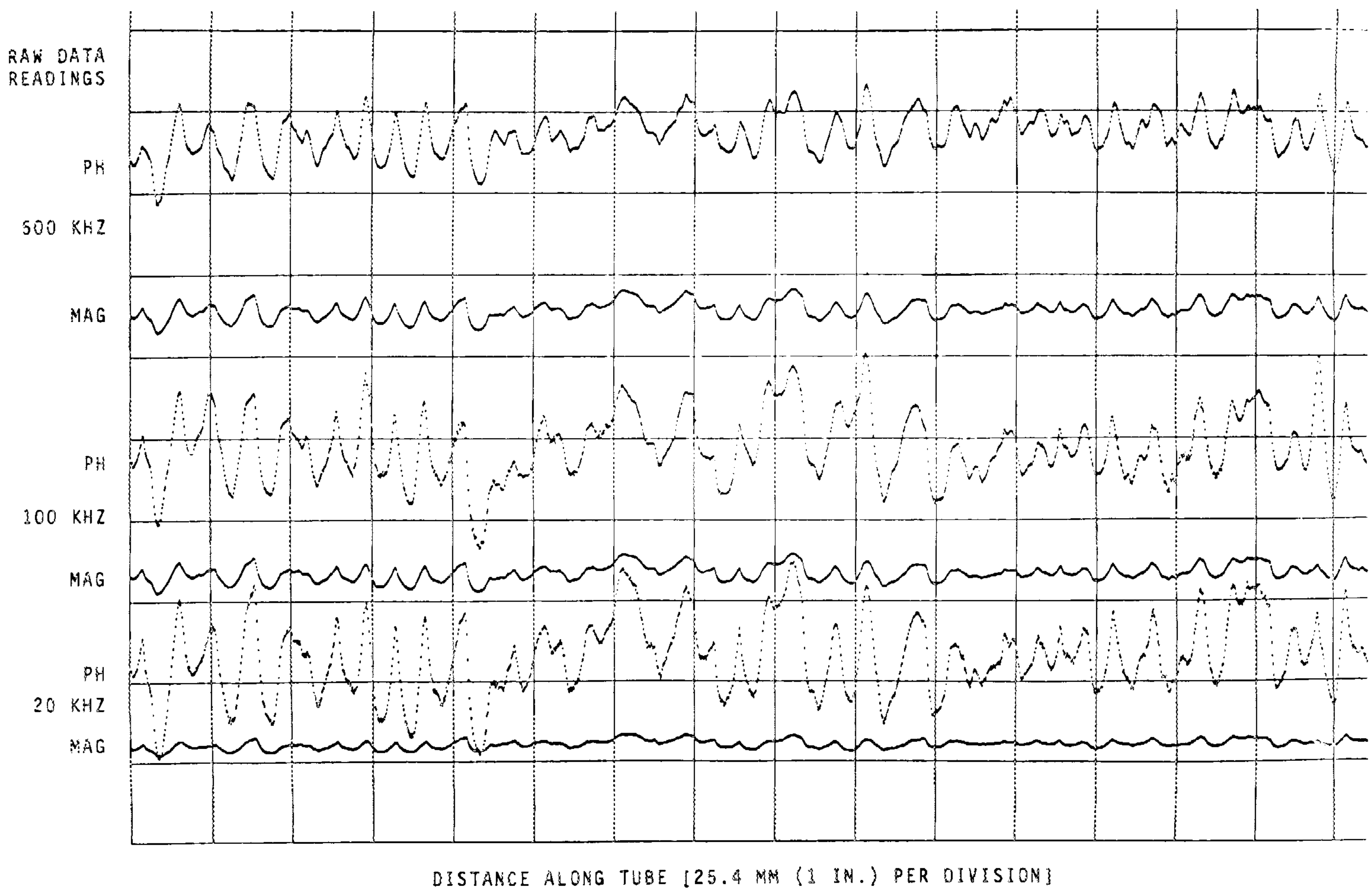

Fig. 16. Raw data readings from a superconductor sample containing only inside-surface discontinuities.

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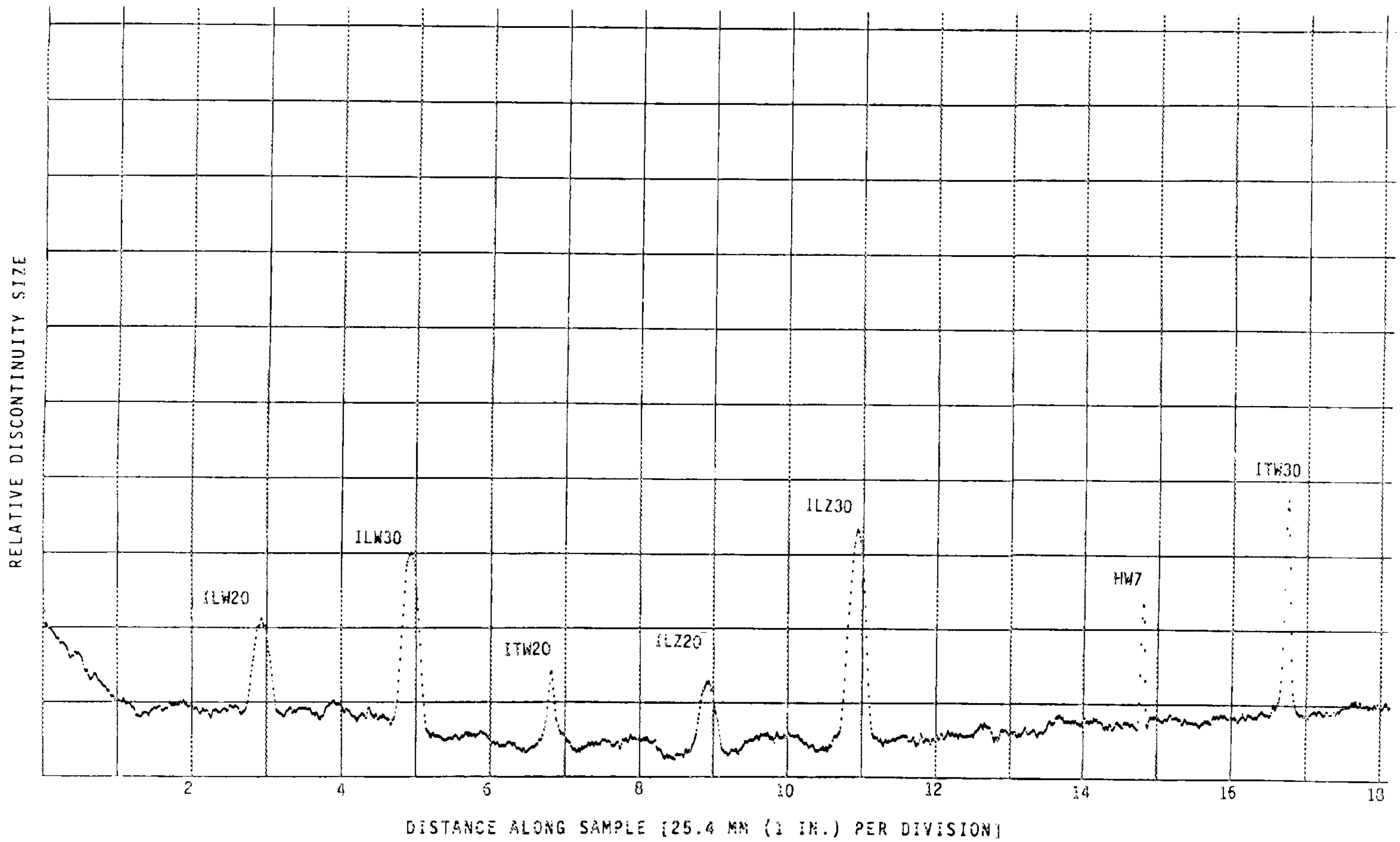

Fig. 17. Calculated data showing relative discontinuity size after the sample was etched (round cross section).

were developed earlier. The respective discontinuity is identified above each signal. (These identities are explained in the section on test samples.) The distinct signals in Fig. 17 represent the various manufactured discontinuities in sheath weld test sample 1 (see Table 1). Comparing Fig. 17 and Table 1, it may be noted that no signal exists in Fig. 17 for the hole in the heat-affected zone. This is because we scanned the weld area, and the eddy-current probe area of coverage does not extend to the heat-affected zone. These data (Figs. 16 and 17) provide a dramatic illustration of the results that can be obtained by combining and mathematically fitting the eddy-current (magnitude and phase) data obtained with three frequencies.

After we completed the calibration and training of the multifrequency eddy-current test system in the laboratory, we developed mathematical coefficients for the various properties that we wanted to monitor, such as lift-off, wall thickness, and defect size and location. Some of our results, especially those related to defect size, appeared a little ambiguous, so we did some additional investigating. Many of the samples containing discontinuities manufactured by electrodischarge machining (EDM) were slightly magnetic in the specific area where the discontinuities were located. The JBK steel is similar to the 300 series stainless steels. It is normally nonmagnetic, but apparently the EDM techniques had changed the magnetic permeability of the material in the vicinity of the discontinuities. The change was so small that it could not be sensed by typical magnetic detection devices, but a sensitive eddy-current instrument can easily detect changes of this magnitude. The end result was that erroneous signals had been obtained from some discontinuities; therefore the mathematical coefficients developed for defect size were also in error. Not all the samples were affected; for those that were, the entire sample was not affected, only the small areas containing some of the discontinuities. For this reason, only those eddy-current signals that represented defect size were in error. We made sure that no changes such as these occurred in the production cables, and we corrected the problem by removing the magnetic variation in the samples and refitting the data to a new polynomial. We removed the magnetic changes by acid-etching the samples to remove a very small amount of material from the surface and then inspected the samples in the presence of a saturating magnetic field. (The saturating field reduces the effects of changes in the magnetic permeability of the material.) Using these techniques we developed a new set of coefficients that represented the superconductor sheath weld in the normal (unmagnetized) condition that occurred at the production site. As a result of the new mathematical fit, the amplitudes of the signals from some of the discontinuities were reduced, but the detection capability was not affected.

SCANNING THE SHEATH WELD

The eddy-current probe was selected to meet two criteria; it had to have sufficient sensitivity to detect the defects specified and it had to cover 100% of the weld and heat-affected zone. In general, with other parameters being fixed, the sensitivity to small defects and the area of coverage of a pancake type eddy-current coil vary, respectively, inversely and directly with the diameter of the coil. The largest eddy-current coil that we had available that met the sensitivity requirements for this examination had a mean radius of 2.11 mm (0.083 in.). When field decay and other nonlinearities are considered, the effective area of coverage for this coil is about 2 mm (0.08 in.). Test specifications required that we inspect the sheath weld and both heat-affected zones. The minimum width that we were required to scan to provide inspection coverage from one heat-affected zone to the other was 8.13 mm (0.320 in.). We could not use a larger coil because of the reduced test sensitivity, so we were faced with two choices. We could use multiple probes (four or five) to scan the weld and heat-affected zone simultaneously, or we could develop a scanning fixture to move a single probe across the weld and heat-affected zone. The multiple probe technique would have required a multiplexer or multiple instrumentation to record the data and would have been relatively complicated and more expensive to develop. In addition, we had a very tight time schedule for developing the test method, so we decided to use the single probe and build a scanning device.

The basic problem was to scan the eddy-current probe mechanically back and forth across the weld and heat-affected zones as the weld moved linearly past the probe (see Fig. 18); however, the problem was not as simple as just providing the mechanical motions. We had to synchronize the probe motion with the weld movement and data recording to assure complete coverage during the inspection, maintain a relatively constant lift-off between the probe and sheath, and synchronize the weld and probe motions with the data recording system to maintain positive identification of the defect location. In addition, we were limited by the electronics in our test system (analog-to-digital converter and microcomputer) to recording only about 80 readings per second.

During production fabrication the steel sheath is formed and welded around the superconductor cable for lengths of up to 100 m. This process is conducted continuously at a speed of about 0.61 m/min (2 ft/min). The weld is 5.1 mm (0.200 in.) wide. To include the heat-affected zones, we needed to inspect at least 1.52 mm (0.060 in.) on either side of the weld for a total width of coverage of 8.13 mm (0.320 in.) (see Fig. 18). The

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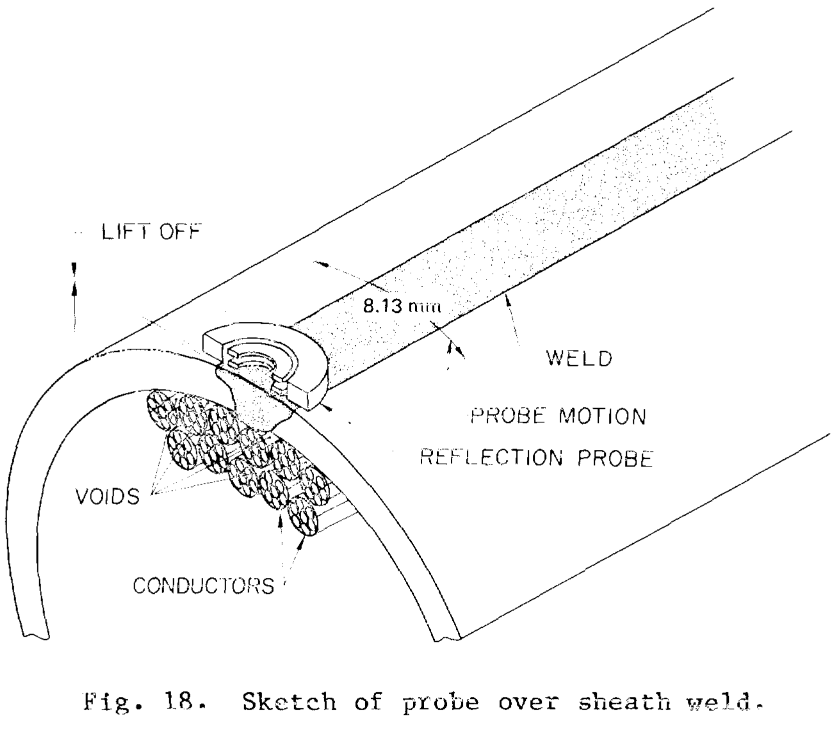

Fig. 18. Sketch of probe over sheath weld.

area of coverage of the eddy-current probe was 2 mm (0.08 in.), so we decided that five readings across the width would be sufficient to cover the weld and both heat-affected zones with some overlap.

We also had to decide what path or scanning pattern we wanted the eddy-current probe to make as it scanned the weld and heat-affected zones. The options were sine wave, saw tooth, and square wave. Our final choice was a sine wave (see Fig. 19) because it was relatively easy to produce and it best fit the method used to output the data.

A crankshaft-type drive was used to move the probe back and forth as the superconductor sheath weld passed underneath the probe in a linear direction. The resultant motion of the eddy-current probe relative to the sheath was sinusoidal. Two views of the scanning device that was designed and built at ORNL are shown in Fig. 20. The spring-loaded Teflon V-block

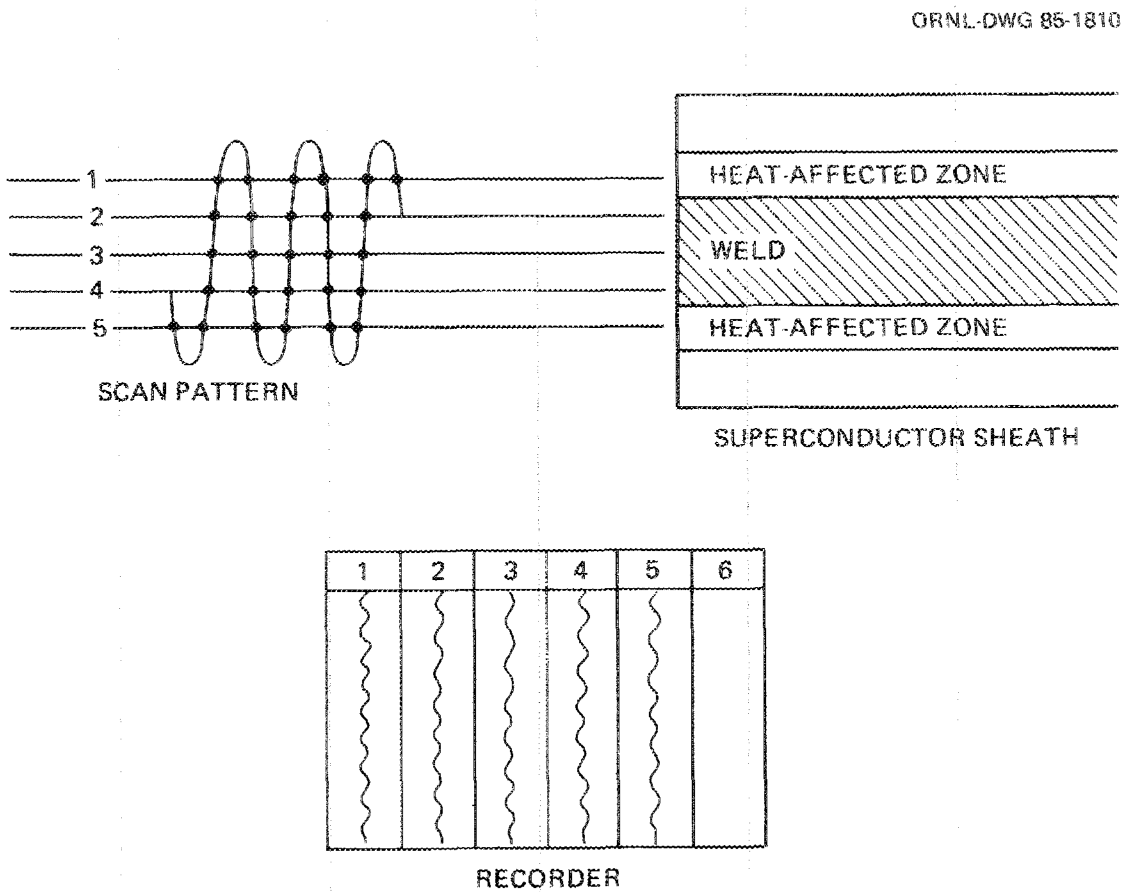

Fig. 19. Sine scan path and eddy-current read location.

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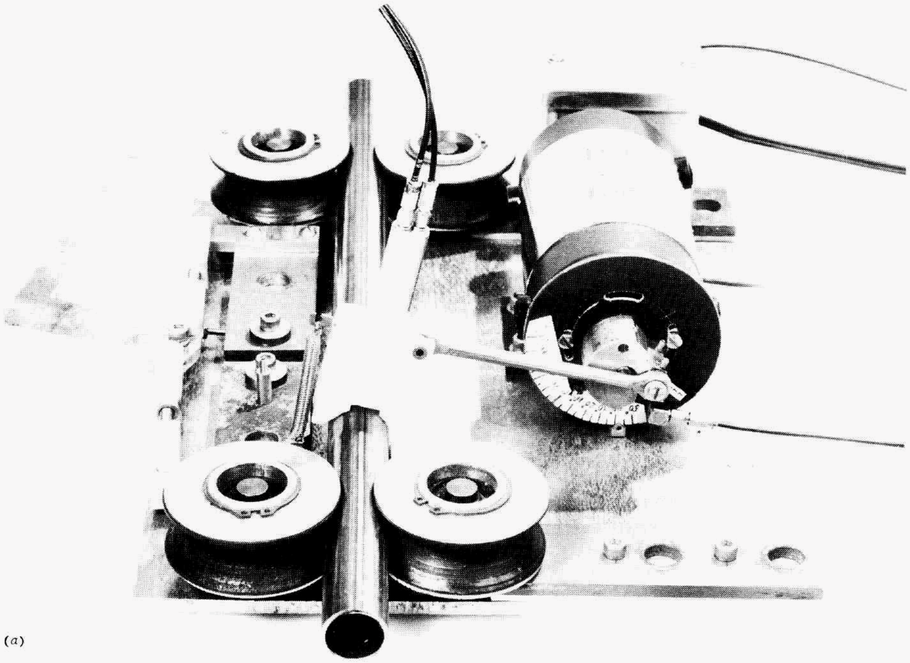

(a)

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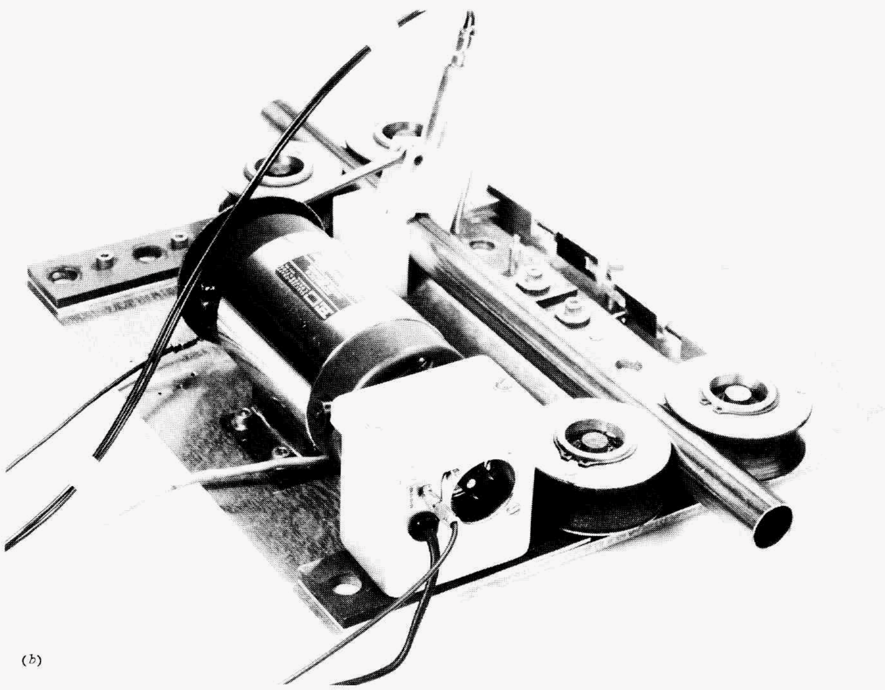

(b)

Fig. 20. Sheath weld scanner.

caused the eddy-current probe to follow an arc path over the sheath weld and to maintain a relatively constant lift-off during the inspection. The eddy-current probe did not contact the part during this inspection, but lift-off was minimized. The weld crown reinforcement varied as much as 1.0 mm (0.040 in.) above the base metal, so we placed a hard plastic wear plate over the end of the eddy-current probe to protect the coil during the inspection. The effect on the data of the variations in lift-off due to changes in the weld crown reinforcement was accounted for when we trained the computer on the test samples.

The electrical outlet in Fig. 20(*b*) supplied power to the marking pen. Electric power to the pen was controlled by the microcomputer using a solid state relay. The system was adjusted to cause the pen to mark areas on the superconductor sheath where discontinuity signals exceeded a preset level.

Rather than record random readings as the eddy-current probe oscillated back and forth across the weld and heat-affected zones, the readings were taken at specific predetermined locations across the weld width. This is illustrated in Fig. 19. Five eddy-current readings were recorded at fixed longitudinal axes each time the probe traversed the weld. A total of ten readings were recorded for each cycle traveled by the probe. The locations of the readings were controlled by computer software and a synchronized pulse generated by the drive motor crankshaft. Readings 1 and 5 were always made in the heat-affected zones, and readings 2, 3, and 4 were taken in the weld area. The next consecutive set of five readings was taken in reverse order along the same corresponding longitudinal axes. These readings were stored in designated arrays in the microcomputer, and corresponding values for consecutive sets of readings were averaged before the data were transmitted to the output devices. This process was repeated for the entire test. The data for each individual axis (three in the weld and two in the HAZ) were fed to the first five channels on the six-channel strip-chart recorder shown in Fig. 12. The data on each channel of the strip-chart recorder then effectively represented a scan down the longitudinal axis where the individual readings were recorded. The first five channels were set to display discontinuities, and the sixth channel was adjusted to indicate the worst case of lack of weld penetration. Worst case refers to the minimum penetration for a given sine wave path of the eddy-current probe. To restate, the depth of weld penetration was monitored for each of the first five channels of data, and the channel exhibiting the minimum depth of weld penetration was displayed on channel 6 of the strip-chart recorder.

The entire recording process and data handling were controlled by the microcomputer in the eddy-current instrument and the computer program SQRWLD. This versatile computer program, included in Appendix E, will be described in more detail in the next section of this report. Figure 21 shows a segment of the strip chart from the analog recorder containing the six scans.

All raw data (magnitude and phase readings for three frequencies) were stored on magnetic tape by the recorder shown in Fig. 12. The six-channel strip-chart recorder displayed the data that we wanted to observe as the test was being conducted. The magnetic tape could be replayed through the microcomputer to reproduce the six channels of strip-chart data, or, by selecting other polynomial coefficients (via memory locations in the computer), we could calculate other properties from the raw data and display the results on the analog recorder.

PERFORMING THE INSPECTION ON THE PRODUCTION LINE

The superconductor cable was assembled in continuous lengths of up to 100 m. A block diagram of the basic operations is shown in Fig. 1. Rolls of the 486-strand twisted cable and the type JBK steel strip were stored at the feed station. The wire and cable were simultaneously fed through the forming stands, where rollers shaped and wrapped the steel strip to form a sheath around the twisted cable. The butt joint, created at the top of the steel sheath, was then welded autogenously by a gas tungsten arc technique. The weld and cable were quenched and fed through the eddy-current inspection station at a speed of 0.61 m/min (2 ft/min). The multifrequency eddy-current inspection of the sheath weld was performed continuously for the entire length of the cable. A procedure, included as Appendix F of this report, was written at ORNL to describe in detail the

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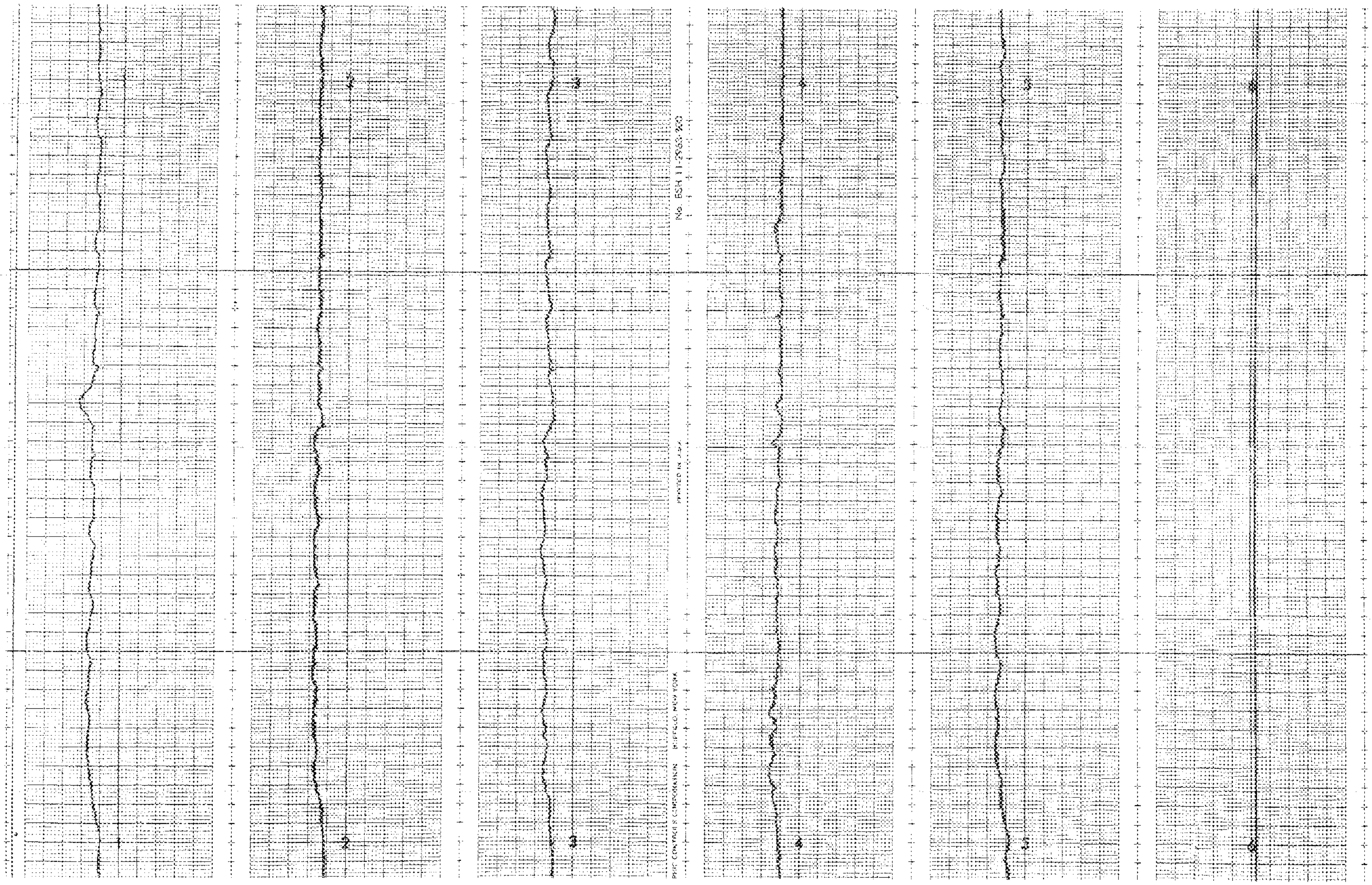

Fig. 21. Example of six-channel strip-chart recording. Channels 1 through 5 indicate discontinuities when they occur in the sheath weld or HAZs. Channel 6 indicates the lack of penetration in the weld. Channels 1 and 5 represent the two HAZs, and channels 2, 3, and 4 represent the weld.

steps necessary to perform the eddy-current inspection. The basic steps were (1) initial check of the system, (2) precalibration, (3) test, and (4) postcalibration. These steps are described in general as follows.

The system checks and calibrations and the data recording and display were controlled with the microcomputer by a program called SQRWLD. A copy of this program is included in Appendix E. The program was written in machine language and was stored on two of the PROM chips located in the microcomputer (see Fig. 3). The operator would set up the equipment and place the test piece or a standard in the scanning device. He would then select the action to be performed by operating a remote switch to a designated position. The SQRWLD program would then take command and make sure that the necessary steps were taken to perform that action. Some of these steps included prompts on the video display defining actions for the operator to take. The eight major actions that could be selected by the operator through the remote control switches were (1) run the main program, (2) read tape, (3) read standard tube, (4) display raw readings, (5) display calculated readings, (6) perform and display calibrations, (7) inspect square conditions, and (8) calibrate the digital or analog converters and recorder. In addition, the program controlled the synchronized data recording with the scanning device. (A synchronization pulse was generated for each revolution of the drive motor crankshaft.)

INITIAL SYSTEM CHECK

The first step is to apply power to all electrical instruments and allow a sufficient warm-up time for the equipment to stabilize. During this warm-up period, the operator makes several checks to ensure that the instruments are working properly and that all systems are ready for the inspection. For example, all electrical connections and switches are checked. The analog (strip-chart) recorder ink and paper supply are checked. General checkouts are made of both recorders (analog and magnetic tape) and the eddy-current probe scanner. In addition, the microcomputer is used to perform the following system checks on command by the operator.

The multifrequency eddy-current instrument contains a calibration module that can be used along with the microcomputer to check the operation of the analog portion of the eddy-current instrument. This step is controlled by the computer program SQRWLD. Simulated eddy-current signals of known values are generated by the calibration module and fed through the amplifiers, phase detectors, and analog-to-digital converters to the microcomputer. These signals are separated into their magnitude and phase components and are displayed on the video terminal. The operator can determine from these magnitude and phase values whether or not any adjustments or corrections are needed in the analog portion of the eddy-current instrument.

The operation of the analog recorder is checked by a series of voltage steps received from the microcomputer through a digital-to-analog converter. This step is also controlled by the computer program SQRWLD. The voltage steps are recorded in a staircase pattern on the analog recorder, as shown in Fig. 22. If the voltage steps cause the recorder pens to move the correct number of increments in the proper direction on the recorder, the system is ready for use. If not, adjustments are made.

The following check was not part of the original test package but was added later because of problems encountered by recording the raw data on magnetic tape at the production site. A technique was developed to check the entire digital recording system. The microcomputer was programmed to generate a set of hexadecimal numbers by counting from 0000 to FFFF. These numbers were transmitted through the transceiver unit and tape buffers and recorded on the magnetic tape. To check the tape, the numbers were then read back from tape and through the buffers and transceiver, compared with the original count in the microcomputer, and then displayed on the video terminal. By comparison of numbers in the microcomputer and the resulting video display, the operator can determine whether the digital recording system is working properly, and, if not, he can localize the problem areas. The procedure for performing this check is in Appendix G. The computer program that generated the hexadecimal number set and controlled the operation was called CHECK. A copy of that program is included in Appendix H. The program was written in machine language and stored on one of the PROM chips in the microcomputer (see Fig. 3).

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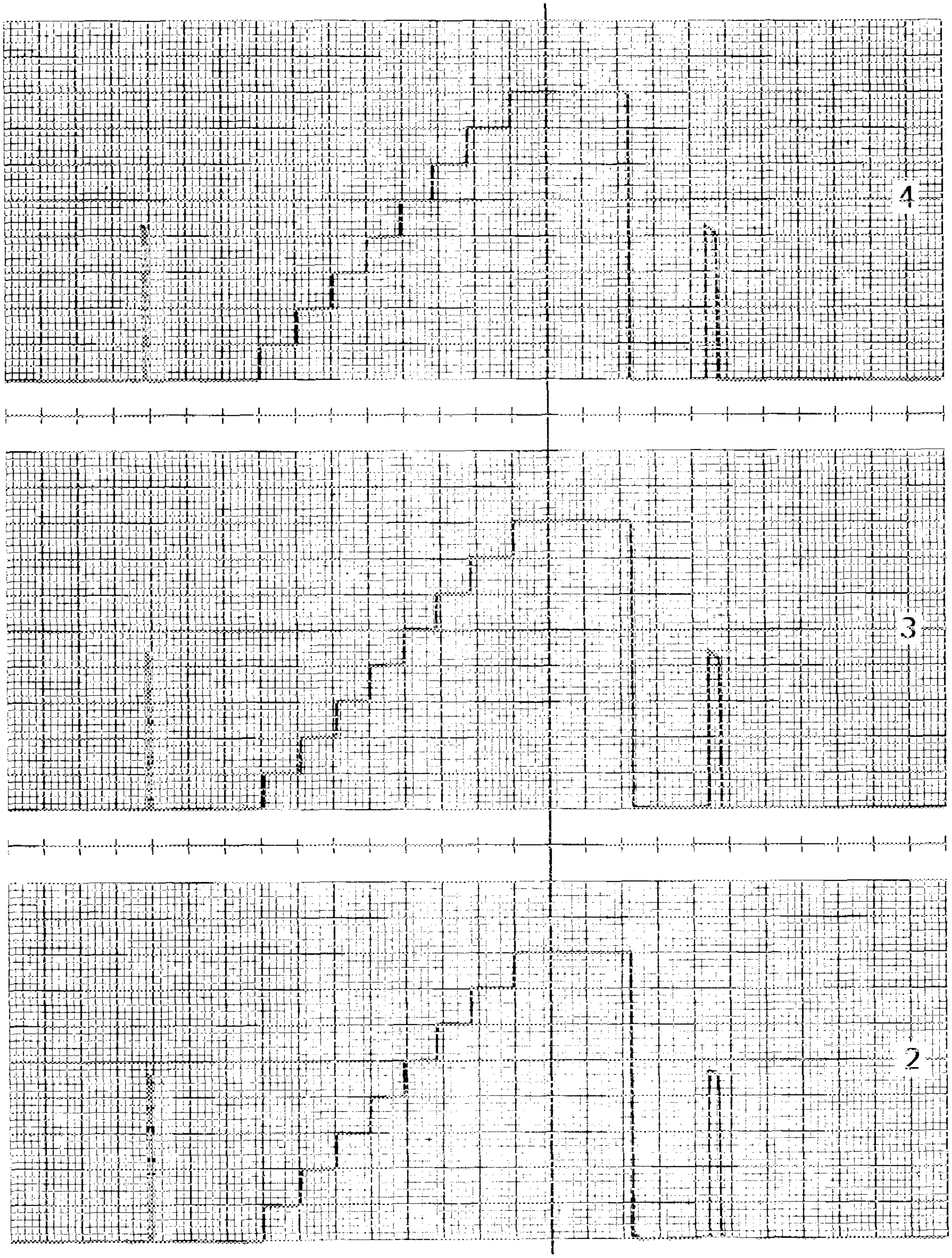

Fig. 22. Step voltage calibration record (strip chart).

PRECALIBRATION

After the eddy-current test system has completed the proper warm-up and stabilization and all systems have been verified, the following pretest calibration checks were performed.

Three different sheath weld test samples were manually pulled through the sheath weld scanner and inspected. The three test samples were identified as A, 1, and 4, and they are described respectively in Tables 3, 1, and 2. (These are the same samples that were used to develop this test in the laboratory.) Three channels of strip-chart data representing only the sheath weld area made during a check of weld test sample 1 at the Oxford-Airco site are shown in Fig. 23. The predominant discontinuity indications can be seen on channel 3 (the center channel). This scan was made down the center of the weld. Scans 2 and 4 were made down the edges of the weld. Transverse notches should be detected by both scans, but the longitudinal notches may or may not be detected because of the limited area of coverage of the eddy-current probe. The discontinuities are identified above the indications on channel 3. These data can be compared with Fig. 17, which represents a single scan of the same sample performed in the laboratory at ORNL. The data from these pretest calibrations were recorded on the analog recorder and were compared with previous data for the same samples to make sure that the test sensitivity and repeatability were satisfactory. The strip-chart recordings were identified and maintained for reference.

PERFORMING THE TEST

The sheath weld scanner was placed on the superconductor cable in the production line assembly. Some initial checks were made, and, in coordination with other functions such as welding, the assembly operation was started. The assembly (welding, forming, inspection, and shaping) then ran continuously until the desired length of the superconductor cable had been fabricated and wound into a large coil. The average continuous inspection time to complete the coil assembly was about 3 h. The raw data (magnitude and phases for three frequencies) were recorded on magnetic tape, and calculated data (discontinuities and lack of weld penetration) were displayed on the strip-chart recorder. The strip-chart data were

ORNL-DWG 85-1812

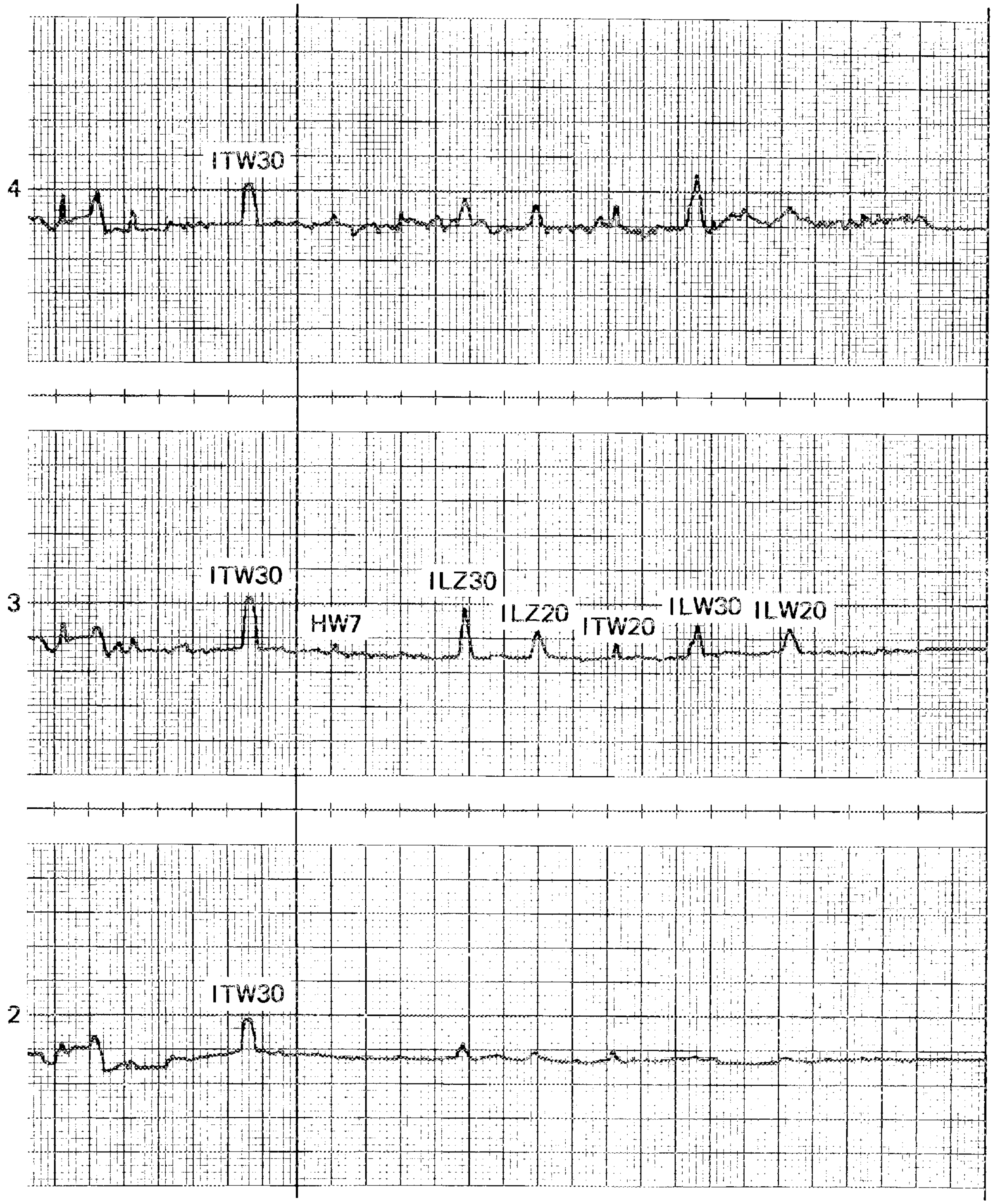

Fig. 23. Strip-chart recording, test calibration (sample 1).

observed during the inspection and were found to be very beneficial to the welder to help maintain alignment of the weld joint. Since we could not stop the superconductor cable for a complete evaluation of each eddy-current indication as it was obtained, we installed a marker pen on the sheath weld scanner. Whenever an eddy-current indication was obtained that exceeded a preset reference level, the microcomputer extended the marker pen (by operating a solid state relay), and an ink mark was placed on the steel sheath in the vicinity of the discontinuity that caused the indication. These areas were later reinspected with the manual scanner to determine whether weld repair was needed.

POSTCALIBRATION

After the completion of the production line inspection, a posttest calibration was performed on the MFEC system. The three weld test samples described under the pretest were rechecked, and the data were compared with the pretest data to make sure that no significant changes had occurred in the test system. These data were identified and recorded on both analog and digital recorders.

After the postcalibration, the data on the tapes (strip chart and magnetic) were reexamined by a manual scanning technique to determine what areas, if any, needed to be reinspected. A more thorough investigation could be made with the manual technique, and the discontinuity could be pinpointed more accurately for repair, if needed. The hand evaluation provides more information about the discontinuity than does the regular production scan. This will discussed in more detail in the next section.

MANUAL INSPECTION FOR WELD REPAIRS

After the production line inspection of the superconductor sheath weld was completed, those areas where significant eddy-current indications had been obtained needed reinspection. (The number of significant eddy-current indications was typically fewer than ten per production run.) The general areas where the indications occurred could be determined by two techniques, by examining the recorded data and by looking for ink marks on the steel sheath. In all cases the strip-chart recordings were reexamined, and a second inspection was performed to examine the area causing the indication to determine if weld repair was necessary.

The technique for inspecting for weld repairs was similar to that for the production line inspection. The major difference was that a hand-held manual scanning device was used, and sheath weld sample D (having a rectangular cross section) was used for the pre- and postcalibration inspections. The data obtained during the manual inspection were recorded on the analog recorder but not recorded on magnetic tape.

The manual scanning setup is shown in Fig. 24. The same instrumentation and eddy-current probe were used with both scanning devices. A time lapse usually occurred between the completion of a production run and the inspection for weld repair; therefore, the four basic procedural steps

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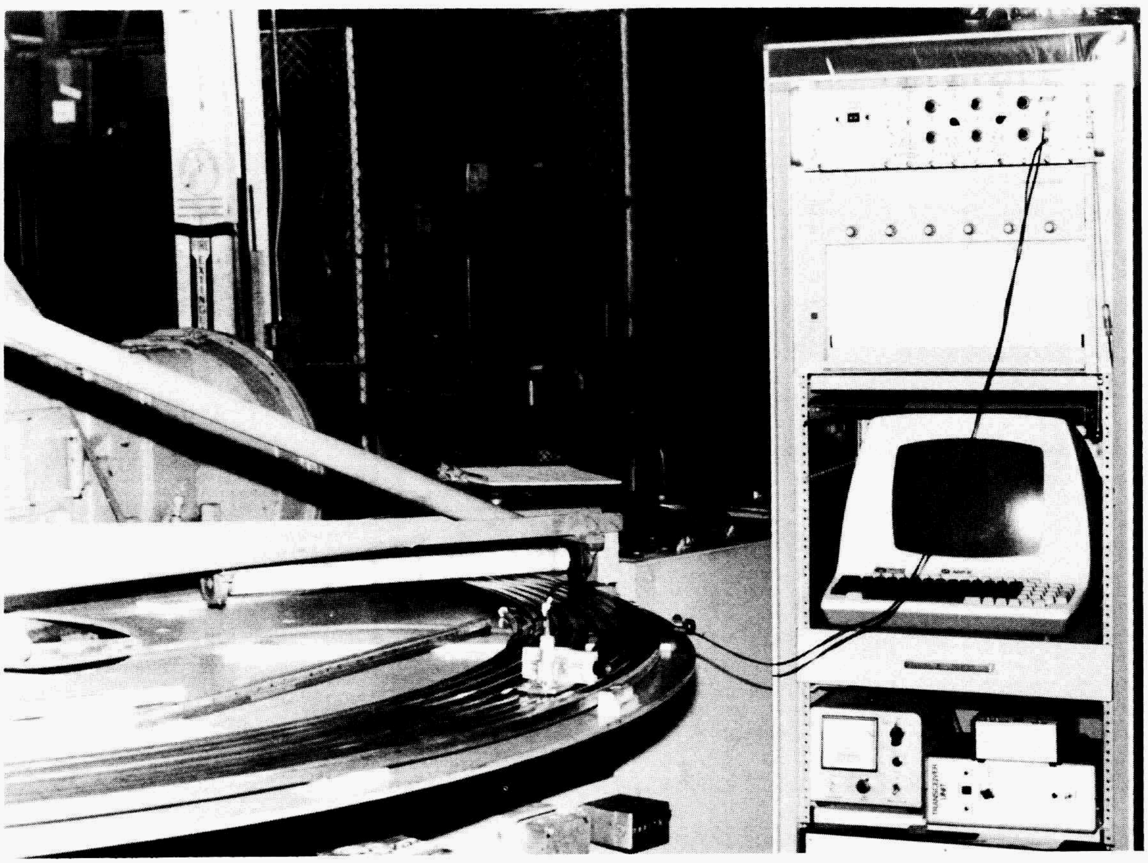

Fig. 24. Manual scanner and instrument.

were normally repeated: (1) initial system check, (2) precalibration, (3) perform test, and (4) postcalibration. The manual inspection procedure was very similar to the production line procedure, and many of the steps were duplicated. The inspection procedure in Appendix I describes the steps necessary to perform the manual inspection for weld repair.

The initial system check was identical except that a few switches were changed on the control box and microcomputer to select different software for the analog data analysis. The manually controlled motion of the eddy-current probe produced only a single scan of raw eddy-current data along one axis of the sheath weld. These data were recorded, analyzed by the microcomputer, and displayed on four channels of the strip-chart recorder. Channels 1 through 4 on the recorder represented, respectively, discontinuities on the outer surface, lift-off, discontinuities on the inner surface, and lack of weld penetration. The operator made as many scans of the suspect area on the weld as were necessary to relocate the indication obtained during the production run. The area was then thoroughly examined to determine if a weld repair was necessary and to determine the size of the area to be repaired. The weld repair was made by locally grinding the weld to remove the bad area and then rewelding. After the weld repair had been completed, the manual eddy-current inspection was repeated to determine if the repair was successful.

The manual inspection was also used to relocate the copper leader and trailer that were swaged to each end of the conductor of the superconductor cable. These areas were not visible after assembly because they were encased by the steel sheath, but their precise location (for removal) was easily accomplished with the eddy-current inspection system.

SUMMARY AND CONCLUSIONS

We have shown that multifrequency eddy-current techniques can be used to selectively suppress the large signals generated by a large central conductor and perform the continuous on-line inspection of a seam weld in a steel sheath. A unique scanning device was developed to provide full inspection coverage for the seam weld and heat-affected zones. The raw eddy-current data were recorded on magnetic tape, and properties such as discontinuity size and location as well as lift-off and lack of weld penetration could be determined from these data. The various properties were determined by applying the appropriate mathematical fits to the raw data by use of a microcomputer. The coefficients for these mathematical fits were predetermined by the use of test samples in the laboratory. This study provided another example of how multiple-parameter problems can be solved by the use of multifrequency eddy-current techniques. Further significant improvements could (and should) be made through development of additional computer-based data processing for decision making (e.g., via pattern recognition). Limitations in available funding restricted the amount of data processing development to only the minimum required.

This successful test was applied on the welding line of the Oxford-Airco plant and assured the welding quality of the superconducting cable used in the large coil superconducting magnet made by Westinghouse.

ACKNOWLEDGMENTS

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Appendix A

PROGRAM BIGRDG

A data file must be established to use this program. The program BIGRDG reads the property and positioning data from the data file through the logical input device (LID). It controls the mechanical scanners and the multifrequency eddy-current (MFEC) instrument to position the eddy-current coil at the specified coordinates on the test sample(s) and then reads and records the magnitude and phase data for each frequency. These magnitude and phase data are stored along with the corresponding property data provided in the data file. Subroutines provide the ability to calibrate the equipment prior to beginning the run. A brief summary of the program follows.

Lines	Actions
1–34	Information and definition of parameters.
35–50	Assign dimensions.
50–58	Define data files.
59–70	Assign data values.
71–90	Print title, time and date.
91–156	Coil, instrument, and test properties are recorded from the data file.
157–165	Property values and positioning data are read from the data file.
166–185	The pretest instrument calibration is performed.
186–196	Voltage readings are recorded from the eddy-current coil (usually placed at a reference position on the standard test sample).
197–214	Initialization and setup for the start of the test.
215–252	Actual eddy-current readings (magnitude and phase) are taken.
253–260	The scanner is returned to the initial or start position.
261–270	The posttest instrument calibration check is made.
271–277	The eddy-current readings are averaged, and standard deviations are calculated.
278–300	The data are stored on the designated RAD file.

Lines	Actions
301–365	Job statistics, calibration readings, and the eddy-current readings are printed out on the line printer.
366–EOP	The subroutine "POSITION" (written in FORTRAN and machine language) is used to control the scanners or positioners that move the eddy-current coil to the areas on the test sample specified by the coordinates in the data file.

```
      PROGRAM BIGRDG
C     (1 JUNE 1981)
C
C THIS PROGRAM READS MAGNITUDE AND PHASE DATA AT DIFFERENT
C     FREQUENCIES,USING THE PHASE SENSITIVE INSTRUMENT AND THE
C     MECHANICAL SCANNER.IT IS DESIGNED FOR LARGE ARRAYS OF READINGS
C     TOO LARGE FOR THE NORMAL READING AND FITTING ROUTINES.
C     THE MAGNITUDE AND PHASE DATA IS STORED AFTER EACH SET OF PROPERTIES
C     THE PROPERTY AND POSITIONING DATA IS READ FROM DEVICE LID.
C
      REAL*8 TITLE(3)
      REAL*6 NPROBE,NCABLE,INSTNO,POWOSC,PICKAM,PHADET,COIL
      DIMENSION XNEW(3),IDAY(3),ITIM(3),IDY(3),ITM(3)
C
C     LI=LOGICAL INPUT TERMINAL(FROM OPERATOR)
C     LID=LOGICAL INPUT TERMINAL(MAY BE ASSIGNED TO A DISK FILE)
C     LOT=LOGICAL OUTPUT TERMINAL(TO OPERATOR)
C     LPT=LINE PRINTER(OUTPUT)TERMINAL
C     MAG=INDEX TO TURN ON THE SATURATING MAGNET(=0 IF NONE USED)
C     MSET=NO OF SETS OF READINGS THAT WILL BE TAKEN
C     NCHS=NUMBER OF CHANNELS
C     NFT=NUMBER OF FREQUENCIES
C     LNF=2*NFT
C     NF=FREQUENCY INDEX
C     NAXIS=NUMBER OF AXIS THAT ARE POSITIONED
C     NSTOP=INDEX TO STOP THE INSTRUMENT READINGS
C     NFILIM=FILE LIMIT ON LINES IN FILE 37, THE DATA FILE
C     NP=PROPERTY INDEX
C     NPROPM=MAX NUMBER OF PROPERTIES THAT MAY VARY
C     NPT=TOTAL NUMBER OF SETS OF PROPERTY VALUES FOR A COMPLETE
C          SET OF READINGS=NO SAMPLES*NO DEFECTS
C     NPHCAL=NUMBER OF PHASE CALIBRATIONS
C     NMGCAL=NUMBER OF MAGNITUDE CALIBRATIONS
C     NCAL=NPHCAL*NMGCAL=TOTAL NUMBER OF CALIBRATION READINGS
C
C     DIMENSION FREQ(NFT),PICKAM(NFT),PHADET(NFT),PHASW(NFT)
C     DIMENSION TMAG(NPT,NFT),PHASE(NPT,NFT),PROP(NPT,NPROPM)
C     DIMENSION SUMCAL(2*NFT,NCAL),SSCAL(2*NFT,NCAL),SDVCAL(2*NFT,NCAL)
C     DIMENSION VOLTS(2+2*NFT),RDGC(2+2*NFT,NCAL),OLRDGC(2+2*NFT,NCAL)
C     DIMENSION PRONAM(NPROPM),POST(NPT,NAXIS)
C     DIMENSION TOFSET(2+2*NFT),TSLOPE(2+2*NFT)
C
      DIMENSION FREQ(3),PICKAM(3),PHADET(3),PHASW(3)
      DIMENSION TMAG(1250,3),PHASE(1250,3),PROP(1250,6)
      DIMENSION SUMCAL(6,4),SSCAL(6,4),SDVCAL(6,4)
      DIMENSION VOLTS(6),VOLSTD(6),RDGC(6,4),OLRDGC(6,4)
      DIMENSION PRONAM(6),POST(1250,2)
C     DIMENSION TOFSET(6),TSLOPE(6)
      COMMON/83/COIL,RBAR,R1,R2,XL,ZL,RLIM,R6,R7,TNDR,TNPU,ZLDR,ZLPU,X
C
C***CAUTION***BE SURE ENOUGH SPACE HAS BEEN ALLOCATED ON RAD FILE 37
C     FOR WRITING ALL THE RECORDS OUTPUT BY THIS PROGRAM. NUMBER OF
C     RECORDS IN THIS DEFINE STATEMENT(NFILIM=FIRST # IN PARENTHESES)
C     SHOULD EQUAL AT LEAST 4*NPT.THE SECOND SHOULD BE .GE. 2+4*NFT
C     +2*NPROPM.
C
      DEFINE FILE 37(1500,40,U,IREC)
      DEFINE FILE 29(80,32,U,NCOIL)
```

```
C
      DATA LI/1/,LID/9/,LOT/5/,LPT/6/,NCHS/6/,NFILIM/1500/,MSET/3/
      DATA TITLE/'TUBING CALIBRATION DATA '/,BLANKS/'     '/
      DATA ITIMS/64/,MAG/0/,NPHCAL/2/,NMECAL/2/
      DATA NAXIS/2/,NPT/1000/,NPROPM/6/
C     DATA TOFSET/2.27,-1.4992,1.01,-1.32,.47935,-.70,2*0./
C     DATA TSLOPE/-.1575,.0906,-.0646,.1034,-.0285,.0596,2*0./
      INLINE
      LDI,3          #0057          RESET,S1 LO,INTERUPT,S2 HI,0101/0111
      ODD,3,6                       OUTPUT TO PORT 36
      FINI
C
C PRINT TITLE AND DATE
C
10    WRITE (LOT,20) TITLE
20    FORMAT(1X,3A8)
30    FORMAT(1H )
      CALL DATE(IDAY)
      CALL TIME(ITIM)
      IT=IDAY(1)-1900
      IDAY(1)=IDAY(2)
      IDAY(2)=IDAY(3)
      IDAY(3)=IT
      WRITE(LOT,40) IDAY,ITIM
40    FORMAT(' DATE  ',2(I2,1H/),I2,'     TIME  ',2(I2,1H:),I2)
      INLINE
      LDI,3          #0067          INTERUPT,S1 LO,RESET,S2 HI,0110/0111
      ODD,3,6                       OUTPUT TO PORT36
      FINI
      WRITE(LOT,50)
50    FORMAT(' TYPE IN THE FOLLOWING DATA AS REQUESTED.')
C
C INPUT DESCRIPTION OF EXPERIMENTAL APPARATUS
C
      WRITE(LOT,60)
60    FORMAT(' PROBE #:  ')
      READ(LID,70)NPROBE
70    FORMAT(A6)
C
C     THE COIL PROPERTIES ARE CALLED FROM FILE 29.
C
      CALL CIRCOL(LI,LOT,NPROBE)
C
      WRITE(LOT,80)
80    FORMAT(' SERIAL #:  ')
      READ(LID,*)NSER
      WRITE(LOT,90)
90    FORMAT(' DRIVER SERIES RESISTANCE:  ')
      READ(LID,*)R0
      WRITE(LOT,100)
100   FORMAT(' DRIVER SHUNT CAP:  ')
      READ(LID,*)CAPDR
      WRITE(LOT,110)
110   FORMAT(' PICK-UP SHUNT RESISTANCE:  ')
      READ(LID,*)R9
      WRITE(LOT,120)
120   FORMAT(' PICK-UP SHUNT CAP:  ')
      READ(LID,*)CAPPU
```

```
      WRITE(LOT,130)
130   FORMAT(' CABLE I.D. #:  ')
      READ(LID,70)NCABLE
      WRITE(LOT,140)
140   FORMAT(' LENGTH OF CABLE:  ')
      READ(LID,*)CABLEL
      WRITE(LOT,150)
150   FORMAT(' CAPACITANCE OF CABLE:  ')
      READ(LID,*)CCABLE
      WRITE(LOT,160)
160   FORMAT(' EDDY CURRENT INSTRUMENT #:  ')
      READ(LID,70) INSTNO
      WRITE(LOT,170)
170   FORMAT(' POWER OSC I.D.:  ')
      READ(LID,70)POWOSC
C
C INPUT FREQUENCY VALUES
C
      WRITE(LOT,190)
190   FORMAT(' NO. OF FREQUENCIES:')
      READ(LID,*)NFT
      WRITE(LOT,200)
200   FORMAT(' INPUT THE VALUE OF EACH FREQ SEPARATED BY A SPACE:',/)
      READ(LID,*)(FREQ(NF),NF=1,NFT)
      WRITE(LOT,210)(FREQ(NF),NF=1,NFT)
210   FORMAT(' INPUT THE FOLLOWING DATA,6 CHAR WITH A SPACE BETWEEN',/,
     * ' FREQUENCY:',10X,10(1PE9.2))
      WRITE(LOT,220)
220   FORMAT(' PICK-UP AMP I.D.:     ')
      READ(LID,230)(PICKAM(NF),NF=1,NFT)
230   FORMAT(10(A6,1X))
      WRITE(LOT,240)
240   FORMAT(' PHASE DETECTOR I.D.: ')
      READ(LID,230)(PHADET(NF),NF=1,NFT)
      WRITE(LOT,250)
250   FORMAT(' 180-DEG SW(OFF/ON):   ')
      READ(LID,260)(PHASW(NF),NF=1,NFT)
260   FORMAT(10(A3,1X))
      READ(LID,270)(PRONAM(NPR),NPR=1,NPROPM)
270   FORMAT(6(A4,1X))
C
C READ PROPERTY VALUES AND LOCATION DATA FOR THE POSITIONERS FROM LID
C
      DO 300 NP=1,NPT
      READ(LID,*)((PROP(NP,NPR),NPR=1,NPROPM),(POST(NP,NAX),NAX=1,
     *NAXIS))
300   CONTINUE
690   ASSIGN 773 TO NSTATE
C
C     THIS SECTION TAKES THE CALIBRATION READINGS.
C
      INLINE
      LDI,3          #0077            S1 LO,RESET,INTERUPT,S2 HI,0111/0111
      ODD,3,6                         OUTPUT TO PORT 36
      FINI
      MSE=0
700   WRITE(LOT,710)
710   FORMAT(' CALIBRATION READINGS:  ')
```

```
750   CALL CALMIC(RDGC,NCHS,NSTOP)
      IF(NSTOP.NE.0.AND.MSE.EQ.0) GO TO 750
      LNF=2*NFT
      NCAL=NPHCAL*NMGCAL
      DO 770 NF=1,LNF
      DO 770 NC=1,NCAL
      OLRDGC(NF,NC)=RDGC(NF,NC)
770   CONTINUE
      GO TO NSTATE
C
C END OF SECTION WHICH TAKES CALIBRATION READINGS
C
C TAKE READINGS ON NOMINAL STANDARD FOR VOLSTD(I) READINGS
C
773   WRITE(LOT,775)
775   FORMAT(' INSERT PROBE INTO STANDARD TUBE')
      WRITE(LOT,920)(BLANKS,II,II, II=1,NFT)
      WRITE(LOT,30)
780   CALL RDGMIC(VOLSTD,NCHS,ITIMS,NRET,NSTOP,0,0)
      WRITE(LOT,950)(VOLSTD(NF),NF=1,LNF)
      IF(NSTOP.NE.0.) GO TO 780
      WRITE(LOT,785)
785   FORMAT(' SET UP SCANER AND CALIB STANDARD,PRESS FOOT SW TO GO')
787   CALL RDGMIC(VOLTS,NCHS,ITIMS,NRET,NSTOP,0,0)
      IF(NSTOP.NE.0.) GO TO 787
C ZERO ARRAYS THAT WILL CONTAIN SUMS OF THE PHASE & MAG READINGS,
C     SUMS OF CALIBRATION READINGS, AND SUMS OF SQUARES OF EACH
C
790   CONTINUE
      DO 800 NF=1,NFT
      DO 800 NP=1,NPT
      TMAG(NP,NF)=0.
      PHASE(NP,NF)=0.
800   CONTINUE
      DO 810 NF=1,LNF
      DO 810 NC=1,NCAL
      SUMCAL(NF,NC)=OLRDGC(NF,NC)
      SSCAL(NF,NC)=OLRDGC(NF,NC)*OLRDGC(NF,NC)
810   CONTINUE
C
C THIS SECTION TAKES THE ACTUAL PHASE & MAGNITUDE DATA READINGS
C
      DO 1150 MSE=1,MSET
      NCOUNT=0
      NRET=1
      DO 980 NP=1,NPT
      WRITE(LOT,900)NP,(PROP(NP,NPR),NPR=1,NPROPM)
900   FORMAT(1X,I4,3X,6(1X,F8.5))
C
C     POSITION SAMPLES BEFORE TAKING READINGS
C
      DO 910 NAX=1,NAXIS
      XNEW(NAX)=POST(NP,NAX)
910   CONTINUE
      CALL POSITION(XNEW,NAXIS)
      MAXCH=2*(NFT-1)+1
      WRITE(LOT,920)(BLANKS,II,II, II=1,NFT)
920   FORMAT(3X,10(A1,'MAG(',I1,')',4X,' PH(',I1,')',5X))
```

```
      WRITE(LOT,30)
930   CALL RDGMIC(VOLTS,NCHS,ITIMS,NRET,NSTOP,0,0)
      WRITE(LOT,950)((VOLTS(JJ),VOLTS(JJ+1)),JJ=1,MAXCH,2)
950   FORMAT(1H+,10(F9.4,2X))
      IF(MAG.EQ.1)CALL RDGMIC(VOLTS,NCHS,12,NRET,NSTOP,MAG,0)
      CALL SATMAG(0)
      NRET=0
      DO 980 NF=1,NFT
      TMAG(NP,NF)=TMAG(NP,NF)+VOLTS(2*NF-1)
      PHASE(NP,NF)=PHASE(NP,NF)+VOLTS(2*NF)
980   CONTINUE
      ASSIGN 1000 TO NSTATE
      GO TO 700
1000  CONTINUE
      DO 1130 NF=1,LNF
      DO 1130 NC=1,NCAL
      SUMCAL(NF,NC)=SUMCAL(NF,NC)+OLRDGC(NF,NC)
      SSCAL(NF,NC)=SSCAL(NF,NC)+OLRDGC(NF,NC)*OLRDGC(NF,NC)
1130  CONTINUE
1150  CONTINUE
C
C     RETURN POSITIONER TO XNEW(II)=0.0 SO THAT POSITIONS CAN BE CHECKED
C
      DO 1160 NAX=1,NAXIS
      XNEW(NAX)=0.0
1160  CONTINUE
      CALL POSITION(XNEW,NAXIS)
C
C BEFORE STOPPING, ADD FINAL SET OF CALIBRATION READINGS TO CUMULATIVE
C         SUM & CALCULATE AVERAGES & STANDARD DEVIATIONS
C
1190  DO 1250 NF=1,LNF
      DO 1250 NC=1,NCAL
      SUMCAL(NF,NC)=SUMCAL(NF,NC)/(FLOAT(MSET+1))
      SDVCAL(NF,NC)=SQRT(ABS((SSCAL(NF,NC)-SUMCAL(NF,NC)*SUMCAL(NF,NC)
     *                *FLOAT(MSET+1))/FLOAT(MSET)))
1250  CONTINUE
C
C CALCULATE AVERAGES & STANDARD DEVIATIONS OF READINGS
C
      DO 1290 NF=1,NFT
      DO 1290 NP=1,NPT
      TMAG(NP,NF)=TMAG(NP,NF)/(FLOAT(MSET))
      PHASE(NP,NF)=PHASE(NP,NF)/(FLOAT(MSET))
1290  CONTINUE
C
C STORE ALL INFORMATION IN DIRECT ACCESS FILE #37 ON DISK
C
      IREC=1
      WRITE(37'IREC) TITLE,IDAY,ITIM
      WRITE(37'IREC) NPROBE,NSER,R0,CAPDR,R9,CAPPU,NCABLE,
     *               CABLEL,CCABLE,INSTNO,POWOSC
      WRITE(37'IREC) NFT,NPT,NPROPM,NPHCAL,NMGCAL
      WRITE(37'IREC)((FREQ(NF),PICKAM(NF),PHADET(NF),PHASW(NF)),
     *NF=1,NFT)
      WRITE(37'IREC)(PRONAM(NPR),NPR=1,NPROPM)
      DO 1295 NF=1,LNF
      WRITE(37'IREC)(SUMCAL(NF,NC),NC=1,NCAL)
```

```
1295  CONTINUE
      WRITE(37'IREC)(VOLSTD(NF),NF=1,LNF)
      DO 1300 NP=1,NPT
      WRITE(37'IREC)((TMAG(NP,NF),PHASE(NP,NF),NF=1,NFT),(PROP(NP,
     *NPR),NPR=1,NPROPM))
1300  CONTINUE
      IF(IREC.GE.NFILIM) WRITE(LOT,1330)
1330  FORMAT(' LIMIT OF FILE 37 IS EXCEEDED.')
C
C END OF SECTION WHICH WRITES DIRECT ACCESS FILE
C PRINT SUMMARY OF JOB STATISTICS ON LPT
C
      WRITE(LPT,1335)
1335  FORMAT(1H1,20X)
      WRITE(LPT,1340) IDAY,ITIM
1340  FORMAT(' TUBRDG: DATE ',2(I2,1H/),I2,'. TIME ',2(I2,1H:),I2)
      WRITE(LPT,1350) NPROBE,NSER
1350  FORMAT(' PROBE NO.:',A6,5X,' SERIAL NO.:',I5)
      WRITE(LPT,1360) R0,CAPDR
1360  FORMAT(' DRIVER SERIES RESISTANCE:',F10.1,5X,'DRIVER SHUNT CAP.:',
     *        E12.4)
      WRITE(LPT,1370) R9,CAPPU
1370  FORMAT(' PICK-UP SHUNT RESISTANCE:',F10.1,5X,'PICK-UP SHUNT CAP.:'
     *        ,E12.4)
      WRITE(LPT,1380) NCABLE,CABLEL,CCABLE
1380  FORMAT(' CABLE I.D. NO.:',A6,5X,'LENGTH:',F10.1,5X,'CAP.:',
     *        E12.4)
      WRITE(LPT,1390) INSTNU
1390  FORMAT(' EDDY CURRENT INSTRUMENT NO.:',A6)
      WRITE(LPT,1400) POWOSC
1400  FORMAT(' POWER OSC I.D.',A6)
      WRITE(LPT,1410) (FREQ(NF),NF=1,NFT)
1410  FORMAT(/,10X,'FREQUENCY:',10(1PE12.4,5X))
      WRITE(LPT,1420) (PICKAM(NF),NF=1,NFT)
1420  FORMAT(' PICK-UP AMP I.D.:',7X,10(A6,9X))
      WRITE(LPT,1430) (PHADET(NF),NF=1,NFT)
1430  FORMAT(' PHASE DETECTOR I.D.:',4X,10(A6,9X))
      WRITE(LPT,1440) (PHASW(NF),NF=1,NFT)
1440  FORMAT(' 180  PHASE SWITCH:',8X,10(A3,12X))
C
C     PRINT CALIBRATION READINGS
C
1600  CONTINUE
      WRITE(LPT,1650) NPHCAL,NMGCAL
1650  FORMAT(1H0,' AVERAGES & STANDARD DEVIATIONS OF CALIBRATION ',
     *       'READINGS:',I3,' MAG',I3,' PHA'/)
      WRITE(LPT,1660) (FREQ(NF),NF=1,NFT)
1660  FORMAT(3(10X,1PE12.4))
      WRITE(LPT,1670)(NF,NF,NF=1,NFT)
1670  FORMAT(5X,3(5X,'MAG',I1,6X,'PHA',I1,1X))
      DO 1700 NC=1,NCAL
      WRITE(LPT,30)
      WRITE(LPT,1680)((SUMCAL(NF,NC)),NF=1,LNF)
1680  FORMAT(5X,6(F10.4))
      WRITE(LPT,1690)((SDVCAL(NF,NC)),NF=1,LNF)
1690  FORMAT(' S.D.',6(F10.4))
1700  CONTINUE
C
```

```
C      READINGS FROM NOMINAL SAMPLE
C
       WRITE(LPT,1745)
1745   FORMAT(' READINGS FROM NOMINAL TUBE SAMPLE')
       WRITE(LPT,1680)(VOLSTD(NF),NF=1,LNF)
C
C      PRINT OUT READINGS AND PROPERTIES
C
       WRITE(LPT,1750)(NF,NF,NF=1,NFT),(PRONAM(NPR),NPR=1,NPROPM)
1750   FORMAT(1X,'PSET',3('      MAG',I1,'      PHA',I1),6(4X,A4,1X))
       DO 1800 NP=1,NPT
       WRITE(LPT,1760)NP,((TMAG(NP,NF),PHASE(NP,NF),NF=1,NFT),(PROP(NP,
      *NPR),NPR=1,NPROPM))
1760   FORMAT(1X,I4,12(F9.4))
1800   CONTINUE
        STOP JOB
       END
C
       SUBROUTINE POSITION(XNEW,NAXIS)
C
C      POSITION       VERSION 4/15/81
C      DETERMINES THE NEW LOCATION FOR 3 DIFFERENT POSITIONERS AND FROM
C      THE OLD LOCATION,THE NUMBER OF STEPS NEEDED TO REACH THE NEW
C      LOCATION.THEN ISSUE THE NUMBER OF PULSES TO GO TO THE NEW LOCATION
C
       INTEGER*2 REG(8),NCOUNT,NAX
       DIMENSION XOLD(3),XNEW(3),NSTEPS(3)
       DATA XOLD/3*0.0/,STEPSZ/0.00025/
       DO 20 IAXIS=1,NAXIS
       NSTEPS(IAXIS)=(0.5*STEPSZ+XNEW(IAXIS)-XOLD(IAXIS))/STEPSZ
       XOLD(IAXIS)=XOLD(IAXIS)+FLOAT(NSTEPS(IAXIS))*STEPSZ
    20 CONTINUE
C
C
     1 DO 200 NAX=1,NAXIS
       IF(NSTEPS(NAX).EQ.0)GO TO 190
       REG(1)=0
       IF(NSTEPS(NAX).GE.0)GO TO 10
       REG(1)=8
       NSTEPS(NAX)=-NSTEPS(NAX)
    10 CONTINUE
C
C      SIGN SET IN REG(1);CONVERT NSTEP TO BCD IN REG(2)-REG(6)
C
       DO 30 NRG=2,6
       REG(NRG)=NSTEPS(NAX)/10000
       NSTEPS(NAX)=(NSTEPS(NAX)-10000*REG(NRG))*10
    30 CONTINUE
C
C      DATA FOR OUTPUT IN REG(NRG);OUTPUT TO APPROIATE CONTROLLER
C
       NCOUNT=NAX-1
       INLINE
       LDI,1          0              ZERO REGISTER 1,USE AS INDEX,COUNTER
       LDM,2          NCOUNT         LOAD THE CONTROLLER SELECT CHANL
       LLS,2,4                       LOGICAL LEFT SHIFT REG2,4 PLACES
       ADM,2,1        REG            ADD SIGN TO REGISTER 2
       MBL,2,2                       SHIFT BYTE LEFT
```

```
        ADI,2           #00FF         LEAVE CALIBRATE BITS ,COUNTER HI
        ODD,2,3                       OUTPUT REG 2 TO MODAC PORT 33
LOP5    IDD,3,1                       INPUT PORT31 INTO REG3
        TBRB,3,15       LOP5          STAY IN LOOP UNTIL BUSY GOES HI
        LBRB,4,14       LOP6          BIT14 IN REG 4 HI,XFER TO LOP6
LOP1    IDD,4,1                       INPUT PORT 31 TO REG 4
LOP6    ABR,1,15                      INCREMENT REGISTER 1
        LDM,2,1         REG           LOAD BCD VALUE INTO REG 2
        MBL,2,2                       SHIFT BYTE IN REG 2 TO LEFT
        ADI,2           #00FF         TAKE INDEX BIT HI,LEAVE CALIBRATE HI
LOP2    IDD,3,1                       INPUT PORT 31 INTO REG 3
        TBRB,3,15       LOP4          JUMP TO ERROR LOOP IF NOT BUSY
        XOR,3,4                       EXCLUSIVE OR REG 3&4,RESULT IN 3
        TOR,3,3                       TAKE ONE'S COMPLIMENT OF REG 3
        TBRB,3,14       LOP2          BIT 14=0 WHEN DATA STROBE SWITCHES
        ODD,2,3                       OUTPUT REG 2 TO MODAC PORT 33
        CRI,1           6             COMPARE REG 1 TO 6
        BLNS,0          LOP1          BRANCH BACK IF REG 1.LT.6
LOP4    LDI,2           #B0FF         LOAD ALL HI INTO 2
        ODD,2,3                       SEND ALL OUTPUTS HI
LOP3    IDD,3,1                       INPUT PORT 31 TO REG 3
        TOR,3,3                       TAKE ONE'S COMPLIMENT OF REG 3
        TBRB,3,15       LOP3          BRANCH BACK IF BUSY
        FINI
  190   CONTINUE
  200   CONTINUE
C
C       CHECK FOR POSITION FINISHED
C       HANG HERE UNTIL ALL POSITIONS ARE REACHED
C
  300   CONTINUE
        JSTEP=0
        DO 400 NAX=1,NAXIS
        NCOUNT=NAX-1
        INLINE
        LDM,2           NAX           LOAD THE COUNTER SELECT CHANL
        LDI,3           #B0FF         LOAD ALL HI INTO 3,TO RD BUSY
        ODD,3,3                       OUTPUT TO PORT 33,READ BUSY,OVERFLOWS
        IDD,4,1                       READ BUSY,OVERFLOWS INTO REG4
        RLS,4,1                       DUMP BUSY BY SHIFT
LOP7    RLS,4,1                       MAKE OVERFLOW(NAX) BIT LEAST SIGNIFICANT
        SBRB,2,15       LOP7          DECREMENT NAX,XFER BACK IF.NE.0
        ETI,4           #FFFE         DUMP ALL BUT LEAST SIGNIFICANT BIT
        LDM,2           NCOUNT        LOAD THE COUNTER SELECT CHANL
        LLS,2,6                       LOGICAL LEFT SHIFT REG2,6 PLACES
        ADI,2           #B00F         LEAVE CALIBRATE BITS HI
        ODD,2,3                       OUTPUT REG 2 TO MODAC PORT 33
        IDD,5,1                       INPUT COUNT NO INTO REG 5
        STMD,4          KSTEPS        STORE COUNT POSITION IN MEMORY
        LDI,2           #B0FF         SEND PROPER OUTPUTS HI
        ODD,2,3                       RESET PORT 33
        FINI
        JSTEPS=(XOLD(NAX)+.5*STEPSZ)/STEPSZ
  350   NSTEPS(NAX)=JSTEPS -KSTEPS
  360   JSTEP=JSTEP+NSTEPS(NAX)*NSTEPS(NAX)
  400   CONTINUE
        IF(JSTEP.GT.2)WRITE(5,410)
  410   FORMAT(' TRANSLATOR ERROR ')
```

```
      IF(JSTEP.GT.2)GO TO 1
  420 CONTINUE
      RETURN
      END
TOTAL RECORDS WRITTEN =   469/      74
EXIT
$AVR CI 4
$END  LIST
```

Appendix B

PROGRAM MICMOD

The program MICMOD (written in machine language) coordinates operations between the microcomputer in the multifrequency eddy-current (MFEC) instrument and the laboratory computer (MODCOMP IV). Actual eddy-current data are recorded from the analog-digital converters by the microcomputer on command from the MODCOMP computer. The data are then transferred to the MODCOMP through the handshake arrangement. The microcomputer will take readings from either the probe or the instrument calibrator on command from the MODCOMP.

```
                        TITLE 'MICMOD PROGRAM VERSION 8 APRIL 81'
                        NAME    MICMOD
                        LIST   B,G,O,T
                  ;     NLIST   I,M,S,T
                  ;
                  ;     PROGRAM TO READ THE ADCONVERTORS ON COMMAND FROM THE
                  ;    MODCOMP AND THEN TRANSFER DATA TO THE MODCOMP IN A
                  ;    HANDSHAKING MANNER.THE S2 LINE IN THE MODCOMP FOLLOWS
                  ;    THE REC LINE IN THE MICROCOMPUTER
                  ;
                        ORG 0800H        START PROGRAM IN SECOND PROM.
                  ; SYMBOL DEFINITIONS
                  ;
                  ;  DEFINE PORT ADDRESSES
                  ;
00F7              PORT1       EQU 0F7H         PORT 1 CONTROL WORD ADDRESS
00F4              PORT1A      EQU 0F4H         PORT1A ADDRESS
00F5              PORT1B      EQU 0F5H         PORT1B ADDRESS
00F6              PORT1C      EQU 0F6H         PORT1C ADDRESS
00EF              PORT2       EQU 0EFH         PORT 2 CONTROL WORD ADDRESS
00EC              PORT2A      EQU 0ECH         PORT2A ADDRESS
00ED              PORT2B      EQU 0EDH         PORT2B ADDRESS
00EE              PORT2C      EQU 0EEH         PORT2C ADDRESS
00DF              PORT3       EQU 0DFH          PORT3 CONTROL WORD ADDRESS
00DC              PORT3A      EQU 0DCH          PORT3A ADDRESS
00DD              PORT3B      EQU 0DDH          PORT3B ADDRESS
00DE              PORT3C      EQU 0DEH          PORT3C ADDRESS
007E              APDATA      EQU 07EH         ARITHMETIC PROCESSOR DATA PORT
                  ;
                  ;  MATH SUBROUTINES FOR THE COMP 9 ARE STORED AS PUBLIC.ANY ROUTINE
                  ;  CAN BE CALLED USING AN 'EXTRN' STATEMENT.
                  ;
                  ;EXTRN         ACOS,ASIN,ATAN,ATANA,BIDEC,BIDECF
                   EXTRN         CHSD,CHSDA,CHSF,CHSFA,CHSS,CHSSA,COS,COSA
                   EXTRN         DADD,DADDA,DADDB,DDIV,DDIVA,DDIVB,DECHD
                   EXTRN         DMUL,DMULA,DMULB,DMUU,DMUUA,DMUUB,DSUB,DSUBA,DSUBB
                   EXTRN         EXP,EXPA,EXP10,FADD,FADDA,FADDB,FDIV,FDIVA,FDIVB
                   EXTRN         FIXD,FIXDA,FIXS,FIXSA,FLTD,FLTDA,FLTS,FLTSA
                   EXTRN         FMUL,FMULA,FMULB,FSUB,FSUBA,FSUBB,LN,LNA,LOG,LOGA
                   EXTRN         NDAD,POPD,POPS,PTOD,PTOS,PUPI,PWR,PWRA,PWRB
                   EXTRN         SADD,SADDA,SADDB,SDIV,SDIVA,SDIVB,SIN,SINA
                   EXTRN         SMUL,SMULA,SMULB,SMUU,SMUUA,SMUUB,SQRT,SQRTA
                   EXTRN         SSUB,SSUBA,SSUBB,TAN,TANA,TOS2,TOS4
                   EXTRN         WRT2,WRT4,XCHD,XCHS
                   EXTRN         CROUT,COPDT,GETCM,PRINT,PRINTF,EPRNT,FPRNT,ZERO
                   EXTRN         GETRM,CO,HMOUT,ECHO,GETCH,GETHX
                  ;
                  ;
                  ;CONSTANTS ARE SET
0001              NRDG        EQU 001H          NRDG=2**N=NUMBER OF RDGS PER CHANNEL=1
                  ;
0008              NCHA        EQU 08H           NCHA=NUMBER OF CHANNELS TO BE READ
0088              PRT1O       EQU 088H          PRT1O=CONTROL WORD FOR PORT1 OUTPUT MODE
0099              PRT1I       EQU 099H          PRT1I=CONTROL WORD FOR PORT1 INPUT MODE
```

```
                       ;
                       ;          RAM ADDRESS DEFINITIONS
                       ;
3C10                   RAWDA         EQU 03C10H      RAW RDGS,4 BYTES/CHNL,MG1,PH1,MG2.. HI-LO
3C2A                   OLDSW         EQU RAWDA+1AH   CALIBRATION SWITCH POSITION FROM MODCOMP

                       ;THREE FREQ PORTSET-UP
0800  3E 99            PRTSU         MVI A,PRT1I     LOAD PROGRAM WORD FOR A&C INPUT,B OUTPUT
0802  D3 F7                          OUT PORT1       SEND TO PORT 1
0804  3E 90                          MVI A,090H      LOAD PROGRAM WORD,A=INPUT,B&C=OUTPUT
0806  D3 EF                          OUT PORT2       SEND TO PORT2.
0808  3E 70                          MVI A,070H      SET MAG TAPE READ,WRITE,DAC LATCH HI
080A  D3 EE                          OUT PORT2C      LEAVE STROBE LINES HI
                       ;
080C  3E 86            RDGLOP        MVI A,086H      SELECT MODCOMP,SET UP TO TOGGLE REC LINE
080E  D3 F5                          OUT PORT1B      SEND TO PORT1B
0810  3E 00                          MVI A,00H       ZERO ACCUMULATOR
0812  D3 EE                          OUT PORT2C      SEND REC LINE LO
0814  DB EC            LOOP1         IN PORT2A       LOOK AT SI LINE
0816  E6 10                          ANI 010H        DUMP OTHER BITS
0818  CA 14 08                       JZ LOOP1        HANG IN THIS LOOP UNTIL MODCOMP IS READY
081B  3E 10                          MVI A,10H
081D  D3 EE                          OUT PORT2C      SEND REC LINE HI
081F  DB EC                          IN PORT2A       GET SAT MAG BIT (DIR LINE)
0821  E6 40                          ANI 040H        DUMP ALL OUT SAT MAG BIT
0823  1F                             RAR             ROTATE RIGHT 3 TIMES
0824  1F                             RAR             2A6>>2A3
0825  1F                             RAR
0826  4F                             MOV C,A         TEMP STORE IN C REG
0827  DB EC                          IN PORT2A       LOOK AT CALIBRATE FUNCTION SW POSITION
0829  E6 07                          ANI 07H         DUMP THE OTHER BITS(AND WITH 0000/0111)
082B  81                             ADD C           ADD SAT MAG BIT TO CALIBRATOR SWITCH BITS
082C  D3 ED                          OUT PORT2B      SET CALIBRATOR SWITCHES,SAT MAG
082E  2A 2A 3C                       LHLD OLDSW      LOAD OLD SWITCH POSITION INTO HL
0831  32 2A 3C                       STA OLDSW       STORE PRESENT SWITCH POS IN RAM
0834  BD                             CMP L           SEE IF SWITCH POS WAS CHANGED FROM LAST TI
0835  CA 41 08                       JZ ROUND1       JUMP AROUND IF NO CHANGE
0838  01 00 00                       LXI B,0000      LOAD DELAY INTO BC
083B  CD AE 08                       CALL DELAY      DELAY UNTIL READINGS SETTLE DOWN
083E  CD AE 08                       CALL DELAY
0841  3E 99            ROUND1        MVI A,PRT1I
0843  D3 F7                          OUT PORT1       SET PORT1 FOR INPUT
0845  3E B0                          MVI A,0B0H      STROBE ADC HI
0847  D3 F5                          OUT PORT1B
0849  3E 90                          MVI A,090H      THEN LEAVE LO
084B  D3 F5                          OUT PORT1B
084D  CD A6 08                       CALL ADBUS      HANG IN LOOP UNTIN ADC FREE
0850  06 01                          MVI B,NRDG      LOAD THE NUMBER OF READINGS INTO B
0852  0E 08                          MVI C,NCHA      LOAD THE NUMBER OF CHANNELS INTO C
0854  CD 63 08                       CALL SMDAT      SUM THE READINGS
0857  3E 88                          MVI A,PRT1O     SET PORT1 FOR OUTPUT
0859  D3 F7                          OUT PORT1
085B  CD B0 08                       CALL WRMOD      WRITE ALL READINGS OUT TO MODCOMP
                       ;                             WAIT ON MODCOMP TO FINISH
085E  C3 0C 08                       JMP RDGLOP      GO BACK TO READING LOOP
```

```
0061  E6 07                  ANI  07H            SET STATUS BITS
                    ;SUMDAT - DATA SUMMATION ROUTINE,STARTING WITH CHANNEL 1,READS NO OF
                             ;CHANNELS IN C,WITH NO OF READINGS PER CHANNEL IN B (UP TO
                             ;255).SUM OF THE DATA WILL BE IN RAWDA -4 + (4*CH. NO.)
                             ;AND DATA IS STORED AS MAG1,PH1,MAG2,PH2,MAG3,PH3;4 BYTES EACH
0062  21 10 [illegible]  [illegible]  LXI H,RAWDA       HL LOADED WITH LAST RAW DATA ADDRESS
0065  C5                     PUSH B              COPY OF REGS B,C STORED ON STACK
0067  79                     MOV A,C             NUMBER OF CHANNELS LOADED INTO A
0068  87                     ADD A
0069  87                     ADD A               4*NO OF CHANNELS IN A
006A  4F                     MOV C,A             4*NO OF CHANNELS IN REG C
006B  AF                     XRA A               A REGISTER ZEROED
006C  CD 00 00      E        CALL ZERO           ZERO RAM FROM HL TO HL+C
006F  C1                     POP B               NO OF CHANNELS (REG C) & TIMES/CH (B) RES
0070  11 [illegible]         LXI D,[illegible]   LOAD [illegible] INTO DE
0073  21 10 00      SMLOP    LXI H,RAWDA+[illegible]  HL LOADED WITH FIRST RAW DATA ADDRESS
0076  C5                     PUSH B              AND COPY STORED ON STACK AGAIN
0077  3E 00         CHLOP    MVI A,NCHA          TOTAL NUMBER OF CHANNELS IN A
0079  91                     SUB C               NCH = TOTAL NO. - CHA COUNT IN REG C
007A  CD 8E 00               CALL ADRDG          MAKE AD CON RDG,ANSWER ON AP TOP OF STACK
007D  CD 00 00      E        CALL [illegible]DA  32 BIT FIXED ADD TO DATA AT HL,HL=HL-3
0080  CD 00 00      E        CALL [illegible]    AP TOP OF STACK STORED IN RAM AT HL
[illegible]  19              DAD D               [illegible] TO HL,POINTS TO NEXT ADDR
0084  0D                     DCR C               CHANNEL COUNT DECREMENTED
0085  C2 77 00               JNZ CHLOP           JUMP BACK TO CHANNEL LOOP IF NOT FINISHED
[illegible]  C1              POP B               RESTORE BC FROM STACK
[illegible]  05              DCR B               DECREMENT THE NUMBER OF RDGS/CHANNEL
008A  C2 73 00               JNZ SMLOP           GO BACK TO THE SUM LOOP IF NOT FINISHED
008D  C9                     RET
                    ;ADRDG   SELECTS THE ACCUMULATOR NUMBER THAT IS IN A,READS THE
                    ;        [illegible] FROM THE CONVERTER,[illegible] ZEROS AND RETURNS WITH
                    ;        A POSITIVE 32 BIT FIXED NUMBER ON THE TOP OF THE APSTACK.
                             [illegible] DATEL [illegible]-BIT[illegible] ANALOG TO DIGITAL CONVERTOR.
008E  C6 [illegible]  ADRDG  [illegible]         [illegible] ON ADC
0090  D3 F5                  OUT PORT[illegible] SET CH. SWITCH TO CH. NO.
0092  DB F4                  IN PORT[illegible]  LOW ORDER BYTE IS BROUGHT IN AND
0094  D3 7E                  OUT APDATA          STORE ON ARITHMETIC PROCESSOR STACK.
0096  DB F6                  IN PORT1C           HIGH ORDER BYTE IS BROUGHT IN.
0098  E6 0F                  ANI 0FH             4 HIGHEST ORDER BITS ARE DUMPED
009A  D3 7E                  OUT APDATA          STORE ON ARITHMETIC PROCESSOR STACK.
[illegible]  AF              [illegible]         [illegible]
[illegible]  D3 7E           OUT APDATA          [illegible] ON ARITHMETIC PROCESSOR STACK.
[illegible]  D3 7E           OUT APDATA          [illegible] ON ARITHMETIC PROCESSOR STACK.
[illegible]  [illegible]     [illegible]         [illegible] LO,DESELECT ADCONVERTORS
[illegible]  D3 F5           OUT PORT1B          [illegible] TO PORT[illegible]
[illegible]  C9              RET                 RETURNS WITH POS. ANSWER ON AP STACK.
                    ;
                    ;        [illegible]         [illegible] ALL BUSY LINES OF THE DATEL
                    ;                    [illegible] ANALOG TO DIGITAL CONVERTORS GOES LOW
                    ;                    [illegible] CAN BE READ FOR
                    ;                    [illegible]

[illegible]  DB F[illegible]  [illegible]  IN [illegible]   [illegible] BUSY [illegible]
[illegible]  E6 1[illegible]           ANI [illegible]     [illegible]
```

```
08AA  C2 A6 08               JNZ ADBUS          STAY IN LOOP UNTIL BUSY LINE LOW
08AD  C9                     RET                START BIT WILL GO LO WHEN DATA CH READ
                  ;DELAY 2 FREQ. - GENERATES A TIME DELAY,DEPENDING ON THE CONSTANT LOADED
                             ;INTO BC, # CYCLES = 20*FFFF/(BC)
08AE  E5          DELAY      PUSH H             SAVE THE CONTENTS OF HL AND
08AF  21 00 00               LXI H,0H          ZERO HL
08B2  09          LOPSM      DAD B              ADD BC TO THE CONTENTS OF HL
08B3  D2 B2 08               JNC LOPSM          STAY IN LOOP UNTIL HL OVERFLOWS.
08B6  E1                     POP H              THEIR ORIGINAL VALUES
08B7  C9                     RET                AND RETURN.
                  ;
                  ;
                  ;          WRMOD              WRITES RAW READINGS TO MODCOMP
                  ;
08B8  01 12 3C    WRMOD      LXI B,RAWDA+2      BC IS STARTING ADDR OF RAW DATA
08BB  11 25 3C               LXI D,RAWDA+015H   DE CONTAINS END ADDR OF RAW DATA
08BE  3E 06                  MVI A,006H         SELECT MODCOMP,SET UP TO TOGGLE REC LINE
08C0  D3 F5                  OUT PORT1B         SEND TO PORT1B
08C2  0A          WRMODL     LDAX B             LOAD BYTE ADDR BY B INTO A
08C3  D3 F4                  OUT PORT1A         SEND TO PORT1A
08C5  CD D4 08               CALL STBMLO        STROBE FIRST HALF OUT,RET WHEN MOD RDGS
08C8  0A                     LDAX B             LOAD NEXT HALF OF ADC WORD
08C9  D3 F4                  OUT PORT1A         SEND TO PORT
08CB  CD E5 08               CALL STBMHI        STROBE 2ND HALF,RET WHEN MOD ACCEPTS
08CE  03                     INX B              INCREMENT B TWICE
08CF  03                     INX B              SKIP ZEROS IN RAM
08D0  D2 C2 08               JNC WRMODL         STAY IN LOOP UNTIL DONE
08D3  C9                     RET
                  ;
                  ;          STBMLO             STROBE REC LO,HANG UNTIL S2 FOLLOWS
                  ;
08D4  3E 00       STBMLO     MVI A,00H          STROBE REC LINE LOW
08D6  D3 EE                  OUT PORT2C
08D8  DB EC       LOLOOP     IN PORT2A          LOOK AT S2
08DA  E6 20                  ANI 020H           TEST TO SEE IF MODCOMP HAS READ DATA
08DC  C2 D8 08               JNZ LOLOOP         STAY IN LO LOOP UNTIL S2 (2A5) IS LO
08DF  03                     INX B              INCREMENT BC RAM ADDR COUNTER
08E0  7B                     MOV A,E            TEST TO SEE IF BC.GT.DE
08E1  91                     SUB C              SUBTRACT BC FROM DE,GET A BORROW WHEN
08E2  7A                     MOV A,D            BC.GT.DE(CARRY IS SET)
08E3  98                     SBB B
08E4  C9                     RET
                  ;
                  ;          STBMHI             STROBE REC HI,HANG UNTIL S2 FOLHIWS
                  ;
08E5  3E 10       STBMHI     MVI A,10H          STROBE REC LINE HI
08E7  D3 EE                  OUT PORT2C
08E9  DB EC       HILOOP     IN PORT2A          LOOK AT S2
08EB  E6 20                  ANI 020H           TEST TO SEE IF MODCOMP HAS READ DATA
08ED  CA E9 08               JZ HILOOP          STAY IN HI LOOP UNTIL S2 (2A5) IS HI
08F0  03                     INX B              INCREMENT BC RAM ADDR COUNTER
08F1  7B                     MOV A,E            TEST TO SEE IF BC.GT.DE
08F2  91                     SUB C              SUBTRACT BC FROM DE,GET A BORROW WHEN
08F3  7A                     MOV A,D            BC.GT.DE(CARRY IS SET)
```

```
217  00F4  90                               SUB D
218  00F5  C9                               RET
219
220  00F6                                   END
```

ASSEMBLER ERRORS =   0

SYMBOL TABLE

A	0007	ADBUS	00A6	ADRDA	009E	APDATA	007E
B	0000	C	0001	CHLOP	0077	CHSD	E 0000
CHSDA	E 0001	CHSF	E 0002	CHSFA	E 0003	CHSS	E 0004
CHSSA	E 0005	CO	E 00CD	COPDT	E 0050	COS	E 0006
COSA	E 0007	CROUT	E 0057	D	0002	DADD	E 0008
DADDA	E 0009	DADDB	E 000A	DDIV	E 000B	DDIVA	E 000C
DDIVB	E 000D	DECHO	E 000E	DELAY	00AE	DMUL	E 000F
DMULA	E 0010	DMULB	E 0011	DMUU	E 0012	DMUUA	E 0013
DMUUB	E 0014	DSUB	E 0015	DSUBA	E 0016	DSUBB	E 0017
E	0003	ECHO	E 0062	EPRNT	E 005C	EXP	E 0018
EXP10	E 001A	EXPA	E 0019	FADD	E 001B	FADDA	E 001C
FADDB	E 001D	FDIV	E 001E	FDIVA	E 001F	FDIVB	E 0020
FIXD	E 0021	FIXDA	E 0022	FIXS	E 0023	FIXSA	E 0024
FLTD	E 0025	FLTDA	E 0026	FLTS	E 0027	FLTSA	E 0028
FMUL	E 0029	FMULA	E 002A	FMULB	E 002B	FPRNT	E 005D
FSUB	E 002C	FSUBA	E 002D	FSUBB	E 002E	GETCH	E 0063
GETCM	E 0059	GETHX	E 0064	GETNM	E 005F	H	0004
HILOOP	00E9	L	0005	LN	E 002F	LNA	E 0030
LOG	E 0031	LOGA	E 0032	LOLOOP	00D0	LOOP1	0014
LOPSM	00D2	M	0006	MVAD	E 0033	MEMORY	M 0000
NCHA	0000	NMOUT	E 0061	[illegible]	0001	OLDSW	3C2A
POPD	E 0034	POPS	E 0035	PORT1	00F7	PORT1A	00F4
PORT1B	00F5	PORT1C	00F6	PORT2	00EF	PORT2A	00EC
PORT2B	00ED	PORT2C	00EE	PORT3	00DF	PORT3A	00DC
PORT3B	00DD	PORT3C	00DE	PRINT	E 005A	PRINTF	E 005B
PRT1I	0099	PRT10	[illegible]	PRTSU	0000	PSU	[illegible]
PTOD	E 0036	PTOS	E 0037	PUPI	E 0038	PWR	E 0039
PWRA	E 003A	PWRB	E 003B	[illegible]	0010	[illegible]	00DC
ROUND1	0041	SADD	E 003C	SADDA	E 003D	SADDB	E 003E
SDIV	E 003F	SDIVA	E 0040	SDIVB	E 0041	SIN	E 0042
SINA	E 0043	SMDAT	[illegible]	[illegible]	[illegible]	[illegible]	E 0044
SMULA	E 0045	SMULB	E [illegible]	[illegible]	E [illegible]	[illegible]	E 0048
SMUUB	E 0049	SP	[illegible]	[illegible]	E [illegible]	[illegible]	E [illegible]
SSUB	E 004C	SSUBA	E [illegible]	[illegible]	E [illegible]	STACK	S [illegible]
STBMHI	00E5	STBMLO	[illegible]	[illegible]	E [illegible]	[illegible]	E [illegible]
TOS2	E 0051	TOS4	E [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WRT2	E 0053	WRT4	E 0054	[illegible]	E [illegible]	[illegible]	E [illegible]
ZERO	E 005E						

Appendix C

PROGRAM BIGFIT

The program BIGFIT performs a mathematical (least squares) fit to the data set obtained with the program BIGRDG. The program also calculates the fit error, a measure of how well the fit matches the data and vice-versa, and the drift error, an estimation of how small variations in eddy-current signal will affect the property determination. The operator selects the type of mathematical fit to be performed and the program calculates the coefficients for that fit. On operator command, the coefficients are stored in a designated memory location. The coefficients are later programmed into a PROM chip for use in the multifrequency eddy-current (MFEC) instrument's microcomputer. A brief summary of the program follows.

Lines	Actions
1–27	Information and definition of parameters.
28–61	Assign dimensions.
62–74	Define data files.
75–79	Assign data values.
80–87	Determine time and date.
88–108	Read test equipment, property, and calibration data recorded by BIGRDG program.
109–114	Print time and date.
115–118	Read eddy-current coil properties from the appropriate file.
119–172	Operator selects (via computer prompts) the property to be fitted and the type of mathematical fit to be performed.
173–183	Read the eddy-current data (magnitude and phase) recorded by BIGRDG.
184–211	The properties to be fitted and the data points used in the fitting process are selected and/or modified by the statements in this section of the program. Then a least-squares fit of the eddy-current readings to the selected properties is made by the subroutine "ALSQS."

Lines	Actions
212–243	The properties to be fit and the data points used in the fitting process are selected and/or modified by the statements in this section (similar to lines 184–211), and the fit error and maximum drifts are calculated.
244–260	The polynomial for the mathematical fit is calculated.
261–302	On command, the entire fit is printed out.
303–323	On command, the coefficients and other information are written on the designated data file.
324–333	Properties are calculated from the eddy-current readings (magnitude and phase) and displayed on the video terminal.
334–356	The eddy-current readings (magnitude and phase) are expanded (via the polynomial) into property readings.
357–375	New readings can be made from the eddy-current instrument to check the mathematical fit obtained.
376–406	This section provides a means to stop the program action by operating a foot switch.
407–432	Test equipment and property data (recorded by BIGRDG) are printed out on the logical output unit (LOU).
433–448	Calibration data (recorded by BIGRDG) are printed out on the LOU.
449–464	The actual eddy-current readings (recorded by BIGRDG) and properties are printed out on the LOU.

```
      PROGRAM BIGFIT
C     (20 JUNE 1982)
C     PROGRAM TO PERFORM A LEAST SQUARES FIT TO DATA READ INTO A DISK
C     FILE BY BIGRDG PROGRAM AND THEN PERFORM CONTINOUS BACK CALCULATIONS
C     USING INSTRUMENT READINGS THAT ARE MADE BETWEEN EACH DISPLAYED SET.
C
C     IRDPRM=MAXIMUM NUMBER OF COEFFICIENTS IN EXPANSION
C     LITEK=LOGICAL INPUT UNIT (1=TTY)
C     LOTEK=LSI OUTPUT UNIT FOR PROMPTING AND DISPLAY
C     LOU=LOGICAL OUTPUT UNIT FOR PERMANENT RECORD
C     NCHS=NUMBER OF DATA CHANNELS
C     NCOED=FILE VARIABLE FOR MIC-COMP DATA=1ST CAL0 DATA BYTE HEX OR DEC
C     NFILIM=FILE LIMIT ON LINES IN FILE 37, THE DATA FILE
C     NF=FREQUENCY INDEX
C     NFT=NUMBER OF FREQUENCIES
C     LNF=2*NFT
C     NP=PROPERTY INDEX
C     NPROPM=MAXIMUM NUMBER OF PROPERTIES CALCULATED(=6 NOW)
C     NPT=TOTAL NUMBER OF SETS OF PROPERTY  VALUES FOR A COMPLETE
C          SET OF READINGS=NO SAMPLES+NO. DEFECTS
C     NPTT=VALUE OF NPT READ FROM FILE 30
C     NPHCAL=NUMBER OF PHASE CALIBRATIONS
C     NMGCAL=NUMBER OF MAGNITUDE CALIBRATIONS
C     NCAL=NPHCAL*NMGCAL=TOTAL NUMBER OF CALIBRATION READINGS
C     NPRINT=PRINT AND TRANSFER INDEX.
C     NSTOP=INDEX TO STOP THE INSTRUMENT READINGS
C     MAG=INDEX TO TURN ON THE SATURATING MAGNET(=0 IF NONE USED)
C
      REAL L2,L4,L3,L5,L6
      REAL*6 NPROBE,NCABLE,INSTNO,POWOSC,PICKAM,PHADET,COIL
      REAL*8 TITLE(3)
C  DIMENSIONS THAT ARE NOT CHANGED:
      DIMENSION ITIM(3),IDAY(3),NCONV(4)
      DIMENSION VOLTS(12),VOLSTD(6),OFSET(6),CGAIN(6),STDV(6)
C
C  DIMENSIONS THAT ARE CHANGED:
C **  DIMENSION READNG(NPT+1,IRDPRM+1),PRO(NPT),POLARY(IRDPRM+1,5)
C     DIMENSION PROP(1,NPROPM),TMDFT(NFT),PHDFT(NFT),JPOL(6,NFT,NPROPM)
C     DIMENSION COE(IRDPRM),COEF(IRDPRM,NPROPM)
C     DIMENSION RDG1(1,IRDPRM),,NPOL(6,NFT)
C     DIMENSION JOFSET(NPROPM),JRDPR(NPROPM)
C     DIMENSION PROPTY(NPROPM),PRONAM(NPROPM),FREQ(NFT),GAIN(NFT)
C     DIMENSION TMAG1(1,NFT),PHASE1(1,NFT)
C     DIMENSION PICKAM(NFT),PHADET(NFT),PHASW(NFT)
C     DIMENSION SUMCAL(NCHS,NCAL),SDVCAL(NCHS,NCAL)
C     DIMENSION RDGC(NCHS,NCAL),RDG0(NCHS,NCAL)
C     DIMENSION TOFSET(NCHS),TSLOPE(NCHS)
C
C  THE APPROPRIATE NUMBERS SHOULD BE INSERTED IN THE FOLLOWING
C  DIMENSION STATEMENTS; COMMENTED STATEMENTS MARKED ** MANDATORY
C
      DIMENSION READNG(325,16),PRO(324),POLARY(16,5),PROP(1,6)
      DIMENSION TMDFT(3),PHDFT(3),JPOL(6,3,6),COE(15),COEF(15,6)
      DIMENSION RDG1(1,15),NPOL(6,3),JOFSET(6),JRDPR(6)
      DIMENSION PROPTY(6),PRONAM(6),FREQ(4),GAIN(4)
      DIMENSION TMAG1(1,3),PHASE1(1,3)
      DIMENSION PICKAM(3),PHADET(3),PHASW(3)
      DIMENSION RDGC(6,4),RDG0(6,4)
```

```
C       DIMENSION TOFSET(6),TSLOPE(6)
C
        COMMON/D3/COIL,RDAR,R1,R2,XL,ZL,RLIM,RG,R7,TNDR,TNPU,ZLDR,ZLPU,X
C
C       FILE 29 CONTAINS THE COIL DATA.
        DEFINE FILE 29(60,32,U,NCOIL)
C
C       FILE 37 CONTAINS THE EXPERIMENTAL MEASUREMENTS MADE USING TUBRDG
        DEFINE FILE 37(1500,40,U,IREC)
C
C       FILE 21 WILL CONTAIN THE COEFFICIENTS OF THE FITS.
        DEFINE FILE 21(30,100,U,ICOEF)
C
C       FILE 31 WILL STORE THE COEFFICIENT DATA FOR THE MICROCOMPUTER.
        DEFINE FILE 31(8192,4,U,NCOED)
C
C   DATA THAT MAY NEED TO BE CHANGED:
        DATA NPT/324/,NPRINT/0/,LOU/6/,LITEK/1/,LOTEK/5/,NFILIM/1500/
        DATA IRDPRM/15/,IR/1/,NCHS/6/,ITIMS/32/,NPROPM/1/,NPROPT/1/
        DATA STOP/'STOP'/,BLANKS/'    '/,NUNIT/1/,NCOED/21000/,ICOEF/1/
C
        DATA OFSET/6*0.0/,CGAIN/6*1./
        INLINE
        LDI,3           #0057            RESET,S1 LO,INTERUPT,S2 HI,0101/0111
        ODD,3,6                          OUTPUT TO PORT36
        FINI
        CALL TIMECK(LOU,'BIGFIT')
        FIND (37'IREC)
        NCOED=NCOED+1
C
C       NCOED INCREMENTED(PROM ADDRESSES START AT 0,TUBFIT ADDRS AT 1)
C   READ INFORMATION IN DIRECT ACCESS FILE #37 ON DISK
C
        IREC=1
        READ(37'IREC) TITLE,IDAY,ITIM
        READ(37'IREC) NPROBE,NSER,R0,CAPDR,R9,CAPPU,NCABLE,
      *               CABLEL,CCABLE,INSTNO,POWOSC
        READ(37'IREC) NFT,NPTT,NPROPM,NPHCAL,NMGCAL
        READ(37'IREC)((FREQ(NF),PICKAM(NF),PHADET(NF),PHASW(NF)),
      *NF=1,NFT)
        READ(37'IREC)(PRONAM(NPR),NPR=1,NPROPM)
        NCAL=NPHCAL*NMGCAL
        LNF=2*NFT
        DO 100 NF=1,LNF
        READ(37'IREC)(RDG0(NF,NC),NC=1,NCAL)
    100 CONTINUE
C       READ NOMINAL  STANDARD VLOTAGES
C
        READ(37'IREC)(VOLSTD(NF),NF=1,LNF)
C
C        THE DATE AND TIME ARE PRINTED
C
        WRITE (LOU,140) IDAY, ITIM
    140 FORMAT (' CALIBRATION DATA TAKEN   ', 2(I2,1H/), I2,
       1  ' TIME  ', 2(I2,1H:), I2,/)
C
C       COIL DATA IS READ FROM  FILE
C
```

```
      CALL CIRCOL(LITEK,LOTEK,NPROBE)
      GO TO 630
C
C     LEAST SQUARES DESIGN SECTION.
C
C     SELECT PROPERTY TO BE FITTED AND SET UP PROPERTY ARRAY.
C
  300 MSET=NPT
      MSET1=MSET+1
      IF(NPROPT.GT.NPROPM) GO TO 860
  310 WRITE(LOTEK,320)(NPR,PRONAM(NPR),NPR=1,NPROPM)
  320 FORMAT(' SELECT NUMBER OF THE PROPERTY TO BE FITTED:',
     */,6(I3,1X,A4),' ? ')
      READ(LITEK,*)NPROP
      IF(NPROP.GT.NPROPM)NPROP=NPROPM
  350 WRITE(LOTEK,360)
  360 FORMAT(' TYPE 1 IF THERE IS OFFSET; 0 IF NO OFFSET:',/)
      READ(LITEK,*) JOFSET(NPROPT)
      IOFSET=JOFSET(NPROPT)
      IRDPR=IOFSET
  370 WRITE(LOTEK,380)
  380 FORMAT(' SELECT THE NUMBER OF THE FUNCTION TYPE, POLYNOMIAL',
     *' DEGREE, & # OF '/,
     *' CROSS TERMS FOR EACH MAGNITUDE & PHASE')
      WRITE(LOTEK,390)
  390 FORMAT(' FUNCTION TYPE:1=LINEAR 2=LOG 3=EXP 4=INV ')
  400 WRITE(LOTEK,160)
  160 FORMAT(1X)
      WRITE(LOTEK,410)
  410 FORMAT(25X,'FCTN POL # CROSS'/,25X'TYPE DEG TERMS')
      DO 450 NF=1,NFT
      DO 440 NC=1,2
      NCC=NC*3
      NCP=NCC-1
      NCF=NCP-1
      IF(NC.EQ.1) WRITE(LOTEK,420) FREQ(NF)
      IF(NC.EQ.2) WRITE(LOTEK,430) FREQ(NF)
  420 FORMAT(' MAG AT ',1PE12.6,' HZ    ')
  430 FORMAT(' PHA AT ',1PE12.6,' HZ    ')
      READ(LITEK,*)
     *JPOL(NCF,NF,NPROPT),JPOL(NCP,NF,NPROPT),JPOL(NCC,NF,NPROPT)
C     JPOL(3,NF,NPROPT)=0
      IRDPR=IRDPR+JPOL(NCP,NF,NPROPT)+JPOL(NCC,NF,NPROPT)
      JRDPR(NPROPT)=IRDPR
      NPOL(NCF,NF)=JPOL(NCF,NF,NPROPT)
      NPOL(NCP,NF)=JPOL(NCP,NF,NPROPT)
      NPOL(NCC,NF)=JPOL(NCC,NF,NPROPT)
  440 CONTINUE
  450 CONTINUE
      IRDPR1=IRDPR+1
      IF(IRDPRM.LT.JRDPR(NPROPT))WRITE(LOTEK,460)
      IF (IRDPRM.LT.JRDPR(NPROPT))GO TO 630
  460 FORMAT(' ERROR: # OF TERMS IN POLARY EXCEEDS DIMENSION')
      JROW=IRDPRM+1
      CALL POLTYP(POLARY,JROW,IRDPR,NPOL,6,NFT,2,IOFSET,LOTEK)
C
C      EXPAND THE RAW READINGS INTO IRDPR READINGS.
C
```

```
  470 DO 480 NF=1,NFT
      TMDFT(NF)=0.
      PHDFT(NF)=0.
  480 CONTINUE
      IREC=7+LNF
      NR=1
      DO 490 NP=1,NPTT
      READ(37'IREC)((TMAG1(1,NF),PHASE1(1,NF),NF=1,NFT),(PROP(1,
     *NPR),NPR=1,NPROPM)
C
C     THE PROPERTIES CAN BE SET AND MODIFIED IN THIS SECTION
C
C     PROP(1,4)=PROP(1,4)-PROP(1,2)
C     PROP(1,1)=PROP(1,1)-PROP(1,2)
C     PROP(1,2)=PROP(1,2)-RLIM*RBAR
C
C     IF THIS PROPERTY IS NOT TO BE USED TRANSFER TO 490
C
      IF(PROP(1,6).GT.0.11.OR.PROP(1,6).LT.-0.11)GO TO 490
C     IF(PROP(1,2).GT.0.001.AND.PROP(1,3).LT.0.020)GO TO 490
C     IF(PROP(1,6).LT.-0.080)GO TO 490
C     IF(PROP(1,6).GT.-0.040)GO TO 490
C     IF(ABS(PROP(1,6)+1.000).GT.0.0001)GO TO 490
C     IF(PROP(1,3).EQ.0.0)GO TO 490
C     IF(ABS(PROP(1,6)).GT.0.155)GO TO 490
      CALL RDGEXP(RDG1,TMAG1,PHASE1,NPOL,IOFSET,TMDFT,PHDFT,
     *1,IRDPR1,1,NFT,1,1,1,1)
      PRO(NR)=PROP(1,NPROP)
      DO 485 IRD=1,IRDPRM
      READNG(NR,IRD)=RDG1(1,IRD)
  485 CONTINUE
      NR=NR+1
  490 CONTINUE
C
C     DO THE LEAST SQUARES FIT OF THE READINGS TO THE PROPERTIES.
C
      CALL ALSQS(READNG,PRO,COE,RSOS,MSET,IRDPR,MSET1)
C
C     CALCULATE THE DIFFERENCES IN THE FIT AND THE MAXIMUM DRIFTS.
C
  500 SSDRIF=0.
      SSDIFF=0.
      IF(NPRINT.EQ.2)WRITE(LOTEK,510)PRONAM(NPROP)
      IF(NPRINT.EQ.2)WRITE(LOU,510)PRONAM(NPROP)
  510 FORMAT(2X,A4,7X,'   CAL ',10X,'DIFF',8X,'DRIFT')
      IREC=7+LNF
      NR=1
      DO 570 NP=1,NPTT
      DRIFT=0.
      READ(37'IREC)((TMAG1(1,NF),PHASE1(1,NF),NF=1,NFT),(PROP(1,
     *NPR),NPR=1,NPROPM)
C
C      TRANSFER TO 570 IF PROPERTY IS NOT THE ONE WE WANT
C
      IF(PROP(1,6).GT.0.11.OR.PROP(1,6).LT.-0.11)GO TO 570
C     IF(PROP(1,2).GT.0.001.AND.PROP(1,3).LT.0.020)GO TO 570
C     IF(PROP(1,6).LT.-0.080)GO TO 570
C     IF(PROP(1,6).GT.-0.040)GO TO 570
```

```
C       IF(ABS(PROP(1,6)+1.000).GT.0.0001)GO TO 570
C       IF(PROP(1,6).NE.0.5)GO TO 570
C       IF(PROP(1,3).EQ.0.0)GO TO 570
C       IF(ABS(PROP(1,6)).GT.0.155)GO TO 570
        DO 540 NF=1,NFT
        DO 530 NC=1,2
C
C       ONE MAGNITUDE OR PHASE DRIFT IS SET ON AT A TIME.
C
        IF(NC.EQ.1)TMDFT(NF)=.0001*TMAG1(1,NF)
        IF(NC.EQ.2)PHDFT(NF)=.001
        CALL RDGEXP(RDG1,TMAG1,PHASE1,NPOL,IOFSET,TMDFT,PHDFT,
       *1,IRDPR1,1,NFT,1,1,1,1)
C
C       THE POLYNOMIAL IS CALCULATED
C
        SUM=0.
        DO 520 IR=1,IRDPR
        SUM=SUM+COE(IR)*RDG1(1,IR)
  520   CONTINUE
        DRIFT=DRIFT+ABS(READNG(NR,IRDPR1)-SUM)
        TMDFT(NF)=0.
        PHDFT(NF)=0.
  530   CONTINUE
  540   CONTINUE
        DIFF=PRO(NR)-READNG(NR,IRDPR1)
        SSDIFF=SSDIFF+DIFF*DIFF
        SSDRIF=SSDRIF+DRIFT*DRIFT
        IF(NPRINT.NE.2)GO TO 565
C
C       THE ENTIRE FIT IS PRINTED OUT
C
        WRITE(LOU,560)NR,PRO(NR),READNG(NR,IRDPR1),DIFF,DRIFT
        WRITE(LOTEK,560)NR,PRO(NR),READNG(NR,IRDPR1),DIFF,DRIFT
  560   FORMAT(1X,I3,4F12.5)
  565   NR=NR+1
  570   CONTINUE
        SDRIF=SQRT(SSDRIF/FLOAT(MSET))
        SDIFF=SQRT(SSDIFF/FLOAT(MSET))
        WRITE(LOU,580)PRONAM(NPROP),SDIFF,SDRIF
        WRITE(LOTEK,580)PRONAM(NPROP),SDIFF,SDRIF
  580   FORMAT(' RMS DIFF IN  ',A4,'=',F10.5,3X,'DRIFT=',F10.5)
  590   IF (NPRINT.NE.3)GO TO 630
        IF(NPROPT.NE.1)GO TO 597
        DO 595 NC=1,NCAL
        WRITE(21'ICOEF)(RDG0(JJ,NC),JJ=1,LNF)
        DO 595 NF=1,LNF
        CALL CONVR9(RDG0(NF,NC),1,NCONV)
        DO 595 II=1,4
        WRITE(31'NCOED)NCONV(II)
  595   CONTINUE
        WRITE(21'ICOEF)(VOLSTD(NF),NF=1,LNF)
        DO 596 NF=1,LNF
        CALL CONVR9(VOLSTD(NF),1,NCONV)
        DO 596 II=1,4
        WRITE(31'NCOED)NCONV(II)
  596   CONTINUE
  597   WRITE(LOU,160)
```

```
      WRITE(LOTEK,160)
      NCOED1=NCOED+4*IRDPRM+1
      WRITE(31'NCOED)IRDPR
      DO 610 I=1,IRDPR
      CALL CONVR9(COE(I),1,NCONV)
C     WRITE(LOU,600)I,COE(I),(NCONV(II),II=1,4),(POLARY(I,J),J=1,5)
      WRITE(LOTEK,600)I,COE(I),(NCONV(II),II=1,4),(POLARY(I,J),J=1,5)
  600 FORMAT(' COEF(',I2,')=',1PE15.7,4X,4(Z2,1X),1X,5A4)
      COEF(I,NPROPT)=COE(I)
      DO 610 NCO=1,4
      WRITE(31'NCOED)NCONV(NCO)
  610 CONTINUE
      NCOED=NCOED1
C
C     THE COEFFICIENT,OFFSET,NPOL AND IRDPR ARE WRITTEN ON THE RAD DISC
C     FILE #21.
C
      WRITE(21'ICOEF)PRONAM(NPROP),IRDPR,JOFSET(NPROPT)
      WRITE(21'ICOEF)(COEF(IR,NPROPT),IR=1,IRDPR)
      DO 620 NF=1,NFT
      WRITE(21'ICOEF)(NPOL(I,NF),I=1,6)
  620 CONTINUE
      WRITE(21'ICOEF)STOP,NFT,NFT
      PROPTY(NPROPT)=PRONAM(NPROP)
      ICOEF=ICOEF-1
      NPROPT=NPROPT+1
C
  630 WRITE(LOTEK,640)
  640 FORMAT(' 1 FIT PROP 2 PRT ENTIRE FIT 3 PRT/SV COEF 4 CHG FCTN/POL'
     *,'TYP 5 RUN TEST',/)
      READ(LITEK,*)NPRINT
      GO TO(300,500,590,350,650),NPRINT
  650 NPROPT=NPROPT-1
      WRITE(LOU,160)
      GO TO 800
C     CALCULATES PROPERTIES FROM MAGNITUDES AND PHASES AND CONTINOUSLY
C     DISPLAYS THE VALUES ON THE LSI TERMINAL.
C
  700 CONTINUE
      IF(NPRINT.EQ.2)WRITE(LOTEK,710)(PROPTY(NPRO),NPRO=1,NPROPT)
  710 FORMAT(1X,6(8X,A4,1X))
      IF(NPRINT.EQ.3)WRITE(LOTEK,715)(II,II,II=1,NFT)
  715 FORMAT(1X,3('       MAG(',I1,')        PHA(',I1,')'))
      WRITE(LOTEK,160)
C
C     EXPANSION OF TMAG1(1,NF) AND PHASE1(1,NF) INTO READNG(1,IRDPRM)
C
  720  DO 800 NPRO=1,NPROPT
      DO 790 NF=1,NFT
      DO 780 I=1,6
      NPOL(I,NF)=JPOL(I,NF,NPRO)
  780 CONTINUE
      TMDFT(NF)=0.
      PHDFT(NF)=0.
  790 CONTINUE
      IOFSET=JOFSET(NPRO)
      IRDPR=JRDPR(NPRO)
      IRDPR1=IRDPR+1
```

```
      CALL RDGEXP(RDG1,TMAG1,PHASE1,NPOL,IOFSET,TMDFT,PHDFT,
     *1,IRDPR1,1,NFT,1,1,1,1)
      PRO(NPRO)=0.
      DO 800 IR=1,IRDPR
      PRO(NPRO)=PRO(NPRO)+COEF(IR,NPRO)*RDG1(1,IR)
  800 CONTINUE
      NSTART=1
      IF(NPRINT.EQ.2)WRITE(LOTEK,805)(PRO(NPRO),NPRO=1,NPROPT)
  805 FORMAT(1H+,6(F13.5))
C
C     NEW READINGS ARE MADE FROM THE EDDY CURRENT INSTRUMENT.
C
  825 IF(MAG.EQ.1) CALL RDGMIC(VOLTS,NCHS,12,1,NSTOP,MAG,8)
      CALL RDGMIC(VOLTS,NCHS,ITIMS,NRET,NSTOP,MAG,8)
      IF(MAG.EQ.1) CALL SATMAG(0)
C     VOLTS(8)=25.*VOLTS(7)/VOLTS(8)
C     DO 830 NC=1,NCHS
C     VOLTS(NC)=VOLTS(NC)+TOFSET(NC)+TSLOPE(NC)*VOLTS(8)
  830 CONTINUE
      IF(NPRINT.EQ.3)WRITE(LOTEK,820)((VOLTS(2*NF-1),VOLTS(2*NF))
     *,NF=1,NFT)
      CALL CORRDG(VOLTS,OFSET,CGAIN,NCHS)
  840 DO 845 NF=1,NFT
      TMAG1(1,NF)=VOLTS(2*NF-1)
      PHASE1(1,NF)=VOLTS(2*NF)
  845 CONTINUE
  820 FORMAT(1H+,6(F12.4))
      IF(NSTOP.GT.0)GO TO 720
C
C     PROGRAM WILL STAY IN THIS LOOP UNTIL THE FOOT PEDAL IS PRESSED.
C
      IF(NLABL+NPRINT.EQ.3)WRITE(LOU,710)(NPRO,NPRO=1,NPROPT)
      NLABL=NPRINT
      IF(NPRINT.EQ.2)WRITE(LOU,850)(PRO(NPRO),NPRO=1,NPROPT)
  850 FORMAT(1H ,6(F12.5))
      IF(NPRINT.EQ.3)WRITE(LOU,850)((VOLTS(2*NF-1),VOLTS(2*NF))
     *,NF=1,NFT)
      GO TO 880
  855 WRITE(LOTEK,857)
  857 FORMAT(' LIMIT OF FILE 37 IS EXCEEDED.')
      GO TO 880
  860 WRITE(LOTEK,870)
  870 FORMAT(' PROP ARRAY IS FILLED.')
  880 WRITE(LOTEK,890)
  890 FORMAT(' PRINT :1.MEAS VOLT & PROPERTIES 2.CAL&DISPLAY PROPS'
     *,'3.RAW RDGS.4.RE-CALIB 5.STOP',/)
      INLINE
      LDI,3          %0067          INTERUPT,S1 LO,RESET,S2 HI,0110/0111
      ODD,3,6                       OUTPUT TO PORT36,INTERUPT INITIATED
      FINI
      READ(LITEK,*)NPRINT
      INLINE
      LDI,3          %0077          S1 LO,RESET,INTERUPT,S2 HI,0111/0111
      ODD,3,6                       OUTPUT TO PORT36
      FINI
      GO TO (1300,700,700,895,900),NPRINT
  895 CALL CALMIC(RDGC,NCHS,NSTOP)
      CALL RESET(RDGC,RDG0,OFSET,CGAIN,STDV,NCHS)
```

```
              GO TO 880
      C
      C       PRINT SUMMARY OF DATA ON FILE 37
      C
       1300   WRITE(LOU,1350) NPROBE,NSER
       1350   FORMAT(' PROBE NO.:',A6,5X,' SERIAL NO.:',I5)
              WRITE(LOU,1360) RD,CAPDR
       1360   FORMAT(' DRIVER SERIES RESISTANCE:',F10.1,5X,'DRIVER SHUNT CAP.:',
             *          E12.4)
              WRITE(LOU,1370) RP,CAPPU
       1370   FORMAT(' PICK-UP SHUNT RESISTANCE:',F10.1,5X,'PICK-UP SHUNT CAP.:'
             *          ,E12.4)
              WRITE(LOU,1380) NCABLE,CABLEL,CCABLE
       1380   FORMAT(' CABLE I.D. NO.:',A6,5X,'LENGTH:',F10.1,5X,'CAP.:',
             *          E12.4)
              WRITE(LOU,1390) INSTNO
       1390   FORMAT(' EDDY CURRENT INSTRUMENT NO.:',A6)
              WRITE(LOU,1400) POWOSC
       1400   FORMAT(' POWER OSC I.D.',A6)
              WRITE(LOU,1410) (FREQ(NF),NF=1,NFT)
       1410   FORMAT(/,10X,'FREQUENCY:', 10(1PE12.4,5X))
              WRITE(LOU,1420) (PICKAM(NF),NF=1,NFT)
       1420   FORMAT(' PICK-UP AMP I.D.:',7X,10(A6,9X))
              WRITE(LOU,1430) (PHDET(NF),NF=1,NFT)
       1430   FORMAT(' PHASE DETECTOR I.D.:',4X,10(A6,9X))
              WRITE(LOU,1440) (PHASW(NF),NF=1,NFT)
       1440   FORMAT(' 180  PHASE SWITCH:',8X,10(A3,12X))
      C
      C       PRINT CALIBRATION READINGS
      C
       1600   CONTINUE
              WRITE(LOU,1650) NPHCAL,NMGCAL
       1650   FORMAT(1H0,' AVERAGES & STANDARD DEVIATIONS OF CALIBRATION
             *       'READINGS:',I5,' MAG',I5,' PHA'/)
              WRITE(LOU,1660) (FREQ(NF),NF=1,NFT)
       1660   FORMAT(3(10X,1PE12.4))
              WRITE(LOU,1670)(NF,NF,NF=1,NFT)
       1670   FORMAT(5X,3(5X,'MAG',I1,6X,'PHA',I1,1X))
              DO 1700 NC=1,NCAL
              WRITE(LOU,100)
              WRITE(LOU,1680)((RDGO(NF,NC)),NF=1,LNF)
       1680   FORMAT(5X,6(F10.4))
       1700   CONTINUE
      C
      C       PRINT OUT READINGS AND PROPERTIES
      C
              WRITE(LOU,100)
              WRITE(LOU,1750)(NF,NF,NF=1,NFT),(PRONAM(NPR),NPR=1,NPROPM)
              IREC=7+LNF
       1750   FORMAT(1X,'PSET',3('       MAG',I1,'       PHA',I1),6(4X,A4,1X))
              DO 1800 NP=1,NPTT
              READ(37'IREC)((TMAG1(1,NF),PHASE1(1,NF),NF=1,NFT),(PROP(1,
             *NPR),NPR=1,NPROPM))
              WRITE(LOU,1760)NP,((TMAG1(1,NF),PHASE1(1,NF),NF=1,NFT),(PROP(1,
             *NPR),NPR=1,NPROPM))
       1760   FORMAT(1X,I4,12(F9.4))
       1800   CONTINUE
              GO TO 560
```

```
      900 STOP JOB
          END
TOTAL RECORDS WRITTEN =   467/     75
EXIT
$AVR CI 4
$END  LIST
```

Appendix D

PROGRAM PLTRDG

The program PLTRDG is used to plot eddy-current data on a Versatec printer-plotter. Plots are made as the test sample is scanned and as data are recorded. Using prompts, the operator may select either the raw data or a calculated property to be plotted. The raw data consist of a magnitude and a phase value for each data point recorded at each frequency. For example, a raw data plot for a three-frequency test will consist of six curves. The calculated property scan uses the coefficients provided by the program BIGFIT to perform a mathematical fit to the raw data to determine the desired property. A calculated property scan usually consists of one curve for each property, but in special cases more than one property can be represented by a single curve; for example, sample thickness and defects. Calculated properties are usually examined one at a time, but, with a slight program modification, more than one property (or curve) can be displayed simultaneously. The prompts provided make running the program almost self-explanatory. It is necessary to execute options 1, 2, and 3 (raw readings, calculate properties, and recalibrate) in numerical order before making a plot.

The program provides the ability to control the scanning devices associated with the test. The operator can specify the start position and scan increment for each scanner used.

A section of the program provides a curve-smoothing capability by averaging successive calculated values. The operator may specify the number of successive data points to average. The number of points averaged should be as small as possible to minimize computer operating time.

The operator can specify the gain and offset value for each curve. The indication size and curve position (on the chart) can be controlled with these two parameters.

```
      PROGRAM PLTRDG
C     21 JANURARY 1981
C
C     PROGRAM WILL PLOT RAW READINGS OR CALCULATED PROPERTIES
C     FROM READINGS MADE BY THE EDDY CURRENT INSTRUMENT ON THE
C     VERSATEC.THE CALCULATE PROPERTIES SECTION MUST BE SELECTED
C     BEFORE THE RECALIBRATE SECTION.
C
      DIMENSION JPOL(6,3,6),IRDPR(6),JOFSET(6)
      DIMENSION READNG(16),NPOL(6,3),TMAGM(3),PHASE(3)
      DIMENSION COEF(16,6),PROP(6),PRONAM(6)
      DIMENSION XLIM(2),YRLIM(2),YPLIM(2),XARG(2)
      DIMENSION VOLSTD(6),VOLTS(12),Y1(2),Y2(2),YVAL(2,12)
      DIMENSION OFSET(6),GAIN(6),STDV(6)
      DIMENSION RDGC(6,4),RDG0(6,4)
      DIMENSION DELTA(3),XNEW(3)
      DIMENSION NDACH(6),ROFSET(6),RGAIN(6),POFSET(6),PGAIN(6)
      DIMENSION NPR(10)
      DEFINE FILE 21(30,100,U,ICOEF)
      DATA NTT/5/,NTT1/4/,NPR/10*700/
      DATA INTER/10/,ICOEF/1/,NPROPM/1/
      DATA NCHS/6/,ITIMS/1/,NRET/1/,NFT/3/
      DATA LVP/17/,MAG/0/,LOU/6/,LITEK/1/,LOTEK/5/
C     VALUES OF OFFSET AND GAIN FOR READINGS
      DATA ROFSET/-4.15,-1.60,-3.90,-0.80,-3.60,-0.55/,RGAIN/6*1000./
C     VALUES OF GAIN AND OFFSET FOR PROPERTIES
      DATA POFSET/3*0.,2.0,2*0./,PGAIN/1.0E4,1.0E4,0.5E4,1.0E2,2*1./
C     VALUES OF GAIN AND OFFSET FOR CALIBRATIONS ARE SET
      DATA DELTA/3*0.0/,XNEW/3*0.0/,OFSET/6*0.0/,GAIN/6*1.0/
      DATA NCOUNT/0/
C     READINGS FROM A STANDARD TUBE ARE SET
C
C     SET ADDRESSES SO THAT INSTRUMENT IS READ
C
      INLINE
      LDI,3          #0057            RESET,S1 LO.INTERUPT,S2 HI,0101/0111
      ODD,3,6                         OUTPUT TO PORT36
      FINI
    5 WRITE(LOTEK,15)
      WRITE(17,10)
   10 FORMAT('1       ')
      JSET=0
      LCOUNT=0
   15 FORMAT(' WHAT NEXT 1.RAW RDG 2.CAL PROPS 3.RECAL'
     *,' 4.SCAN/RAW 5.SCAN/CAL 6.RST 7.STOP? ')
      INLINE
      LDI,3          #0067            INTERUPT,S1 LO,RESET,S2 HI,0110/0111
      ODD,3,6                         OUTPUT TO PORT36
      FINI
      READ(1,*)NPRINT
      INLINE
      LDI,3          #0077            S1 LO,RESET,INTERUPT,S2 HI,0111/0111
      ODD,3,6                         OUTPUT TO PORT36
      FINI
      IF(NPRINT.EQ.4)WRITE(LOTEK,17)
      IF(NPRINT.EQ.5)WRITE(LOTEK,17)
   17 FORMAT(' TYPE XNEW(1),XNEW(2),DELTA(1),DELTA(2) FOR POSITIONER ')
      IF(NPRINT.EQ.4)READ(1,*)XNEW(1),XNEW(2),DELTA(1),DELTA(2)
```

```
      IF(NPRINT.EQ.5)READ(1,*)XNEW(1),XNEW(2),DELTA(1),DELTA(2)
      GO TO (20,200,300,20,200,400,500),NPRINT
   20 CONTINUE
   30 IF(MAG.EQ.1) CALL RDGMIC(VOLTS,NCHS,12,NRET,NSTOP,1,8)
      LNF=NFT*2
      WRITE(LOTEK,110)(NF,NF,NF=1,NFT)
      WRITE(LOTEK,120)
  110 FORMAT('      ',3('MAG(',I1,')      PHA(',I1,')      '))
  120 FORMAT(1X)
  130 IF(NPRINT.EQ.1)GO TO 140
      XNEW(1)=XNEW(1)+DELTA(1)
      IF(XNEW(1).LT.0.0)XNEW(1)=0.0
      XNEW(2)=XNEW(2)+DELTA(2)
      IF(XNEW(2).LT.0.0)XNEW(2)=0.0
      CALL POSITION(XNEW,2)
  140 CALL RDGMIC(VOLTS,NCHS,ITIMS,NRET,NSTOP,MAG,8)
      CALL CORRDG(VOLTS,OFSET,GAIN,NCHS)
      K=MOD(NCOUNT,INTER)
      NCOUNT=NCOUNT+1
      IF(K.EQ.0)WRITE(LOTEK,150)(VOLTS(NF),NF=1,LNF)
  150 FORMAT(1H+,6(F11.5))
      DO 60 NF=1,LNF
      NDACH(NF)=RGAIN(NF)*(ROFSET(NF)+VOLTS(NF))
   60 CONTINUE
      CALL PLOTDA(NDACH,LNF,0,LCOUNT)
      IF(NSTOP.EQ.1)GO TO 130
      CALL SATMAG(0)
      CALL PLOTDA(NDACH,LNF,1,LCOUNT)
      IF(NPRINT.EQ.4)CALL TIMECK(17,'1750-1')
      IF(NPRINT.EQ.4)WRITE(17,150)(VOLTS(NF),NF=1,LNF)
      DO 65 NF=1,LNF
      VOLTS(NF)=VOLTS(NF)+ROFSET(NF)
   65 CONTINUE
      IF(NPRINT.EQ.4)WRITE(17,150)(VOLTS(NF),NF=1,LNF)
      IF(NPRINT.EQ.4)WRITE(17,150)(ROFSET(NF),NF=1,LNF)
      GO TO 5
C
C     PROPERTY CALCULATION AND DISPLAY SECTION
C
  200 IF(ICOEF.NE.1)GO TO 215
C
C     FILE 21 CONTAINS DATA FORM TUBFIT OR RFLFIT
C     LINE 1-4 CONTAINS THE INITIAL CALIBRATION DATA FROM TUBFIT
C     LINE 5 HAS THE PROPERTY NAME,PRONAM,THE # TERMS,IRDPR,ADD OFFSET
C     LINE 6 HAS IRDPR COEFFICIENTS
C     LINE 7 THROUGH 6 + NFT HAS JPOL(6,NFT,NPROM)
C     THE LAST LINE HAS 'STOP' 0,0
C
      DO 205 NC=1,4
      READ(21'ICOEF)(RDG0(NF,NC),NF=1,LNF)
  205 CONTINUE
      READ(21'ICOEF)(VOLSTD(NF),NF=1,LNF)
  210 READ(21'ICOEF)PRONAM(NPROPM),IRDPR(NPROPM),JOFSET(NPROPM)
      IF(PRONAM(NPROPM).EQ.'STOP')GO TO 214
      IRDP=IRDPR(NPROPM)
      READ(21'ICOEF)(COEF(IR,NPROPM),IR=1,IRDP)
      DO 213 NF=1,NFT
      READ(21'ICOEF)(JPOL(I,NF,NPROPM),I=1,6)
```

```
 213 CONTINUE
     NPROPM=NPROPM+1
     GO TO 210
 214 CONTINUE
     NPROPM=NPROPM-1
 215 CONTINUE
     WRITE(LOTEK,217)(PRONAM(NPRO),NPRO=1,NPROPM)
 217 FORMAT(1X,' TUB LOC ',6(6X,A4,1X))
     WRITE(LOTEK,120)
 220 IF(NPRINT.EQ.2)GO TO 221
     XNEW(1)=XNEW(1)+DELTA(1)
     IF(XNEW(1).LT.0.0)XNEW(1)=0.0
     XNEW(2)=XNEW(2)+DELTA(2)
     IF(XNEW(2).LT.0.0)XNEW(2)=0.0
     CALL POSITION(XNEW,2)
 221 CALL RDGMIC(VOLTS,NCHS,ITIMS,NRET,NSTOP,MAG,8)
     CALL CORRDG(VOLTS,OFSET,GAIN,NCHS)
     DO 260 NPRO=1,NPROPM
     IRDPR1=IRDPR(NPRO)+1
     IOFSET=JOFSET(NPRO)
     DO 230 NF=1,NFT
     PHASE(NF)=VOLTS(2*NF)
     TMAGM(NF)=VOLTS(2*NF-1)
     DO 225 I=1,6
     NPOL(I,NF)=JPOL(I,NF,NPRO)
 225 CONTINUE
 230 CONTINUE
     CALL RDEXP(READNG,TMAGM,PHASE,NPOL,IOFSET,IRDPR1,NFT)
     PROP(NPRO)=0.
     IRDP=IRDPR(NPRO)
     DO 240 IR=1,IRDP
     PROP(NPRO)=PROP(NPRO)+READNG(IR)*COEF(IR,NPRO)
 240 CONTINUE
     NDACH(NPRO)=PGAIN(NPRO)*(POFSET(NPRO)+PROP(NPRO))
 260 CONTINUE
     IF(JSET.EQ.0)POFSET(3)=0.140-PROP(3)
     JSET=1
C
C    SECTION TO SMOOTH THE DEFECT INDICATION BY AVERAGING SUCESSIVE
C    DEFECT CALCULATIONS
C
     DO 265 NT=1,NTT1
     NPR(NT)=NPR(NT+1)
 265 CONTINUE
     NPR(NTT)=NDACH(3)
     NDACH(3)=0
     DO 167 NT=1,NTT
     NDACH(3)=NDACH(3)+NPR(NT)
 167 CONTINUE
     NDACH(3)=NDACH(3)/NTT
C
C    END OF SECTION
C
     K=MOD(NCOUNT,INTER)
     NCOUNT=NCOUNT+1
     IF(K.EQ.0)WRITE(LOTEK,270)XNEW(1),(PROP(NPRO),NPRO=1,NPROPM)
 270 FORMAT(1H+,F8.3,6(F11.4))
     CALL PLOTDA(NDACH,NPROPM,0,LCOUNT)
```

```
      IF(NSTOP.EQ.1)GO TO 220
      CALL PLOTDA(NDACH,LNF,1,LCOUNT)
      CALL TIMECK(17,'I750-1')
      GO TO 5
  300 CONTINUE
      CALL CALMIC(RDGC,NCHS,NSTOP)
      CALL RESET(RDGC,RDGO,OFSET,GAIN,STDV,NCHS)
      GO TO 5
 400  CALL RDGMIC(VOLTS,NCHS,40,NRET,NSTOP,MAG,0)
      DO 450 NOF=1,NCHS
      OFSET(NOF)=VOLSTD(NOF)-GAIN(NOF)*VOLTS(NOF)
 450  CONTINUE
      GO TO 5
  500 CONTINUE
      STOP JOB
      END
      SUBROUTINE PLOTDA(NDACH,NPLO,NRET,LCOUNT)
C
C     VERSION 2 8 79
C
      INTEGER*2 ITEST,ILATT(64)
      INTEGER*2 I(6),IAR(64,6)
      DIMENSION NDACH(6)
      DATA INTER/100/
      DATA IAR/384*0/
C
      DATA ILATT/Z8000,5*0,Z800,5*0,Z80,5*0,Z8,6*0,Z8000,5*0,Z800,5*0,
     *Z80,5*0,Z8,6*0,Z8000,5*0,Z800,5*0,Z80,0/
      DO 50 NPL=1,NPLO
      I(NPL)=1+NDACH(NPL)/16
      IF(I(NPL).GT.64)I(NPL)=64
      IF(I(NPL).LT.0)I(NPL)=0
      IAR(I(NPL),NPL)=7*2**(15-MOD(NDACH(NPL),16))/2
   50 CONTINUE
      ITEST=MOD(LCOUNT,INTER)
      INLINE
      LDI,15         #8400          LOAD COMMAND WORD INTO REG 1
      OCA,15,8                      OUTPUT COMMAND WORD TO VERSATEC
      LDI,1          0              SET COUNTER IN REG 1 TO 0
      LDM,14         ITEST          LOAD VERTICAL LINE TEST IN REG 14
LOOP  ISA,3,8                       INPUT STATUS INTO REG 3
      TBRB,3,8       LOOP           TEST BIT 8 AND LOOP BACK IF HI
      TRR,2,1                       COPY OFFSET FROM REG1 TO REG2.
      LDM,3,1        ILATT          LOAD LATTICE INTO REG3
      XOM,3,2        IAR            EXCLUSIVE OR IAR(REG1,NPL)WITH REG3
      ABR,2,9                       ADD 64 TO REG2
      XOM,3,2        IAR            EXCLUSIVE OR IAR(REG1,NPL)WITH REG3
      ABR,2,9                       ADD 64 TO REG2
      XOM,3,2        IAR            EXCLUSIVE OR IAR(REG1,NPL)WITH REG3
      ABR,2,9                       ADD 64 TO REG2
      XOM,3,2        IAR            EXCLUSIVE OR IAR(REG1,NPL)WITH REG3
      ABR,2,9                       ADD 64 TO REG2
      XOM,3,2        IAR            EXCLUSIVE OR IAR(REG1,NPL)WITH REG3
      ABR,2,9                       ADD 64 TO REG2
      XOM,3,2        IAR            EXCLUSIVE OR IAR(REG1,NPL)WITH REG3
      ZBRB,14,0      SKIP           SKIP AROUND IF REG 14 NOT ZERO
      TOR,3,3                       TAKE ONE'S COMPLEMENT OF REG 3
SKIP  ODA,3,8                       SEND DATA OUT TO THE VERSATEC
```

```
      ABR,1,15                              INCREMENT COUNTER IN REG 1
      ZBRB,1,9        LOOP                   STAY IN LOOP UNTIL FINISHED
      LDI,15           #4500        LOAD END OF BLOCK COMMAND
      OCA,15,8                      SEND TO VERSATEC
      FINI
      DO 60 NPL=1,NPLO
      IAR(I(NPL),NPL)=0
   60 CONTINUE
      LCOUNT=LCOUNT+1
      IF(NRET.EQ.0)GO TO 900
C
C      SECTION TO ADVANCE VERSATEC
C
      INLINE
LOP1  ISA,2,8                             INPUT STATUS INTO REG 2
      TBRB,2,8        LOP1                TEST BIT 8 AND LOOP BACK IF HI
      LDI,2           #8000               LOAD COMMAND WORD INTO REG 1
      OCA,2,8                             OUTPUT COMMAND WORD TO VERSATEC
LOP2  ISA,2,8                             INPUT STATUS INTO REG 2
      TBRB,2,8        LOP2                TEST BIT 8 AND LOOP BACK IF HI
      LDI,2           #1818               LOAD LINE FEED INTO REG 1
      ODA,2,8                             OUTPUT WORD TO VERSATEC
LOP3  ISA,2,8                             INPUT STATUS INTO REG 2
      TBRB,2,8        LOP3                TEST BIT 8 AND LOOP BACK IF HI
      LDI,2           #4400        LOAD TERMINATE COMMAND
      OCA,2,8                      SEND TO VERSATEC
      FINI
  900 RETURN
      END
      SUBROUTINE RDEXP(READNG,TMAG,PHASE,NPOL,IOFSET,IRDPR1,NFT)
      DIMENSION READNG(IRDPR1),NPOL(6,NFT)
      DIMENSION TMAG(NFT),PHASE(NFT)
C
C     NPOL CONTAINS A NUMBER FOR THE FUNCTION TYPE, THE POLYNOMIAL
C     DEGREE, AND THE NUMBER OF CROSS TERMS
C     FOR THE MAGNITUDE AND PHASE AT EACH FREQUENCY,STORED AS NPOL
C     (NF;1-MAG FUN, 2-MAG POL,3-MAG #CROSS TERMS,4-PH FUN,5-PH POL,
C     6-PH # CROSS TERMS).  IF IOFSET=0, NO OFF-SET
C     WILL BE INCLUDED,=1 OFF-SET IS INCLUDED.IF
C      NPOL(NCP,NF) =0,THAT PARTICULAR MAGNITUDE AND PHASE FOR THAT
C     FREQUENCY WILL BE SKIPPED.
C
      READNG(1)=1.
      N=1
      IF(IOFSET.EQ.1)N=2
      DO 210 NF=1,NFT
      DO 200 NC=1,2
      NCC=NC*3
      NCP=NCC-1
      NCF=NCP-1
      ROLD=RDG
      IF(NPOL(NCP,NF).EQ.0) GO TO 200
      IF(NC.EQ.1) RDG=TMAG(NF)
      IF(NC.EQ.2) RDG=PHASE(NF)
C
C     THE TYPE OF FUNCTION IS SELECTED
C
      IF(NPOL(NCF,NF).EQ.1)RDG=RDG
```

```
      IF(NPOL(NCF,NF).EQ.2)RDG=ALOG(RDG)
      IF(NPOL(NCF,NF).EQ.3)RDG=EXP(RDG)
      IF(NPOL(NCF,NF).EQ.4)RDG=1./RDG
C
C     THE TYPE OF POLYNOMIAL IS SELECTED
C     AND THE POLYNOMIAL VALUES ARE CONSTRUCTED.
C
      READNG(N)=RDG
      N=N+1
      NDEG=NPOL(NCP,NF)-1
      IF(NDEG.LT.1) GO TO 15
      DO 10 I=1,NDEG
      READNG(N)=RDG*READNG(N-1)
      N=N+1
   10 CONTINUE
C
C     CROSS TERMS ARE CONSTRUCTED
C
C  15 IF(NPOL(NCC,NF).EQ.0) GO TO 200
      RDY=ROLD
      NCTERM=NPOL(NCC,NF)
      DO 20 I=1,NCTERM
      RDY=ROLD*RDY
   20 CONTINUE
      IF(RDY.NE.0) RINV=RDG/ROLD
      IF(RDY.EQ.0) RINV=0.
      DO 30 I=1,NCTERM
      RDY=RDY*RINV
      READNG(N)=RDY
      N=N+1
   30 CONTINUE
C
  200 CONTINUE
  210 CONTINUE
      RETURN
      END
      SUBROUTINE POSITION(XNEW,NAXIS)
C
C     DETERMINES THE NEW LOCATION FOR 4 DIFFERENT POSITIONERS AND FROM
C     THE OLD LOCATION,THE NUMBER OF STEPS NEEDED TO REACH THE NEW
C     LOCATION.THEN CALLS STEPER TO MOVE THE MOTORS TO THE NEW LOCATION
C
      DIMENSION XOLD(3),XNEW(3),NSTEPS(3)
      DATA XOLD/3*0.0/,STEPSZ/0.00025/
      DO 20 IAXIS=1,NAXIS
      NSTEPS(IAXIS)=(0.5*STEPSZ+XNEW(IAXIS)-XOLD(IAXIS))/STEPSZ
      XOLD(IAXIS)=XOLD(IAXIS)+FLOAT(NSTEPS(IAXIS))*STEPSZ
   20 CONTINUE
      CALL STEPER(NSTEPS,XOLD,STEPSZ,NAXIS)
      RETURN
      END
      SUBROUTINE STEPER(NSTEPS,XOLD,STEPSZ,NAXIS)
C
C      SEND PROPER NUMBER OF STEPS TO PROPER AXIS CONTROLLER
C
      INTEGER*2 REG(8),NCOUNT
      DIMENSION XOLD(3),NSTEPS(3)
    1 DO 200 MAX=1,NAXIS
```

```
      IF(NSTEPS(NAX).EQ.0)GO TO 200
      REG(1)=0
      IF(NSTEPS(NAX).GE.0)GO TO 10
      REG(1)=8
      NSTEPS(NAX)=-NSTEPS(NAX)
   10 CONTINUE
      IF(NSTEPS(NAX).GE.65536)NSTEPS(NAX)=65535
C
C     SIGN SET IN REG(1);CONVERT NSTEP TO BCD IN REG(2)-REG(6)
C
      DO 30 NRG=2,6
      REG(NRG)=NSTEPS(NAX)/10000
      NSTEPS(NAX)=(NSTEPS(NAX)-10000*REG(NRG))*10
   30 CONTINUE
C     WRITE(6,40)(REG(I),I=1,6)
   40 FORMAT(1X,6I2)
C
C     DATA FOR OUTPUT IN REG(NRG);OUTPUT TO APPROIATE CONTROLLER
C
      NCOUNT=NAX-1
      INLINE
      LDI,1          0              ZERO REGISTER 1,USE AS INDEX,COUNTER
      LDM,2          NCOUNT         LOAD THE CONTROLLER SELECT CHANL
      LLS,2,4                       LOGICAL LEFT SHIFT REG2,4 PLACES
      ADM,2,1        REG            ADD SIGN TO REGISTER 2
      MBL,2,2                       SHIFT BYTE LEFT
      ADI,2          #00FF          LEAVE CALIBRATE BITS ,COUNTER HI
      ODD,2,3                       OUTPUT REG 2 TO MODAC PORT 33
LOP5  IDD,3,1                       INPUT PORT31 INTO REG3
      TBRB,3,15      LOP5           STAY IN LOOP UNTIL BUSY GOES HI
      LBRB,4,14      LOP6           BIT14 IN REG 4 HI,XFER TO LOP6
LOP1  IDD,4,1                       INPUT PORT 31 TO REG 4
LOP6  ABR,1,15                      INCREMENT REGISTER 1
      LDM,2,1        REG            LOAD BCD VALUE INTO REG 2
      MBL,2,2                       SHIFT BYTE IN REG 2 TO LEFT
      ADI,2          #00FF          TAKE INDEX BIT HI,LEAVE CALIBRATE HI
LOP2  IDD,3,1                       INPUT PORT 31 INTO REG 3
      TBRB,3,15      LOP4           JUMP TO ERROR LOOP IF NOT BUSY
      XOR,3,4                       EXCLUSIVE OR REG 3&4,RESULT IN 3
      TOR,3,3                       TAKE ONE'S COMPLIMENT OF REG 3
      TBRB,3,14      LOP2           BIT 14=0 WHEN DATA STROBE SWITCHES
      ODD,2,3                       OUTPUT REG 2 TO MODAC PORT 33
      CRI,1          6              COMPARE REG 1 TO 6
      BLNS,0         LOP1           BRANCH BACK IF REG 1.LT.6
LOP4  LDI,2          #00FF          LOAD ALL HI INTO 2
      ODD,2,3                       SEND ALL OUTPUTS HI
LOP3  IDD,3,1                       INPUT PORT 31 TO REG 3
      TOR,3,3                       TAKE ONE'S COMPLIMENT OF REG 3
      TBRB,3,15      LOP3           BRANCH BACK IF BUSY
      FINI
  200 CONTINUE
C
C     CHECK FOR POSITION FINISHED
C     HANG HERE UNTIL ALL POSITIONS ARE REACHED
C
  300 CONTINUE
      JSTEP=0
      DO 400 NAX=1,NAXIS
```

```
      NCOUNT=NAX-1
      INLINE
      LDM,2          NCOUNT         LOAD THE COUNTER SELECT CHANL
      LLS,2,6                       LOGICAL LEFT SHIFT REG2,6 PLACES
      ADI,2          #000F          LEAVE CALIBRATE BITS HI
      ODD,2,3                       OUTPUT REG 2 TO MODAC PORT 33
      XOR,2,2                       ZERO REG 2,IT WILL BE HI ORDER OF WRD
      IDD,3,1                       INPUT COUNT NO INTO REG 2,3
      STMD,2         KSTEPS         STORE COUNT POSITION IN MEMORY
      LDI,2          #00FF          SEND PROPER OUTPUTS HI
      ODD,2,3                       RESET PORT 33
      FINI
      JSTEPS=(XOLD(NAX)+.5*STEPSZ)/STEPSZ
  350 NSTEPS(NAX)=JSTEPS -KSTEPS
      IF(NSTEPS(NAX).LT.65535)GO TO 360
      KSTEPS=KSTEPS+65536
      GO TO 350
C     COUNTER ONLY GOES TO 65535,THEN STARTS BACK OVER AT 0
C     WRITE(5,390)NAX,JSTEPS,KSTEPS
  360 JSTEP=JSTEP+NSTEPS(NAX)*NSTEPS(NAX)
  390 FORMAT(1X,3I6)
  400 CONTINUE
C     IF(JSTEP.NE.0)WRITE(5,410)
  410 FORMAT(' TRANSLATOR ERROR ')
      IF(JSTEP.GT.2)GO TO 1
  420 CONTINUE
      RETURN
      END
TOTAL RECORDS WRITTEN =    435/      66
EXIT
$AVR CI 4
$END  LIST
```

Appendix E

PROGRAM SQRWLD

The program SQRWLD (written in assembly language) controls the entire inspection process of the seam weld in the steel sheath for the superconducting cable. The program controls the calibration of all instrumentation (including the magnetic tape recorder), and the recording of the calibration data. It provides prompts to the operator to remind him to perform the necessary steps in the correct order to perform the examination. The program controls the recording of raw data on magnetic tape and controls the calculated properties that are displayed on the strip-chart recorder as the test is conducted. It also allows the playback of the magnetic tape through the microcomputer in the transceiver unit to determine additional properties not determined during the on-line examination. The program provides operator prompts to control the calibration and operational procedure required to perform the manual inspection for weld repair.

The program performs the following functions, depending on the position of the switch on the computer module or the remote control box. A remote control box was used to select the test functions for this particular examination. The switches on the computer module in the multiple-frequency eddy-current instrument were used to select the correct PROM for the particular eddy-current probe being used.

Switch position	Function
0	Main running loop
1	Read tape
2	Read standard tube
3	Display raw readings
4	Display calculated readings
5	Perform and display calibrations
6	Inspect square conductors
7	Calibrate the digital-to-analog converters and recorder

Position 0 is used for the automated on-line examination of the superconductor cable (see Appendix F). In position 0, the microcomputer controls the fixed locations across the scan path where eddy-current readings are taken. (The readings are synchronized with the mechanical scanning system by a pulse generated from the crankshaft drive mechanism.) The program also maintains the various readings in separate data arrays. This allows the output data to be represented in the form of continuous scans at fixed axes on the weld and heat-affected zones.

Position 1 provides a means to read the magnetic tape back through the microcomputer in the transceiver unit. The operator can designate other parameters to be calculated from the raw data and displayed on the analog recorder (Appendix F).

Position 2 is used for calibration and calibration corrections (see Appendix F).

Position 3 provides a means to observe the raw phase and magnitude data on the video terminal during the initial setup. This position is used to check the phase detectors and the bandpass amplifiers in the multifrequency eddy-current instrument (see Appendix F).

Position 4 provides a means to observe calculated data on the video terminal. This function was not used for this examination.

In position 5, the video terminal displays signals that are generated by the calibrator module and fed through the bandpass amplifiers and phase detectors. This allows the operator a means to check the calibration of the multifrequency eddy-current instrument (see Appendix F).

Position 6 is used for the manual inspection of the superconductor cable (see Appendix G).

Position 7 is used to check the operation of the digital-to-analog converters and to check the calibration of the analog recorder (see Appendix F).

```
                         TITLE 'SQRWLD PROGRAM VERSION 10,26 APRIL 83'
                         NAME     SQRWLD
                         LIST   B,G,O,T
               ;         NLIST   I,M,S,T
                         ORG 0800H          START PROGRAM IN SECOND PROM.
               ; SYMBOL DEFINITIONS
               ;
               ;  DEFINE PORT ADDRESSES
               ;
00F7           PORT1        EQU 0F7H          PORT 1 CONTROL WORD ADDRESS
00F4           PORT1A       EQU 0F4H          PORT1A ADDRESS
00F5           PORT1B       EQU 0F5H          PORT1B ADDRESS
00F6           PORT1C       EQU 0F6H          PORT1C ADDRESS
00EF           PORT2        EQU 0EFH          PORT 2 CONTROL WORD ADDRESS
00EC           PORT2A       EQU 0ECH          PORT2A ADDRESS
00ED           PORT2B       EQU 0EDH          PORT2B ADDRESS
00EE           PORT2C       EQU 0EEH          PORT2C ADDRESS
00DF           PORT3        EQU 0DFH           PORT3 CONTROL WORD ADDRESS
00DC           PORT3A       EQU 0DCH           PORT3A ADDRESS
00DD           PORT3B       EQU 0DDH           PORT3B ADDRESS
00DE           PORT3C       EQU 0DEH           PORT3C ADDRESS
007E           APDATA       EQU 07EH          ARITHMETIC PROCESSOR DATA PORT
007F           APSTS        EQU 07FH           ARITHMETIC PROCESSOR CONTROL/STATUS ADDR
00FB           USSTS        EQU 0FBH           USART CONTROL/STATUS ADDRESS
               ;
               ;  MATH SUBROUTINES FOR THE COMP 9 ARE STORED AS PUBLIC.ANY ROUTINE
               ;  CAN BE CALLED USING AN 'EXTRN' STATEMENT.
               ;
               ;EXTRN           ACOS,ASIN,ATAN,ATANA,BIDEC,BIDECF
                EXTRN           CHSD,CHSDA,CHSF,CHSFA,CHSS,CHSSA,COS,COSA
                EXTRN           DADD,DADDA,DADDB,DDIV,DDIVA,DDIVB,DECNO
                EXTRN           DMUL,DMULA,DMULB,DMUU,DMUUA,DMUUB,DSUB,DSUBA,DSUBB
                EXTRN           EXP,EXPA,EXP10,FADD,FADDA,FADDB,FDIV,FDIVA,FDIVB
                EXTRN           FIXD,FIXDA,FIXS,FIXSA,FLTD,FLTDA,FLTS,FLTSA
                EXTRN           FMUL,FMULA,FMULB,FSUB,FSUBA,FSUBB,LN,LNA,LOG,LOGA
                EXTRN           MDAD,POPD,POPS,PTOD,PTOS,PUPI,PWR,PWRA,PWRB
                EXTRN           SADD,SADDA,SADDB,SDIV,SDIVA,SDIVB,SIN,SINA
                EXTRN           SMUL,SMULA,SMULB,SMUU,SMUUA,SMUUB,SQRT,SQRTA
                EXTRN           SSUB,SSUBA,SSUBB,TAN,TANA,TOS2,TOS4
                EXTRN           WRT2,WRT4,XCHD,XCHS
                EXTRN           CROUT,COPDT,GETCM,PRINT,PRINTF,EPRNT,FPRNT,ZERO
                EXTRN           GETNM,CO,NMOUT,ECHO,GETCH,GETHX
               ;
               ;  PROM DATA ASSIGNMENTS
               ;INITIAL CORRECTION FACTOR ASSIGNMENTS,4 BYTES EACH STARTING AT CRFRO
               ;AS OFSET1,SLOP1,OFST2,SLOP2...STORED AS FLOATING BINARY;EX HI MD LO.
               ;COEFICIENT DATA,4 BYTES EACH STORED IN FLOATING BINARY AS EX,HI-LO.
               ;STARTING AS C10,C11,C12..C1N;C20,C21,C22...C2N.THERE ARE UP TO 15
               ;PER PROPERTY,SIX PROPERTIES.STARTING ADDRESS IS COEDT.THE NUMBER OF
               ;COEFFICIENTS USED FOR EACH PROPERTY IS STORED BEFORE EACH SET.
               ;
               ;CONSTANTS ARE SET
               ;
0000           RDGOF        EQU 0H             READING OFFSET IS SET (ONLY ONE SET NOW).
```

```
003D          COEOF     EQU 03DH          COEFFICIENT OFFSET(15 COEF EA *4 BY +1)
0001          NRDG      EQU 001H          NRDG=2**N=NUMBER OF RDGS PER CHANNEL=1
0006          NCHA      EQU 06H           NCHA=NUMBER OF CHANNELS TO BE READ
0004          NCALC     EQU 04H           NCALC=NUMBER OF CALIBRATION RDGS/CHANNEL
0002          PROPN     EQU 02H           PROPN=NUMBER OF PROPS TO BE CALCULATED
0080          PRT1O     EQU 080H          PRT1O=CONTROL WORD FOR PORT1 OUTPUT MODE
0099          PRT1I     EQU 099H          PRT1I=CONTROL WORD FOR PORT1 INPUT MODE
0093          PRTS      EQU 093H          CONTROL WORD FOR A INPUT,
              ;                           B INPUT (C C1-3 INPUT,C4-7 OUT)
000D          CR        EQU 0DH           DEFINE CARRIAGE RETURN <CR>
000A          LF        EQU 0AH           DEFINE LINE FEED <LF>
0009          POSCHN    EQU 09H           NUMBER OF POSITION CHANNELS+1
              ;
              ; RAM ADDRESS DEFINITIONS
              ;
3C10          TRMCT     EQU 03C10H       SINGLE BYTE COUNT OF NUMBER OF TERMS
3C11          CHANO     EQU TRMCT+1       CALIBRATION CHANNEL NUMBER
3C12          DSPAD     EQU CHANO+1      ADDRESS FOR THE FRONT PANEL DISPLAY,2 BYTES
3C14          PCALN     EQU DSPAD+2      COUNTER FOR THE NUMBER OF PROPERTY CALCS.
3C15          PCAL1     EQU PCALN+1      NUMBER OF FIRST PROPERTY TO BE CALCULATED.
3C16          PCAL2     EQU PCAL1+1      NUMBER OF 2ND PROPERTY TO BE CALCULATED.
3C17          PCAL3     EQU PCAL2+1      NUMBER OF THIRD PROPERTY TO BE CALCULATED.
3C18          PCAL4     EQU PCAL3+1      NUMBER OF FOURTH PROPERTY TO BE CALCULATED.
3C19          CONTN     EQU PCAL4+1H      2 BYTES,COUNT NUMBER FOR MEASUREMENTS
3C1B          RAWDA     EQU CONTN+02      RAW RDGS,4 BYTES/CHNL,MG1,PH1,MG2.. HI-LO
              ;         CRDAT,1L00 CORRECTED RDGS,4 BYTS EA;MAG1,PH1,MAG2;EX,HI-LO
3C35          CRFTA     EQU RAWDA+1AH    CORR FACTOR,4BYTES EA,OFS1,SLOP1,OFS2,...
3C65          DACOFS    EQU CRFTA+30H    PROPN WORDS 2BY EA(HI-LO)16 BIT FIXED DAC O
3C79          RDGDA     EQU DACOFS+2*POSCHN+2     4 BY EA(EX HI-LO),RDG11 RDG21..RDGC
                                         ;RDGDA=288 BYTES TOTAL (0120H).
3D99          CALRD     EQU RDGDA+0120H   CALIBRATION READINGS,060H,96D BYTES
3DF9          SUMXX     EQU CALRD+060H    4 BYTES,SUM OF CALRD(NCALC)**2
3DFD          SUMX      EQU SUMXX+04H     4 BYTES,SUM OF CALRD(NCALC)
3E01          SUMYY     EQU SUMX+04H      4 BYTES,SUM OF CALO(NCALC)**2
3E05          SUMY      EQU SUMYY+04H     4 BYTES,SUM OF CALO(NCALC)
3E09          SUMXY     EQU SUMY+04H      4 BYTES,SUM OF CALRD(NCALC)*CALO(NCALC)
3E0D          XBAR      EQU SUMXY+04H     4 BYTES,SUM OF CALRD(NCALC)/NCALC
3E11          YBAR      EQU XBAR+04H      4 BYTES,SUM OF CALO(NCALC)/NCALC
3E15          PROFA     EQU YBAR+04H      16H BYTES,CALCULATED PROPERTIES
3E2B          CLOADR    EQU PROFA+16H     1 BYTE, BASE ADR OF INITIAL CAL RDGS
3E2C          VOLNEW    EQU CLOADR+1      NEW STANDARD RDGS,24 BYTES
3E44          VSTDYT    EQU VOLNEW+18H    BYTE TO SHOW THAT TUBE STANDARD HAS BEEN R
3E45          POSCH     EQU VSTDYT+1      POSITION CHANNEL ,2 BYTES
3E47          DAOLD     EQU POSCH+2       OLD ADC VALUES,2*(POSCHN+1) BYTES
3E5B          POSNAD    EQU DAOLD+2*POSCHN+2     NEW POSITION CHN RDG ADDR
3E5D          POSOAD    EQU POSNAD+2      OLD POSITION CHANNEL RDG ADDR
3E5F          DACCH     EQU POSOAD+2      ADC CHANNEL NUMBER BYTE
3E60          ALARM     EQU DACCH+1       ALARM BYTE
3E61          THMIN     EQU ALARM+1       MIN THICKNESS VALUE,2 BYTES
3E63          BYCNT     EQU THMIN+2H     2 BYTES,BYTE COUNT FOR RDG TAPE
3E65          FILECT    EQU BYCNT+2       1 BYTE,FILE COUNTER
3E66          COILNT    EQU FILECT+1      2 BYTES,COIL NUMBER FROM TAPE
3E68          RECNO     EQU COILNT+2      RECORD NO FROM TERMINAL
3E6A          NPROP     EQU RECNO+2       1 BYTES,NO OF PROP TO BE CALCULATED
```

```
3E6C                    RCNT       EQU NPROP+2      ONE BYTE,NO. OF TAPE READINGS TO BE MADE
                        ;          RAM ADDRESS FOR TAPE READBACK WITH LOST DATA  MUST HAVE
                        ;          A 2K RAM
3800                    TAPDAT     EQU 3000H        TAPE READBACK DATA 400 BYTES
                        ;THREE FREQ PORTSET-UP
0800  3E 99             PRTSU      MVI A,PRT1I       LOAD PROGRAM WORD FOR A&C INPUT,B OUTPUT
0802  D3 F7                        OUT PORT1        SEND TO PORT 1
0804  3E 90                        MVI A,090H       LOAD PROGRAM WORD,A=INPUT,B&C=OUTPUT
0806  D3 EF                        OUT PORT2        SEND TO PORT2.
0808  3E 07                        MVI A,007H        LOAD 0000/0111 INTO A,CHART OFF,
080A  D3 ED                        OUT PORT2B        TURN CALIBRATOR RELAYS OFF
080C  3E 70                        MVI A,070H       SET MAG TAPE READ,WRITE,DAC LATCH HI
080E  D3 EE                        OUT PORT2C       LEAVE STROBE LINES HI
0810  3E 93                        MVI A,PRT3        LOAD WORD FOR A OUT, B INPUT,C I/O
0812  D3 DF                        OUT PORT3
                        ;          COPY INITIAL CORRECTION FACTORS INTO RAM
0814  21 52 12                     LXI H,CRFRO       ADDR OF CORR FAC IN ROM IN HL
0817  01 95 12                     LXI B,DAFAC-1     ADDR OF LAST BYTE TO BE COPIED
081A  11 35 3C                     LXI D,CRFRA       ADDR WHERE CORR FAC IS COPIED TO IN RAM
081D  CD 00 00      E              CALL COPDT        COPY DATA SUB CALL,START IN HL.
0820  3E 00                        MVI A,0           LOAD 0 INTO A
0822  32 15 3C                     STA PCAL1         SET 1ST PROP TO BE CALCULATED
0825  3E 01                        MVI A,1           LOAD 1 INTO A
0827  32 16 3C                     STA PCAL2         SET 2ND PROP TO BE CALCULATED
082A  3E 02                        MVI A,2           LOAD 2 INTO A
082C  32 17 3C                     STA PCAL3         SET 3RD PROP TO BE CALCULATED
082F  3E 03                        MVI A,3           LOAD 3 INTO A
0831  32 18 3C                     STA PCAL4         SET 4TH PROP TO BE CALCULATED
                        ;
                        ;  READ THE TEN'S BCD SWITCH TO SEE WHICH SET OF INITIAL
                        ;  CALIBRATION READINGS TO USE IN THIRD PROM.
                        ;
0834  DB DE                        IN PORT3C         READ BCD SWITCHES IN REMOTE 3 FREQ INST
0836  E6 0F                        ANI 0FH           ONLY LOOK AT FIRST 4 BITS
0838  07                           RLC               MULTIPLY BY 2, GET OFFSET FROM ORG
0839  C6 18                        ADI 18H           ADD ORG, WE HAVE HI BYTE OF CAL0 ADDR
083B  32 2B 3E                     STA CL0ADR        STORE THIS HI BYTE
                        ;
                        ; BE SURE ALL TAPE CONTROL LINES ON CONN C8 ARE FALSE
                        ;
083E  3E 20                        MVI A,020H        HOLD GNF(PORT3C5),0010/0000,HI
0840  D3 DE                        OUT PORT3C
                        ;          DECISION BRANCH POINT FOR 3 FREQUENCY INSTRUMENT
                        ;          FRONT PANEL SWITCHES ALLOWS CONTROL OF ACTION
                        ;          TO BE TAKEN.ACTION SUMMARY IS:
                        ;          0.MAIN RUNNING LOOP-RECALIBRATE,RECORD
                        ;                               RUN/RAW,RECORD,CALC UNTIL .NE.0
                        ;                               RECALIBRATE,RECORD,STOP
                        ;          1.READ TAPE
                        ;          2.READ STANDARD TUBE
                        ;          3.DISPLAY RAW READINGS
                        ;          4.DISPLAY CALCULATED READINGS
                        ;          5.PERFORM AND DISPLAY CALIBRATIONS
                        ;          6.INSPECT SQUARE CONDUCTORS
```

```
                              ;          7.CALIBRATE THE DIG TO ANALOG CONVERTERS & RECORDER
                              ;
0842  DB EC                   MAIND      IN PORT2A         INPUT PORT2A,LOOK AT FRONT PANEL SWITCHES
0844  E6 07                              ANI  07H          SET STATUS BITS
0846  32 12 3C                           STA DSPAD         STORE IN RAM
0849  CA CB 08                           JZ RUNM           IF SWITCHES EQ 0,JUMP TO MAIN RUN LOOP
084C  FE 01                              CPI 001H          TEST FOR READ TAPE
084E  CA C9 0F                           JZ RWCLTP         JUMP TO READ TAPE ROUTINE IF 2A.EQ.1
0851  FE 02                              CPI 002H          TEST FOR READ STANDARD
0853  CA DA 0E                           JZ RDSTD          CALL READ STANDARD ROUTINE
0856  FE 03                              CPI 003H          TEST FOR RAW RDGS LOOP
0858  CC 72 08                           CZ RADWD          CALL RAW READINGS ROUTINE
085B  FE 04                              CPI 004H          TEST FOR CAL PROPS LOOP
085D  CC 98 08                           CZ CALPRO         CALL CALCULATED PROPERTIES ROUTINE
0860  FE 05                              CPI 005H          TEST FOR CALIBRATIN LOOP
0862  CC 0A 0D                           CZ CALIB          CALL CALIBRATION LOOP
0865  FE 06                              CPI 006H          TEST FOR WELD REPAIR LOOP
0867  CA 9E 09                           JZ RUNWS          JUMP TO RUN LOOP FOR WELD REPAIR
086A  FE 07                              CPI 07H           CALIBRATION PROGRAM FOR DIGITAL
086C  CC E4 0D                           CZ DACALB         TO ANALOG CONVERTERS.
086F  C3 42 08                           JMP MAIND         LOOP BACK TO READ FRONT PANEL AGAIN
                              ;
                              ;CRAW READING ROUTINE
                              ;
0872  06 01                   RADWD      MVI B,NRDG        NUMBER OF READINGS/CHANNEL IN B
0874  0E 06                              MVI C,NCHA        NUMBER OF CHANNELS IN C
0876  CD AE 0A                           CALL SMDAT        AD CONVERTOR READ,DATA SUMMED
0879  3A 12 3C                           LDA DSPAD         SEE WHERE WE WERE CALLED FROM
087C  E6 01                              ANI 01            CONTINUE NORMALY FOR ODD FUNCTIONS
087E  C8                                 RZ                IF IT IS 0 OR 4, WAIT UNTIL RDGS ARE WRITT
                              ;                            ON MAG TAPE BEFORE FLOATING & CORRECTING
087F  06 06                   FLTCOR     MVI B,NCHA        NUMBER OF CHANNELS LOADED IN B
0881  CD 0F 0A                           CALL CRFAC        READINGS ARE CORRECTED
0884  21 1D 3C                           LXI H,RAWDA       LOAD ADDRESS OF RAW DATA IN HL
0887  16 06                              MVI D,NCHA        LOAD NO OF CHANNELS INTO D
0889  1E 01                              MVI E,01H         ONE LINE TO BE PRINTED LOADED INTO E
088B  01 04 09                           LXI B,0904H       LOAD FIXED FORMAT,9 DIGS,4 AFTER DEC
088E  3A 12 3C                           LDA DSPAD         LOAD DISPLAY NO FROM RAM
0891  FE 03                              CPI 003H          SEE IF WE ARE IN RAW RDG LOOP
0893  CC 09 08         E                 CZ FPRNT          PRINT RAW READINGS IF SO
0896  AF                                 XRA A             ZERO ACCUMULATOR
0897  C9                                 RET               RETURN TO CALLING ROUTINE
                              ;
                              ;          CALCULATE PROPERTIES ROUTINE
                              ;
0898  CD 72 08                CALPRO     CALL RADWD        ENTRY POINT FOR FCTN 4
089B  CD 7F 08                CALFR      CALL FLTCOR       FLOAT AND CORRECT RAW RDGS
089E  3E 02                              MVI A,PROPN       NUMBER OF PROPERTIES IN A
08A0  32 14 3C                           STA PCALN         STORED IN RAM
08A3  21 15 3E                           LXI H,PROPA       PROPERTY ADDRESS IN HL
08A6  E5                      CALPRL     PUSH H            HL STORED ON STACK
08A7  21 14 3C                           LXI H,PCALN       ADDRESS OF PROP NO CAL IN HL
08AA  4E                                 MOV C,M           NUMBER OF PROPS LEFT TO BE CAL IN C
08AB  06 00                              MVI B,0           BC=NO OF PROPS LEFT TO BE CAL
```

```
08AD  09                    DAD B            HL = PCAL(N)=PROP NO TO BE CAL
08AE  7E                    MOV A,M          LOADED INTO A
08AF  CD 38 0A              CALL POLSM       CALCULATE POLYNOMIAL FOR PROP1
08B2  E1                    POP H            ADDR TO STORE PROPS RESTORED TO HL
08B3  CD 00 00    E         CALL TOS4        TOP OF APSTACK STORED IN RAM
08B6  23                    INX H            HL INCREMENTED FOR NEXT CAL PROP
08B7  3A 14 3C              LDA PCALN        LOAD PROP CAL NO INTO A
08BA  3D                    DCR A            DECREMENT PROP CAL COUNTER
08BB  32 14 3C              STA PCALN
08BE  C2 A6 08              JNZ CALPRL       LOOP BACK IF NOT DONE
08C1  3A 12 3C              LDA DSPAD        LOAD THE FRONT PANNEL CONTROL DATA
08C4  FE 04                 CPI 004H         SEE IF WE ARE IN CAL PROP LOOP
08C6  CC 2F 0F              CZ PCALP         PRINT CALCULATED PROPERTIES ON TERMINAL
08C9  AF                    XRA A            ZERO ACCUMULATOR
08CA  C9                    RET              RETURN TO CALLING ROUTINE
                      ;
                      ;     RUNM             MAIN RUNNING LOOP
                      ;       RECALIBRATE,RUN UNTIL FRONT PANEL SWITCH IS MOVED
                      ;     FROM 0,THEN MAKE A SET OF CALIBRATION READINGS.ALL
                      ;     DATA IS RECORDED ON MAGNETIC TAPE.
                      ;
08CB  21 00 00        RUNM  LXI H,0000H      ZERO BYTE COUNT FOR MAG TAPE WRITES
08CE  22 63 3E              SHLD BYCNT       STORE BYTE COUNT IN RAM
08D1  22 19 3C              SHLD CONTN       STORE READING COUNT NO IN RAM
08D4  3E 88                 MVI A,PRT10      SET PORT1 FOR OUTPUT TO TAPE
08D6  D3 F7                 OUT PORT1        SEND CONTROL WORD
08D8  CD 6C 11              CALL WRTID       WRITE IDENTIFICATION ON TAPE
08DB  CD 00 00    E         CALL CROUT       CARRIAGE RETURN ,LINE FEED
08DE  3E 99                 MVI A,PRT1I      SETUP FOR RECAL LOOP
08E0  D3 F7                 OUT PORT1
08E2  CD 99 0B              CALL RECAL       CALL RECALIBRATION PROGRAM
08E5  01 99 3D              LXI B,CALRD      ADDRESS OF CALIBRATION RDGS IN BC
08E8  11 F8 3D              LXI D,CALRD+05FH 60H BYTES OF CALB RDGS TO BE STORED
08EB  3E 88                 MVI A,PRT10      SET PORT1 FOR OUTPUT TO TAPE
08ED  D3 F7                 OUT PORT1        SEND CONTROL WORD
08EF  CD 57 0F              CALL WRTAP       DATA FROM BC THRU DE STORED
08F2  01 35 3C              LXI B,CRFRA      ADDR OF CORRECTION FACTOR IN BC
08F5  11 64 3C              LXI D,CRFRA+02FH LAST CORR FACT ADDR IN DE
08F8  CD 57 0F              CALL WRTAP       WRITE ON TAPE
08FB  3E 99                 MVI A,PRT1I      SETUP FOR RECAL LOOP
08FD  D3 F7                 OUT PORT1
08FF  21 45 3E              LXI H,POSCH      LOAD HL WITH CHANNEL POSITION ADDR
0902  CD 57 09              CALL RESET       RESET ALL CHANNELS,START RDGS AFTER STROBE
0905  CD 72 08        RUNM1 CALL RADWD       MAKE RAW RDGS, NO CORR YET
0908  01 1D 3C              LXI B,RAWDA+2    ADDR OF NON ZERO PART OF 1ST RAW DAT.
090B  11 32 3C              LXI D,RAWDA+17H  WRITE FROM COUNT NO THRU RAW DAT
090E  3E 88                 MVI A,PRT10      SET PORT1 FOR OUTPUT TO DAC
0910  D3 F7                 OUT PORT1        CONTROL WORD SENT
0912  CD 78 0F              CALL WRTAPF      STORE RAW RDGS ON TAPE
0915  CD 98 08              CALL CALPR       CALC PROPS FROM RDGS ALREADY TAKEN
0918  CD FF 0C              CALL DACON1      DEFECT CALCULATIONS AVERAGED & SENT TO DAC
091B  CD 4B 0E              CALL DACON2      SELECT MIN TH,SEND TO DAC IF POSCH=0
                            CALL OUTLIF      SEND MINIMUM LIFTOFF TO TERM EVERY F TIMES
091E  21 45 3E              LXI H,POSCH      LOAD HL WITH CHANNEL POSITION ADDR
```

```
0921  35                      DCR M              DECREMENT CHANNEL POSITION INDEX IN MEM
0922  FC 57 09                CM RESET           RESET POS CH,INR COUNT NO,WAIT FOR NEXT ST
0925  3E 99                   MVI A,PRT1I        SET PORT1 BACK FOR INPUT
0927  D3 F7                   OUT PORT1          CONTROL WORD SENT
0929  C3 05 09                JMP RUNN1          LOOP BACK FOR ANOTHER RUN
092C  C1             STOPR    POP B              POP STACK TO GET BACK CORRECT
092D  01 19 3C                LXI B,CONTN        ADDR OF COUNT NO
0930  11 1A 3C                LXI D,CONTN+1      LAST BYTE OF COUNT NO.
0933  CD 57 0F                CALL WRTAP         STORE ON TAPE,NO INCREMENT
0936  3E 99                   MVI A,PRT1I        SETUP FOR CALIBRATION LOOP
0938  D3 F7                   OUT PORT1
093A  CD 0A 0B                CALL CALIB         MAKE ANOTHER CALIBRATION
093D  3E 88                   MVI A,PRT1O        SET PORT1 FOR OUTPUT TO TAPE
093F  D3 F7                   OUT PORT1          SEND CONTROL WORD
0941  01 99 3D                LXI B,CALRD        ADDRESS OF CALIBRATION RDGS IN BC
0944  11 F0 3D                LXI D,CALRD+05AH   90H BYTES OF CALB RDGS TO BE STORED
0947  CD 57 0F                CALL WRTAP         DATA FROM BC THRU DE STORED
094A  CD 36 11                CALL DUMPOF        DUMP THE REST OF THE BUFFER ON TAPE
094D  CD 4E 11                CALL WEOF          WRITE END OF FILE ON TAPE
0950  3E 99                   MVI A,PRT1I        SET PORT 1 FOR INPUT
0952  D3 F7                   OUT PORT1          SEND CONTROL WORD
0954  C3 00 00       E        JMP GETCH          RETURN TO MONITOR
                     ;
0957  36 09          RESET    MVI M,POSCHN       RESET POSITION CHANNEL NUMBER
0959  DB EC                   IN PORT2A          LOOK AT FRONT PANEL CONTROL SWICHES
095B  E6 07                   ANI 07H            DUMP SPEED,DIR SELECTION BITS
095D  C2 2C 09                JNZ STOPR          STOP RUN IF NOT ZERO
0960  DB EC                   IN PORT2A          INPUT CHANNEL SYNC BIT
0962  E6 08                   ANI 08H            AND WITH 0000/1000,SYNC BIT
0964  C2 57 09                JNZ RESET          HANG IN LOOP UNTIL PROBE STARTS ACROSS
0967  DB EC                   IN PORT2A          LOOK AT 2A-CHECK FOR REZERO
0969  E6 40                   ANI 040H           SEE IF 0100/0000 IS HI
096B  C4 00 0D                CNZ REZRO          RESET DAC OFFSETS IF HI
096E  2A 19 3C                LHLD CONTN         LOAD COUNT NUMBER FROM RAM
0971  23                      INX H              INCREMENT COUNT NUMBER
0972  22 19 3C                SHLD CONTN         STORE BACK IN RAM
0975  01 19 3C                LXI B,CONTN        LOAD COUNT NO ADDR INTO BC
0978  11 1A 3C                LXI D,CONTN+1      END OF COUNT NO IN DE
097B  CD 57 0F                CALL WRTAP         WRITE ON MAG TAPE
097E  21 00 3E                LXI H,ALADD        LOAD ADDRESS OF ALARM BYTE INTO HL
0981  7E                      MOV A,M            LOAD ALARM BIT(B6=0100 0000)FROM RAM
0982  F6 37                   ORI 037H           OR WITH 0011 0111,BITS FOR CALIBRATOR
0984  D3 ED                   OUT PORT2B         SET ALARM ACCORDING TO B6
0986  AF                      XRA A              ZERO ACC
0987  77                      MOV M,A            RESET ALARM BIT
0988  21 59 3E                LXI H,DAOLD+2*POSCHN
098B  22 5B 3E                SHLD POSADD        STORED FOR NEW RDGS ADDR
098E  21 40 3E                LXI H,DAOLD+1      LO ORDER BYTE OF 1ST RDG
0991  22 5D 3E                SHLD POSOLD        STORED FOR OLD FROM RDGS
0994  AF                      XRA A              ZERO ACCUMULATOR
0995  32 0F 3E                STA DACCH          ZERO DAC CHANNEL NUMBER
0998  3E 0F                   MVI A,0FH          LOAD BACK MAX VALUE INTO A
099A  32 01 3E                STA TRMHI          STORE AS HI ORDER MIN TR VALUE
099D  C9                      RET
```

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                        ;
                        ;           RUNMS               RUNNING LOOP FOR WELD REPAIR SAMPLES
                        ;             RECALIBRATE,RUN UNTIL FRONT PANEL SWITCH IS MOVED
                        ;           FROM 6,THEN MAKE A SET OF CALIBRATION READINGS.ALL
                        ;           DATA IS RECORDED ON MAGNETIC TAPE.
                        ;
099E  21 00 00          RUNMS       LXI H,0000H         ZERO BYTE COUNT FOR MAG TAPE WRITES
09A1  22 63 3E                      SHLD BYCNT          STORE IN RAM
09A4  3E 88                         MVI A,PRT1O         SET PORT1 FOR OUTPUT TO TAPE
09A6  D3 F7                         OUT PORT1           SEND CONTROL WORD
09A8  CD 6C 11                      CALL WRTID          WRITE IDENTIFICATION ON TAPE
09AB  CD 00 00      E               CALL CROUT          CARRIAGE RETURN ,LINE FEED
09AE  3E 99                         MVI A,PRT1I         SETUP FOR RECAL LOOP
09B0  D3 F7                         OUT PORT1
09B2  CD 99 08                      CALL RECAL          CALL RECALIBRATION PROGRAM
09B5  01 99 3D                      LXI B,CALRD         ADDRESS OF CALIBRATION RDGS IN BC
09B8  11 F8 3D                      LXI D,CALRD+05FH    60H BYTES OF CALB RDGS TO BE STORED
09BB  3E 88                         MVI A,PRT1O         SET PORT1 FOR OUTPUT TO TAPE
09BD  D3 F7                         OUT PORT1           SEND CONTROL WORD
09BF  CD 57 0F                      CALL WRTAP          DATA FROM BC THRU DE STORED
09C2  01 35 3C                      LXI B,CRFRA         ADDR OF CORRECTION FACTOR IN BC
09C5  11 64 3C                      LXI D,CRFRA+02FH    LAST CORR FACT ADDR IN DE
09C8  CD 57 0F                      CALL WRTAP          WRITE ON TAPE
09CB  3E 99                         MVI A,PRT1I         SETUP FOR RECAL LOOP
09CD  D3 F7                         OUT PORT1
09CF  21 00 00                      LXI H,0000          ZERO HL FOR COUNT NUMBER
09D2  22 19 3C                      SHLD CONTN          STORE IN RAM
09D5  CD 72 08          RUNMS1      CALL RADWD          MAKE RAW RDGS, NO CORR YET
09D8  2A 19 3C                      LHLD CONTN          LOAD COUNT NUMBER FROM RAM
09DB  23                            INX H               INCREMENT COUNT NUMBER
09DC  22 19 3C                      SHLD CONTN          STORE BACK IN RAM
09DF  01 1D 3C                      LXI B,RAWDA+2       ADDR OF NON ZERO PART OF 1ST RAW DATA
09E2  11 32 3C                      LXI D,RAWDA+17H     WRITE FROM COUNT NO THRU RAW DAT
09E5  3E 88                         MVI A,PRT1O         SET PORT1 FOR OUTPUT TO DAC
09E7  D3 F7                         OUT PORT1           CONTROL WORD SENT
09E9  CD 7B 0F                      CALL WRTAPF         STORE RAW RDGS ON TAPE
09EC  CD 7F 08                      CALL FLTCOR         FLOAT AND CORRECT RAW RDGS
09EF  3E 04                         MVI A,PROPN+2       NUMBER OF PROPS. FOR SQRWLD IN A
09F1  32 14 3C                      STA PCALN           STORED IN RAM
09F4  21 15 3E                      LXI H,PROPA         PROPERTY ADDRESS IN HL
09F7  CD A5 08                      CALL CALPRL         CALCULATE THE PROPERTIES
09FA  CD 8A 0E                      CALL DACONS         CONVERT TO ANALOG FOR WELD REPAIR
09FD  3E 99                         MVI A,PRT1I         SET PORT1 BACK FOR INPUT
09FF  D3 F7                         OUT PORT1           CONTROL WORD SENT
0A01  DB EC                         IN PORT2A           LOOK AT FRONT PANEL CONTROL SWICHES
0A03  E6 07                         ANI 07H             DUMP SPEED,DIR SELECTION BITS
0A05  FE 06                         CPI 006H            SEE IF VAL IS STILL 06H
0A07  CA D5 09                      JZ RUNMS1           STAY IN LOOP IF IT IS
0A0A  3E 88                         MVI A,PRT1O         SET PORT1 FOR OUTPUT TO TAPE
0A0C  D3 F7                         OUT PORT1           SEND CONTROL WORD
0A0E  01 19 3C                      LXI B,CONTN         ADDR OF COUNT NO
0A11  11 1A 3C                      LXI D,CONTN+1       LAST BYTE OF COUNT NO.
0A14  CD 57 0F                      CALL WRTAP          STORE ON TAPE
0A17  3E 99                         MVI A,PRT1I         SETUP FOR CALIBRATION LOOP
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0A19  D3 F7                     OUT PORT1
0A1B  CD 0A 0B                  CALL CALIB          MAKE ANOTHER CALIBRATION
0A1E  3E 88                     MVI A,PRT1O         SET PORT1 FOR OUTPUT TO TAPE
0A20  D3 F7                     OUT PORT1           SEND CONTROL WORD
0A22  01 99 3D                  LXI B,CALRD         ADDRESS OF CALIBRATION RDGS IN BC
0A25  11 F8 3D                  LXI D,CALRD+05FH    60H BYTES OF CALB RDGS TO BE STORED
0A28  CD 57 0F                  CALL WRTAP          DATA FROM BC THRU DE STORED
0A2B  CD 36 11                  CALL DUMPBF         DUMP THE REST OF THE BUFFER ON TAPE
0A2E  CD 4E 11                  CALL WEOF           WRITE END OF FILE ON TAPE
0A31  3E 99                     MVI A,PRT1I         SET PORT 1 FOR INPUT
0A33  D3 F7                     OUT PORT1           SEND CONTROL WORD
0A35  C3 00 00      E           JMP GETCM           RETURN TO MONITOR

                    ;
                    ;POLSM - SUBROUTINE CALCULATES PROPK FROM COEFS (CKI) AND RDGS (RIK)
                    ;PROPK = OFFSET + CK1*R1K + CK2*R2K + CK3*R3K ...+CKJ*RJK.
                    ;THE "READINGS" MUST ALREADY BE CALCULATED AND STORED IN RAM,AT ADDRESS
                    ;STARTING AT RDGDA + K*(COEFFICIENT OFFSET(COEOF).THE TERMS ARE
                    ;CALCULATED AND SUMMED FROM THE HICEST ORDER TO THE LOWEST ORDER.
                    ;THE PROPERTY NUMBER TO BE CALCULATED MUST BE SET IN A.
0A38  D3 7E         POLSM       OUT APDATA          LOAD PROPERTY NO INTO AP STACK
0A3A  AF                        XRA A               ZERO A
0A3B  D3 7E                     OUT APDATA          LOAD 2ND BYTE INTO AP STACK
0A3D  CD 00 00      E           CALL PTOS           AP STACK CONTAINS 2 COPIES OF PROP NO
0A40  3E 00                     MVI A,RDGOF         READING OFFSET LOADED INTO A
0A42  D3 7E                     OUT APDATA          AND STORED ONTO APSTACK
0A44  AF                        XRA A               A ZEROED
0A45  D3 7E                     OUT APDATA          SECOND BYTE ON AP STACK
0A47  CD 00 00      E           CALL SMUL           LOW ORDER TWO BYTE PRODUCT CALCULATED
0A4A  DB 7E                     IN APDATA           READ FROM APSTACK
0A4C  57                        MOV D,A             STORED IN D
0A4D  DB 7E                     IN APDATA           LO ORDER BYTE READ
0A4F  5F                        MOV E,A             LOADED INTO E
0A50  21 1B 3C                  LXI H,RAWDA         STARTING ADDR OF RDG DATA LOADED INTO HL
0A53  19                        DAD D               HL HAS START RDG ADD +(RDGOF)*(PRO NO)
0A54  EB                        XCHG                MOVED TO DE
0A55  3E 3D                     MVI A,COEOF         COEFFICIENT OFFSET MOVED INTO A
0A57  D3 7E                     OUT APDATA          STORED ON AP STACK
0A59  AF                        XRA A               A ZEROED
0A5A  D3 7E                     OUT APDATA          AND STORED ON STACK
0A5C  CD 00 00      E           CALL SMUL           LOW ORDER (COEF OFFSET)*(CH NO) CALC
0A5F  DB 7E                     IN APDATA           HI BYTE READ IN
0A61  67                        MOV H,A             AND STORED IN H
0A62  DB 7E                     IN APDATA           LOW ORDER BYTE READ
0A64  6F                        MOV L,A             AND STORED IN L,HL=(COEF OFF)*(CH NO)
0A65  3A 2B 3E                  LDA CLBADR          LOAD COEBT STARTING COEFF IN BC
0A68  47                        MOV B,A             GET HI BYTE INTO B
0A69  0E 78                     MVI C,COEBT-CALB    GET OFFSET FROM CALB TO COEBT
0A6B  09                        DAD B               AND ADDED TO HL,=COEBT+(CH NO)*COEOF
0A6C  7E                        MOV A,M             NO OF TERMS IN POLYNOMIAL LOADED IN A
0A6D  87                        ADD A               NO TERMS DOUBLED
0A6E  87                        ADD A               THEN 4 TIMES(SINCE THERE ARE 4 BYTES EACH)
0A6F  4F                        MOV C,A             4*(NO TERMS) IN C
0A70  06 00                     MVI B,0H            B ZEROED,BC CONTAINS 4*(NO TERMS)
0A72  09                        DAD B               HL=COEBT+COEOF+4*(NO TERMS)
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0A73  EB                       XCHG              DE=COEDT+COEOF*(RDG NO)+4*(NO TERMS)
0A74  09                       DAD B             HL=RDGDA+RDGOF*(RDG NO)+4*(NO TERMS)
0A75  2B                       DCX H             READING CALS CONTAINS 1 LESS BYTE THAN COE
0A76  1F                       RAR               ACCUMULATOR ROTATED RIGHT TWICE
0A77  1F                       RAR               TO GET COUNT NO,RATHER THAN 4*(COUNT NO)
0A78  47                       MOV B,A           NO OF TERMS IN POLYNOMIAL COUNT IN B
0A79  AF                       XRA A             ZERO ACCUMULATOR,WILL BE LOADED IN AP
0A7A  D3 7E                    OUT APDATA        FIRST BYTE SENT OUT
0A7C  D3 7E                    OUT APDATA        2ND AND 3RD BYTES SENT TO AP
0A7E  D3 7E                    OUT APDATA        AP NOW CONTAINS 32 BIT,4 BYTE
0A80  D3 7E                    OUT APDATA        FLOATING POINT ZERO
0A82  CD 00 00    E   POLLP    CALL FMULB        MULTIPLY READING*COEFFICIENT
0A85  CD 00 00    E            CALL FADD         ADD RESULT TO RUNNING SUM ON AP STACK
0A88  1B                       DCX D             DECREMENT DE,COEFFICIENT ADDR POINTER
0A89  2B                       DCX H             DECREMENT HL,READING ADDR POINTER
0A8A  05                       DCR B             DECREMENT B,TERM COUNTER
0A8B  C2 82 0A                 JNZ POLLP         STAY IN LOOP UNTIL ALL TERMS DONE
0A8E  C9                       RET               RETUTN WITH ANSWER ON AP STACK WHEN DONE
                      ;CRFAC - PROGRAM APPLIES CORRECTION FACTORS AI + BI*RI = R'I TO
                               ;NO OF READINGS STORED IN REG.B.THE PROGRAM STARTS WITH THE
                               ;LAST RAW READING (4 BYTES) MULTIPLIES THE GAIN,ADDS THE
                               ;OFFSET,AND STORES THE RESULT BACK IN PLACE OF THE RAW DATA.
                               ;THE PROGRAM EXITS WHEN THE FIRST CHANNEL HAS BEEN DONE.
                               ;HL,DE,B&A REGISTERS ARE OVERWRITTEN.
0A8F  21 32 3C        CRFAC    LXI H,RAWDA+17H   HL SET FOR LAST RAW DATA BYTE
0A92  11 64 3C                 LXI D,CRFRA+2FH   DE = ADDR OF LAST BYTE OF CORR FAC
0A95  CD 00 00    E   CORLP    CALL FLTDA        FLOAT THE RAW READING
0A98  EB                       XCHG              XCHANGE HL WITH DE(ADDR OF CORR FACT IN HL
0A99  CD 00 00    E            CALL FMULA        MULTIPLY RAW DATA BY CORR FAC
0A9C  2B                       DCX H             DECREMENT HL TO OFFSET
0A9D  CD 00 00    E            CALL FADDA        ADD OFFSET TO READING
0AA0  2B                       DCX H             SET ADDRESS FOR NEXT CORRECTION FACTOR
0AA1  EB                       XCHG              STORE BACK IN DE
0AA2  CD 00 00    E            CALL TOS4         CORRECTED READING STORED BACK
0AA5  2B                       DCX H             HL DECREMENTED 4 TIMS,ADDR NEXT RAW DAT
0AA6  2B                       DCX H
0AA7  2B                       DCX H
0AA8  2B                       DCX H
0AA9  05                       DCR B             DECREMENT THE COUNTER IN B
0AAA  C2 95 0A                 JNZ CORLP         LOOP BACK IF B .NE. 0
0AAD  C9                       RET               RETURN TO CALLING PROG IF DONE
                      ;SMDAT - DATA SUMMATION ROUTINE,STARTING WITH CHANNEL 1,READS NO OF
                               ;CHANNELS IN C,WITH NO OF READINGS PER CHANNEL IN B (UP TO
                               ;255).SUM OF THE DATA WILL BE IN RAWDA -4 + (4*CH. NO.)
                               ;RAW DATA IS STORED AS MAG1,PH1,MAG2,PH2,MAG3,PH3;4 BYTES EACH
0AAE  21 1B 3C        SMDAT    LXI H,RAWDA       HL LOADED WITH LAST RAW DATA ADDRESS
0AB1  C5                       PUSH B            COPY OF REGS B,C STORED ON STACK
0AB2  79                       MOV A,C           NUMBER OF CHANNELS LOADED INTO A
0AB3  87                       ADD A
0AB4  87                       ADD A             4*NO OF CHANNELS IN A
0AB5  4F                       MOV C,A           4*NO OF CHANNELS IN REG C
0AB6  AF                       XRA A             A REGISTER ZEROED
0AB7  CD 00 00    E            CALL ZERO         ZERO RAM FROM HL TO HL+C
0ABA  C1                       POP B             NO OF CHANNELS (REG C) & TIMES/CH (B) RES
```

```
0ABB  11 04 00               LXI D,0004H        LOAD +4 INTO DE
0ABE  21 1E 3C      SMLOP    LXI H,RAWDA+03H    HL LOADED WITH FIRST RAW DATA ADDRESS
0AC1  C5                     PUSH B             AND COPY STORED ON STACK AGAIN
0AC2  CD F4 0A               CALL ADBUS         CHECK FOR BUSY,START NEXT CONVERSION
0AC5  3E 06         CHLOP    MVI A,NCHA         TOTAL NUMBER OF CHANNELS IN A
0AC7  91                     SUB C              NCH = TOTAL NO. - CHA COUNT IN REG C
0AC8  CD DC 0A               CALL ADRDG         MAKE AD CON RDG,ANSWER ON AP TOP OF STACK
0ACB  CD 00 00    E          CALL DADDA         32 BIT FIXED ADD TO DATA AT HL,HL=HL-3
0ACE  CD 00 00    E          CALL TOS4          AP TOP OF STACK STORED IN RAM AT HL
0AD1  19                     DAD D              DE (+4) ADDED TO HL,POINTS TO NEXT ADDR
0AD2  0D                     DCR C              CHANNEL COUNT DECREMENTED
0AD3  C2 C5 0A               JNZ CHLOP          JUMP BACK TO CHANNEL LOOP IF NOT FINISHED
0AD6  C1                     POP B              RESTORE BC FROM STACK
0AD7  05                     DCR B              DECREMENT THE NUMBER OF RDGS/CHANNEL
0AD8  C2 BE 0A               JNZ SMLOP          GO BACK TO THE SUM LOOP IF NOT FINISHED
0ADB  C9                     RET
                    ;ADRDG   SELECTS THE ADCONVERTOR NUMBER THAT IS IN A,READS THE
                    ;        12 BITS FROM THE CONVERTOR,ADDS 20 ZEROS AND RETURNS WITH
                    ;        A POSITIVE 32 BIT FIXED NUMBER ON THE TOP OF THE APSTACK.
                    ;        FOR DATEL ADC-ET12B ANALOG TO DIGITAL CONVERTOR.
0ADC  C6 D8         ADRDG    ADI 0C0H           CH SEL NO +C0^S ON 8004,SEL ON ADC
0ADE  D3 F5                  OUT PORT1B         SET CH. SWITCH TO CH. NO.
0AE0  DB F4                  IN PORT1A          LOW ORDER BYTE IS BROUGHT IN AND
0AE2  D3 7E                  OUT APDATA        STORE ON ARITHMETIC PROCESSOR STACK.
0AE4  DB F6                  IN PORT1C          HIGH ORDER BYTE IS BROUGHT IN.
0AE6  E6 0F                  ANI 0FH            4 HIGHEST ORDER BITS ARE DUMPED
0AE8  D3 7E                  OUT APDATA        STORE ON ARITHMETIC PROCESSOR STACK.
0AEA  AF                     XRA A              ZERO ACCUMULATOR
0AEB  D3 7E                  OUT APDATA        STORE ON ARITHMETIC PROCESSOR STACK.
0AED  D3 7E                  OUT APDATA        STORE ON ARITHMETIC PROCESSOR STACK.
0AEF  3E 00                  MVI A,000H        LEAVE START LO,DESELECT ADCONVERTORS
0AF1  D3 F5                  OUT PORT1B        SEND TO PORT1B
0AF3  C9                     RET                RETURNS WITH POS. ANSWER ON AP STACK.
                    ;
                    ;        ADBUS             HANG HERE UNTIL ALL BUSY LINES OF THE DATEL
                    ;                      ADC-ET12B ANALOG TO DIGITAL CONVERTORS GOES LOW
                    ;                      THEN START THE NEXT CONVERSION AND RETURN.THE
                    ;                      DATA FROM THE LAST CONVERSION CAN BE READ FOR
                    ;                      THE NEXT 9 MILLISECONDS.
                    ;
0AF4  DB F6         ADBUS    IN PORT1C          CHECK PORT1C,BIT4 FOR BUSY (HI)
0AF6  E6 10                  ANI 010H           DUMP ALL BITS EXCEPT 4
0AF8  C2 F4 0A               JNZ ADBUS          STAY IN LOOP UNTIL BUSY LINE LOW
0AFB  3E 80                  MVI A,080H         SEND START BIT HI
0AFD  D3 F5                  OUT PORT1B         STROBE BIT HI,STARTS CONVERSION
0AFF  C9                     RET                START BIT WILL GO LO WITH DATA CH READ
                    ;DELAY 2 PROG. - GENERATES A TIME DELAY,DEPENDING ON THE CONSTANT LOADED
                              ;INTO BC, # CYCLES = 26*FFFF/(BC)
0B00  E5            DELAY    PUSH H             SAVE THE CONTENTS OF HL AND
0B01  21 00 00               LXI H,0H          ZERO HL
0B04  09            LOPSH    DAD B              ADD BC TO THE CONTENTS OF HL
0B05  D2 04 0B               JNC LOPSH          STAY IN LOOP UNTIL HL OVERFLOWS.
0B08  E1                     POP H              THEIR ORIGINAL VALUES
0B09  C9                     RET                AND RETURN.
```

```
                           ;
                           ;CALIB     CALIBRATION PROGRAM - MAKES 4 SETS OF CALIBRATION READINGS
                           ;          FOR EACH OF NCALC CALIBRATION READINGS PER DATA CHANNEL.EACH
                           ;          CALIBRATION READING IS MADE 4*16 TIMES,AND THE READINGS ARE
                           ;          AVERAGED AND STORED STARTING AT CALRD
                           ;
0B0A  AF                   CALIB      XRA A            ZERO ACCUMULATOR,SO RAM CAN BE ZEROED
0B0B  21 99 3D                        LXI H,CALRD      RAM ADDRESS TO BE ZEROED LOADED
0B0E  0E 60                           MVI C,060H       NUMBER OF BYTES TO BE ZEROED IN C
0B10  CD 00 00      E                 CALL ZERO        RAM ZEROED FROM CALRD TO CALRD+5FH
0B13  3E 04                           MVI A,04H        INITIAL NO OF CALIBRATIONS SET TO 4
0B15  32 10 3C             CALLP      STA TRMCT        NO OF CALIBRATIONS STORED IN TRMCT
                           ;  TRMCT IS NUMBER OF TIMES EACH CALIBRATOR VALUE READ
0B18  21 9C 3D                        LXI H,CALRD+03H  HL LOADED WITH FIRST ADDRESS
0B1B  11 04 00                        LXI D,0004H      LOAD +4 INTO DE
0B1E  AF                              XRA A            ZERO A
                           ; NOW LOOP OVER NUMBER OF MAG & PH CALIBRATOR VALUES
0B1F  32 11 3C             CHALP      STA CHANO        STORE CHANNEL NUMBER BACK IN CHANO
0B22  E6 03                           ANI 03H          DUMP ALL BUT TWO LOWER BITS
                           ;          ADI 040H         TURN ON STRIP CHART REC DURING CALIBRATE
0B24  D3 ED                           OUT PORT2B       SET CALIBRATOR ADDRESSES
0B26  01 00 00                        LXI B,0000       LOAD DELAY FOR BC
0B29  CD 00 0B                        CALL DELAY       DELAY FOR 150 MS TO ALLOW RDGS TO SETTLE
0B2C  CD 00 0B                        CALL DELAY       DELAY FOR 150 MS TO ALLOW RDGS TO SETTLE
0B2F  06 10                           MVI B,010H       16D RDGS/CH IN B,6 CHS IN C
0B31  0E 06                           MVI C,NCHA       NUMBER OF DATA CHANNELS TO BE READ IN C
0B33  E5                              PUSH H           HL STORED ON STACK
0B34  3E 80                           MVI A,080H       SEND START BIT HIGH
0B36  D3 F5                           OUT PORT1B       STROBE START LINE HI, STARTS CONVERSION
                           ;                           FOR FIRST READING
0B38  3E 90                           MVI A,090H       SEND START BIT LOW
0B3A  D3 F5                           OUT PORT1B       STROBE START LINE LOW
                           ;  LOOP OVER NUMBER OF TIMES MAG & PHASE VALUES READ FOR
                           ;  EACH CALIBRATOR SETTING
0B3C  E1                   SMCLP      POP H            HL ADDRESSES RESTORED
0B3D  E5                              PUSH H           HL COPIED ON STACK AGAIN
0B3E  C5                              PUSH B           BC COPIED ON STACK AGAIN
0B3F  CD F4 0A                        CALL ADBUS       HANG HERE UNTIL ADC'S ARE READY
                           ;  LOOP OVER NUMBER OF MAG & PHASE VALUES AT EACH FREQUENCY
0B42  3E 06                CHCLP      MVI A,NCHA       CALIBRATION CHANNEL LOOP,CH NO IN A
0B44  91                              SUB C            NCH = TOTAL NO. - CHA COUNT IN REG C
0B45  CD DC 0A                        CALL ADRDG       MAKE AD CON RDG,ANSWER ON AP STACK
0B48  CD 00 00      E                 CALL DADDA       32 BIT FIXED ADD TO DATA AT HL;HL=HL+3
0B4B  CD 00 00      E                 CALL TOS4        AP TOP OF STACK STORED IN RAM AT HL
0B4E  19                              DAD D            DE (+4) ADDED TO HL
0B4F  0D                              DCR C            CHANNEL COUNT DECREMENTED
0B50  C2 42 0B                        JNZ CHCLP        DO NEXT CHANNEL IF NOT FINISHED
0B53  C1                              POP B            RESTORE BC FROM STACK
0B54  05                              DCR B            DECREMENT NUMBER OF RDGS PER CHANNEL
0B55  C2 3C 0B                        JNZ SMCLP        GO BACK TO SUM LOOP IN NOT DONE
0B58  C1                              POP B            FORMER HL IS POPPED INTO B,CLEARING STACK
0B59  3A 11 3C                        LDA CHANO        THE CALIBRATION CH NO LOADED INTO A
0B5C  3C                              INR A            INCREMENT CH NO.
0B5D  FE 04                           CPI NCALC        ZERO BIT WILL BE SET WHEN CHANO=NCALC
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0B5F  C2 1F 0B                JNZ CHALP          LOOP BACK IF NOT DONE
0B62  3A 10 3C                LDA TRMCT          LOAD THE NUMBER OF TIMES THRU CALB LOOP IN
0B65  3D                      DCR A              DECREMENT TIMES THRU LOOP
0B66  C2 15 0B                JNZ CALLP          GO BACK THRU CALIBRATION LOOP UNTIL DONE
0B69  3E 07                   MVI A,007H         LOAD 0000/0111 INTO A,CHART OFF,
0B6B  D3 ED                   OUT PORT2B         TURN CALIBRATOR RELAYS BACK OFF
                      ;
                      ;       FLOAT AND CORRECT,AND DISPLAY CALIBRATION READINGS
                      ;
0B6D  21 9C 3D                LXI H,CALRD+03H    LOAD ADDRESS OF FIRST RAW BYTE IN HL
0B70  06 18                   MVI B,18H          COUNTER IN B SET FOR 18H(24D) CORRECTIONS
0B72  CD 00 00     E  CALL2   CALL FLTDA         FLOAT RAW READINGS
0B75  EB                      XCHG               STORE HL IN DE TEMPORARILY
0B76  21 4D 12                LXI H,CALFR+03     LOAD ADDRESS OF CALIB CORR FAC IN HL
0B79  CD 00 00     E          CALL FMULA         MULTIPLY READING BY CORRECTION FACTOR
0B7C  EB                      XCHG               RESTORE THE RAW CALIB DATA ADDR IN HL
0B7D  CD 00 00     E          CALL TOS4          STORE CORRECTED DATA BACK IN RAM
0B80  23                      INX H              HL ICRMTED 4 TIMES TO POINT TO NEXT ADDR
0B81  23                      INX H
0B82  23                      INX H
0B83  23                      INX H
0B84  05                      DCR B              DECREMENT COUNTER IN B
0B85  C2 72 0B                JNZ CALL2          LOOP BACK IF NOT DONE
0B88  21 99 3D        PRCLB   LXI H,CALRD        LOAD ADDRESS OF CALIBRATION RDGS IN HL
0B8B  11 04 06                LXI D,0604H        LOAD NO PER LINE,NO OF LINES IN DE
0B8E  01 04 09                LXI B,0904H        LOAD FIXED FORMAT,9 DIGS,4 AFTER DEC
0B91  CD 00 00     E          CALL FPRNT         PRINT CALIBRATION RDGS ON CRT
0B94  CD 00 00     E          CALL CROUT         PRINT CARRIAGE RETURN,LINEFEED
0B97  AF                      XRA A              ZERO ACC SO MAIN LOOP WILL RUN CORRECT
0B98  C9                      RET                RETURN TO CALLING PROGRAM
                      ;
                      ;RECAL   RECALIBRATION PROGRAM-MAKES A NEW SET OF CALIBRATION RDGS
                      ;   AND DOES A LEAST SQUARES FIT OF THE NEW READINGS TO THE CALIBRATION
                      ;  READINGS THAT WERE TAKEN BY TUBRDG & USED WHEN THE COEFFICIENTS WERE
                      ;  CALCULATED BY TUBFIT.THE FIT IS DONE FOR NCHA DATA CHANNELS,FOR
                      ;  NCALC CALIBRATION RDGS PER CHANNEL.  CALO=OFSET+SLOPE*CALRD
                      ;
0B99  CD 0A 0B        RECAL   CALL CALIB         MAKE A NEW SET OF CALIBRATION READINGS
0B9C  06 06                   MVI B,NCHA         NUMBER OF DATA CHANNELS IN REG B
0B9E  11 03 00                LXI D,03           DE WILL CONTAIN THE OFFSET FOR CALRD&CALO
0BA1  AF              RECLP   XRA A              ZERO ACCUMULATOR,WILL ZERO INITIAL VALUES
0BA2  21 F9 3D                LXI H,SUMXX        FIRST LOCATION TO BE ZEROED IN HL
0BA5  0E 1C                   MVI C,01CH         SET C COUNTER FOR 28 D BYTES TO BE ZEROED
0BA7  CD 00 00     E          CALL ZERO          ZERO SUMS
0BAA  0E 04                   MVI C,NCALC        THE NUMBER OF CALIB RDGS TO BE USED IN C
0BAC  21 99 3D        RECL2   LXI H,CALRD        HL LOADED WITH ADDR OF 1ST CALIB RDG.
0BAF  19                      DAD D              + DE OFST ADDR,ADDRESSES CALRD(NCHA,NCALC)
0BB0  CD 00 00     E          CALL LDT4          LOAD DATA AT HL ADDR IN RAM ON APSTACK
0BB3  CD 00 00     E          CALL PTOD          MAKE 2ND COPY OF CALRD ON APSTACK
0BB6  CD 00 00     E          CALL PTOD          MAKE 3RD COPY OF CALRD ON APSTACK
0BB9  CD 00 00     E          CALL PTOD          MAKE 4TH COPY OF CALRD ON APSTACK
0BBC  CD 00 00     E          CALL FMUL          CALRD**2 ON TOP OF APSTACK
0BBF  21 FC 3D                LXI H,SUMXX+03H    LOAD ADDR OF CALRD**2 SUM
0BC2  CD 00 00     E          CALL FADDA         ADD CALRD**2 TO SUM
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0BC5  CD 00 00     E     CALL TOS4         STORE BACK IN RAM (DCXS HL 3 TIMES)
0BC8  21 00 3E           LXI H,SUMX+03H    ADDR OF SUMX IN HL
0BCB  CD 00 00     E     CALL FADDA        CALRD + SUM OF CALRDS,HL DCXED BY 3
0BCE  CD 00 00     E     CALL TOS4         SUM CALRDS IN RAM,HL INXED BY 3
0BD1  3A 2B 3E           LDA CLOADR        PUT ADDR OF INIT CALIB RDGS IN HL
0BD4  67                 MOV H,A
0BD5  AF                 XRA A             ZERO LO BYTE
0BD6  6F                 MOV L,A
0BD7  19                 DAD D             DE OFST ADDED,ADDR OF CAL0(NCHA,NCALC) IN
0BD8  CD 00 00     E     CALL WRT4         CAL0(NCHA,NCALC) ON TOP OF APSTACK
0BDB  CD 00 00     E     CALL PTOD         2ND COPY OF CAL0 ON APSTACK
0BDE  CD 00 00     E     CALL PTOD         3RD COPY OF CAL0 ON APSTACK
0BE1  CD 00 00     E     CALL FMUL         CAL0**2 ON TOP OF APSTACK
0BE4  21 04 3E           LXI H,SUMYY+03H   SUM OF CAL0S**2 ADDR BY HL
0BE7  CD 00 00     E     CALL FADDA        CAL0**2 ADDED TO SUM
0BEA  CD 00 00     E     CALL TOS4         SUM OF CAL0**2S STORED BACK IN RAM
0BED  CD 00 00     E     CALL PTOD         2 COPIES OF CAL0 ON APSTACK NOW
0BF0  21 08 3E           LXI H,SUMY+03H    SUM OF CAL0S ADDR BY HL
0BF3  CD 00 00     E     CALL FADDA        ADDED TO CAL0 ON APSTACK
0BF6  CD 00 00     E     CALL TOS4         STORED IN RAM
0BF9  CD 00 00     E     CALL FMUL         MULTIPLY CAL0*CALRD
0BFC  21 0C 3E           LXI H,SUMXY+03H   ADDR OF CAL0*CALRDS IN HL
0BFF  CD 00 00     E     CALL FADDA        CAL0*CALRD+SUM OF CAL0*CALRDS
0C02  CD 00 00     E     CALL TOS4         STORED BACK IN RAM
0C05  7B                 MOV A,E           MOVE OFFSET IN DE TO ACCUMULATOR
0C06  C6 18              ADI 4*NCHA        INCREASE THE OFFSET TO NEXT NCALC RDG
0C08  5F                 MOV E,A           STORE BACK IN DE
0C09  0D                 DCR C             DECREMENT NCALC COUNTER IN C
0C0A  C2 AC 0B           JNZ RECL2         LOOP BACK FOR NEXT CALCULATIONS & SUMS
0C0D  3E 04              MVI A,NCALC       DONE,LOAD NCALC INTO APSTACK & FLOAT
0C0F  D3 7E              OUT APDATA        NCALC SENT TO APSTACK
0C11  AF                 XRA A             ZERO A
0C12  D3 7E              OUT APDATA        APSTACK HAS 16 BIT FIXED NO
0C14  CD 00 00     E     CALL FLTS         NCALC NOW A 32 BIT FLOATING BINARY NO
0C17  CD 00 00     E     CALL PTOD         2 COPIES ON APSTACK
0C1A  21 00 3E           LXI H,SUMX+03H    ADDR OF SUMX IN HL
0C1D  CD 00 00     E     CALL WRT4         SUMX 1ST ON APSTACK,NCALC 2ND,3RD
0C20  CD 00 00     E     CALL XCHD         NCALC 1ST,SUMX 2ND,NCALC
0C23  CD 00 00     E     CALL FDIV         SUMX/NCALC 1ST,NCALC 2ND
0C26  21 0D 3E           LXI H,XBAR        ADDR OF XBAR IN HL
0C29  CD 00 00     E     CALL TOS4         XBAR STORED IN RAM FROM APSTACK
0C2C  21 08 3E           LXI H,SUMY+03H    ADDR OF SUMY IN HL
0C2F  CD 00 00     E     CALL WRT4         LOADED ON APSTACK,SUMY 1ST,NCALC 2ND
0C32  CD 00 00     E     CALL XCHD         NCALC 1ST SUMY 2ND
0C35  CD 00 00     E     CALL FDIV         SUMY/NCALC ON APSTACK
0C38  21 11 3E           LXI H,YBAR        ADDR OF YBAR IN HL
0C3B  CD 00 00     E     CALL TOS4         YBAR STORED IN RAM
0C3E  21 00 3E           LXI H,SUMX+03H    ADDR OF SUMX IN RAM
0C41  CD 00 00     E     CALL WRT4         SUMX ON APSTACK
0C44  CD 00 00     E     CALL PTOD         2ND COPY OF SUMX ON APSTACK
0C47  21 14 3E           LXI H,YBAR+03H    ADDR OF YBAR IN HL
0C4A  CD 00 00     E     CALL FMULA        YBAR*SUMX ON TOP OF APSTACK
0C4D  CD 00 00     E     CALL CHSF         -YBAR*SUMX ON APSTACK
0C50  21 0C 3E           LXI H,SUMXY+03H   HL ADDRESSES SUMXY
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0C53  CD 00 00   E          CALL FADDA          SUMXY-SUMX*YBAR ON TOP OF APSTACK
0C56  CD 00 00   E          CALL XCHD           SUMX TOP OF APSTACK,SUMXY-SUMX*YBAR 2ND
0C59  21 10 3E              LXI H,XBAR+03H      ADDR OF XBAR IN HL
0C5C  CD 00 00   E          CALL FMULA          XBAR*SUMX TOP OF APSTACK
0C5F  CD 00 00   E          CALL CHSF           -XBAR*SUMX TOP OF APSTACK
0C62  21 FC 3D              LXI H,SUMXX+03H     SUMXX ADDR IN HL
0C65  CD 00 00   E          CALL FADDA          SUMXX-XBAR*SUMX TOS,SUMXY-SUMX*YBAR NEXT
0C68  CD 00 00   E          CALL FDIV           (SUMXY-SUMX*YBAR)/(SUMXX-XBAR*SUMX) TOS
0C6B  CD 00 00   E          CALL PTOD           2ND COPY OF GAIN STORED
0C6E  3E 06                 MVI A,NCHA          TOTAL NO OF CHANNELS IN A
0C70  90                    SUB B               A=TOTAL CHA NUMBER - PRESENT COUNT IN B
0C71  87                    ADD A               NCH*8,4 BYTES FOR OFSET,4 BYTES FOR SLOP
0C72  87                    ADD A               NCH*4 IN A
0C73  4F                    MOV C,A             STORE A TEMP COPY OF 4*NCH IN C
0C74  87                    ADD A               NCH*8 IN A
0C75  21 39 3C              LXI H,CRFRA+04H     HL ADDRESS 1ST BYTE OF 1ST SLOPE
0C78  5F                    MOV E,A             D WAS 0,CRFRA OFFSET MOVED TO E
0C79  19                    DAD D               DE ADDED TO HL
0C7A  CD 00 00   E          CALL TOS4           SLOPE STORED IN RAM
0C7D  21 35 3C              LXI H,CRFRA         1ST BYTE OF 1ST OFSET IN HL
0C80  19                    DAD D               HL ADDRESSES OFSET(NCH)
0C81  EB                    XCHG                TEMP STORE IN DE
0C82  21 10 3E              LXI H,XBAR+03H      ADDR OF XBAR IN HL
0C85  CD 00 00   E          CALL FMULA          GAIN*XBAR ON APSTACK
0C88  CD 00 00   E          CALL CHSF           -GAIN*XBAR ON APSTACK
0C8B  21 14 3E              LXI H,YBAR+03H      YBAR ADDRESSED BY HL
0C8E  CD 00 00   E          CALL FADDA          YBAR-GAIN*XBAR ON APSTACK
0C91  EB                    XCHG                HL ADDRESSES OFSET(NCH)
0C92  CD 00 00   E          CALL TOS4           STORE OFSET(NCH) IN RAM
0C95  79                    MOV A,C             CALCULATE OFFSET AMOUNT FOR NCHS LOOP
0C96  C6 07                 ADI 07H             OFFSET DE FOR NEXT NCHS LOOP,A=4*NCH+3
0C98  5F                    MOV E,A             DE = NCH OFFSET FOR NEXT ADDR
0C99  16 00                 MVI D,0             REZERO D FOR OFFSET VALUE
0C9B  05                    DCR B               DECREMENT NCH COUNTER IN B REG
0C9C  C2 A1 0B              JNZ RECLP           LOOP BACK FOR NEXT CHANNEL IF NOT DONE
0C9F  11 2C 3E              LXI D,VOLNEW        ADDRESS IN RAM TO BE COPIED TO
0CA2  3A 44 3E              LDA VSTBYT          LOAD TEST BYTE INTO A
0CA5  FE AA                 CPI 0AAH            COMPARE TO AA,SEE IF TUBE STD WAS READ
0CA7  C2 D7 0C              JNZ RECL4           JUMP AROUND IF STD TUBE HASN'T BEEN READ
0CAA  0E 06                 MVI C,NCHA          SET COUNTER FOR NO OF CHANNELS
0CAC  3A 2B 3E              LDA CLBADR          LOAD HI PART OF VOLSTD ADDR IN A
0CAF  67                    MOV H,A             AND STORE IN H
0CB0  2E 77                 MVI L,COEDT-CAL6-1     ;LOAD OFFSET TO LAST BYTE OF VOLSTD IN
0CB2  E5                    PUSH H              STORE ADDR ON STACK
0CB3  21 43 3E              LXI H,VOLNEW+17H     VALUE OF LAST BYTE TO BE CORRECTED
0CB6  11 64 3C              LXI D,CRFRA+2FH     ADDR OF LAST BYTE OF SLOPS
0CB9  CD 00 00   E   RECL3  CALL FMULD          SLOPE*VOLNEW ON APSTACK
0CBC  2B                    DCX H               HL ADDR OF OFSG+3
0CBD  2B                    DCX H               HL ADDR OFSG+2
0CBE  2B                    DCX H               OFSG+1
0CBF  2B                    DCX H               HL ADDR OFSG
0CC0  E3                    XTHL                SAV ADDR OF 1ST BYTE OF OFSG ON STACK,GET
0CC1  CD 00 00   E          CALL FSUBA          SLOPE*VOLNEW-VOLSTD ON APSTACK
0CC4  CD 00 00   E          CALL CHSF           VOLSTD-(SLOPE*VOLNEW) ON APSTACK
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0CC7  2B                      DCX H            ADDR OF VOLSTDS+3 IN HL
0CC8  E3                      XTHL             STORED BACK FOR NEXT ROUND,ADD OF OFS6,1ST
0CC9  CD 00 00    E           CALL TOS4        STR VOLSTDS-(SLOP6*VOLNEW6) AS NEW OFSET
0CCC  1B                      DCX D            DE ADDR VOLNEW5+3
0CCD  EB                      XCHG             HL ADDR VOLNEW5,DE ADDR 4TH BYTE OF OFS6
0CCE  1B                      DCX D
0CCF  1B                      DCX D
0CD0  1B                      DCX D
0CD1  1B                      DCX D            DE ADDR SLOP5+3
0CD2  0D                      DCR C            CHECK COUNTER IN C
0CD3  C2 B9 0C                JNZ RECL3        CALCULATE NEXT CORR FACTOR IF NOT DONE
0CD6  E1                      POP H            GET STACK BACK RIGHT
0CD7  21 35 3C        RECL4   LXI H,CRFRA      WILL PRINT OUT CORRECTION FACTORS,OFSET,SL
0CDA  11 06 02                LXI D,0206H      PRINT 2 PER LINE,6 LINES
0CDD  01 06 0A                LXI B,0A06H      LOAD FIXED FORMAT,10 DIGITS,6 AFTER DEC
0CE0  CD 00 00    E           CALL FPRNT       PRINT IN FIXED FORMAT
0CE3  CD 00 00    E           CALL CROUT       CALL CARRIAGE RETURN,LINEFEED
0CE6  0E 06                   MVI C,NCHA       MULTIPLY SLOPE BY CONVER FACTOR
0CE8  21 3C 3C                LXI H,CRFRA+07H  1ST SLOPE ADDR IN HL
0CEB  11 59 12        RECL5   LXI D,CRFRD+07H  CON FACT=5/(4095*NRDG)
0CEE  CD 00 00    E           CALL FMULB       CRFRA*5/(4095*NRDG) ON APSTACK
0CF1  EB                      XCHG             XCHANGE HL&DE,B SUFFIX CALL REVERSED
0CF2  CD 00 00    E           CALL TOS4        SAVE NEW CORRFACTOR IN RAM
0CF5  11 08 00                LXI D,08H        ADD 8 TO ADDR OF HL
0CF8  19                      DAD D            HL=ADDR OF NEXT SLOPE
0CF9  0D                      DCR C            DECREMENT CHANNEL COUNT IN C,SEE IF WE ARE
0CFA  C2 EB 0C                JNZ RECL5        JUMP BACK IF NOT DONE
0CFD  AF                      XRA A            ZERO ACC SO MAIN LOOP WILL RUN CORRECT
0CFE  C9                      RET              RETURN TO CALLING ROUTINE
                      ;
                      ;       DACON1           PROGRAM TO WRITE DATA OUT TO DIGITAL
                      ;                        TO ANALOG CONVERTERS.DATA STORED AT PROPA
                      ;                        IS MULTIPLIED BY DAFAC AND OUTPUTTED.CHANN
                      ;                        ADDRESSED BY VALUE AT POSCH IS ADDED TO TH
                      ;                        FORMER RDG FOR THAT CHANNEL & OUTPUTTED
                      ;
0CFF  21 18 3E        DACON1  LXI H,PROPA+3    ADDR OF PROPERTY TO BE CALCULATED
0D02  11 99 12                LXI D,DAFAC+3    DE CONTAIN CONVERSION FACTOR ADDR
0D05  CD 00 00    E           CALL FMULB       FLOATING MULTIPLICATION PERFORMED
0D08  CD 00 00    E           CALL FIXS        CONVERTED NO FIXED
0D0B  21 66 3C                LXI H,DACOFS+1   LOAD ADDRESS OF OFFSET INTO HL
0D0E  3A 5F 3E                LDA DACCH        LOAD DAC CHANNEL NO INTO A
0D11  87                      ADD A            DOUBLE A
0D12  5F                      MOV E,A          MOVE ADDR OFFSET TO E
0D13  16 00                   MVI D,0          DE CONTAINS OFFSET
0D15  19                      DAD D            INCREMENT HL BY 2*DACCH
0D16  CD 00 00    E           CALL SADDA       ADD OFFSET
0D19  CD 00 00    E           CALL PTOS        SAVE A COPY OF NEW RDG ON APSTACK
0D1C  2A 5D 3E                LHLD POSOAD      LOAD ADDR FOR OLD RDGS
0D1F  CD 00 00    E           CALL SADDA       ADD NEW VAL TO OLD,RESULT ON APSTACK
0D22  23                      INX H            INCREMENT HL THREE TIMES
0D23  23                      INX H            CONTAINS VALUE OF ADDR OF
0D24  23                      INX H            NEXT OLD RDG
0D25  22 5D 3E                SHLD POSOAD      STORE FOR NEXT TIME
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0D28   DB 7E                     IN APDATA          HI ORDER BYTE FROM APSTACK TO A REG
0D2A   FE 80                     CPI 080H           IF HI BYTE.GE. 80H NUMBER IS NEG
0D2C   D2 65 0D                  JNC DTMIN          SET DATA TO MINIMUM VALUE (0)
0D2F   FE 10                     CPI 010H           IF HI BYTE.GE. 10,NUMBER.GT.4095
0D31   D2 6D 0D                  JNC DTMAX          SET DATA TO 4095 (0000/1111 1111/1111)
0D34   D3 F6          DALP2      OUT PORT1C         OUTPUTTED TO PORT1C,DAC LINES
0D36   FE 07                     CPI 07H            COMPARE HI ORDER BYTE TO 0000/0111;1792 DE
0D38   D4 7A 0D                  CNC ALARM          SET ALARM BIT IF DAC VAL .GE.1792(44 MILS)
0D3B   DB 7E                     IN APDATA          LOW ORDER BYTE FROM APSTACK TO A REG
0D3D   D3 F4                     OUT PORT1A         LATCHED ON PORT1A,ADC LINES
0D3F   2A 5B 3E                  LHLD POSNAD        LOAD ADDRESS OF NEW RDGS IN HL
0D42   CD 00 00     E            CALL TOS?          SAVE NEW CALC AS OLD VALUE
0D45   2B                        DCX H              DECREMENT HL TWICE TO ADDRESS
0D46   2B                        DCX H              HI BYTE OF NEXT NEW RDG
0D47   2B                        DCX H
0D48   22 5B 3E                  SHLD POSNAD        SAVE AS NEW ADDR
0D4B   3A 5F 3E                  LDA DACCH          LOAD DAC CHANNEL NUMBER INTO A
0D4E   3C                        INR A              INCREMENT DAC CHANNEL NO
0D4F   32 5F 3E                  STA DACCH          STORE BACK IN RAM
0D52   3D                        DCR A              DECREMENT A,BACK TO ORIG CH COUNT
0D53   FE 05                     CPI 05             SEE IF IT IS LARGER THAN 5
0D55   D4 76 0D                  CNC DACSET         USE VALUE OF POSCH IF DACCH.GE.5
0D58   C6 80                     ADI 080H           ADD 1000/0000,B1,0304S SELECTED,TR HI
0D5A   D3 F5                     OUT PORT1B         CONTROL LINES SET FOR DAC
0D5C   3E 60                     MVI A,060H         STROBE DACS LO,THEN HI
0D5E   D3 EE                     OUT PORT2C         DAC LOAD ON PORT2C
0D60   3E 70                     MVI A,070H         TAKE 0111/0000 HI
0D62   D3 EE                     OUT PORT2C
0D64   C9                        RET                RETURN TO CALLING ROUTINE
0D65   DB 7E          DTMIN      IN APDATA          CLEAR LOW ORDER BYTE OUT OF AP
0D67   AF                        XRA A              ZERO ACCUMULATOR
0D68   D3 7E                     OUT APDATA         ZERO 2ND BYTE IN APSTACK
0D6A   C3 34 0D                  JMP DALP2          GO BACK AND OUTPUT ZERO
0D6D   DB 7E          DTMAX      IN APDATA          CLEAR LOW ORDER BYTE OUT OF AP
0D6F   3E FF                     MVI A,0FFH         SET ACC ALL ONES
0D71   D3 7E                     OUT APDATA         SET 2ND BYTE IN APSTACK TO ONES
0D73   C3 34 0D                  JMP DALP2          GO BACK AND OUTPUT MAX VALUE(4095)
0D76   3A 45 3E       DACSET     LDA POSCH          LOAD VALUE OF POSITION CHANNEL INTO A
0D79   C9                        RET
0D7A   3E 40          ALARM      MVI A,040H         SET BG,0100/0000
0D7C   32 60 3E                  STA ALADD          STORE IN ALARM ADDRESS
0D7F   C9                        RET
                      ;          REZRO              CALCULATES OFNEW=OFOLD+OPG-(BIOLD+
                      ;                             BINEW)*.5   USED TO PUT ADC OUT AT .020
0D80   21 5A 3E       REZRO      LXI H,DAOLD+2*POSCHN+1
0D83   22 5B 3E                  SHLD POSNAD        STORED FOR NEW RDGS ADDR
0D86   21 48 3E                  LXI H,DAOLD+1      LO ORDER BYTE OF 1ST RDG
0D89   22 5D 3E                  SHLD POSOAD        STORED FOR OLD ADDR RDGS
0D8C   AF                        XRA A              ZERO ACCUMULATOR
0D8D   32 5F 3E                  STA DACCH          ZERO DAC CHANNEL NUMBER
0D90   2A 5D 3E       REZRL1     LHLD POSOAD        LOAD ADDR FOR OLD RDGS
0D93   EB                        XCHG               MOVE TO DE
0D94   2A 5B 3E                  LHLD POSNAD        LOAD ADDR FOR NEW RDGS
0D97   CD 00 00     E            CALL SADDB         ADD NEW TO OLD RDGS
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0D9A  23                         INX H               OLD ADDR COUNTS UP-INCREMENT 3X
0D9B  23                         INX H
0D9C  23                         INX H
0D9D  22 5D 3E                   SHLD POSOAD         STORE BACK IN RAM
0DA0  EB                         XCHG                SWITCH NEW ADDR INTO HL
0DA1  2B                         DCX H               DECREMENT NEW ADDR COUNTS DOWN
0DA2  22 5B 3E                   SHLD POSNAD         RESTORE NEW POSITION ADDRESS
0DA5  3E 02                      MVI A,02H           LOAD 2 INTO APSTACK
0DA7  D3 7E                      OUT APDATA
0DA9  AF                         XRA A
0DAA  D3 7E                      OUT APDATA
0DAC  CD 00 00      E            CALL SDIV           DIVIDE SUM OF OLD&NEW RDG BY 2
0DAF  CD 00 00      E            CALL CHSS           CHANGE AVGERAGE TO NEGATIVE
0DB2  3A 5F 3E                   LDA DACCH           LOAD DAC CHANNEL NO INTO A
0DB5  87                         ADD A               DOUBLE A
0DB6  21 83 12                   LXI H,DACOF+1       BASE ADDR OF DAC ZERO OFFSETS
0DB9  5F                         MOV E,A             MOVE ADDR OFFSET TO E
0DBA  16 00                      MVI D,0             DE CONTAINS OFFSET
0DBC  19                         DAD D               INCREMENT HL BY 2*DACCH
0DBD  CD 00 00      E            CALL SADDA          APSTACK =DACOF0-BSUM/2
0DC0  21 66 3C                   LXI H,DACOFS+1      BASE ADDR OF OLD DACOFFSET RDGS
0DC3  19                         DAD D               INCREMENT BY CHANNEL COUNT
0DC4  CD 00 00      E            CALL SADDA          APSTACK=DACOFOLD+DACOF0-BSUM/2
0DC7  CD 00 00      E            CALL TOS2           SAVE NEW DACOFFSET AT PROPER RAM ADDR
0DCA  3A 5F 3E                   LDA DACCH
0DCD  FE 09                      CPI POSCHN          COMPARE TO NO OF POSITION CHS
0DCF  D0                         RNC                 RETURN IF COUNT.GE.NO POS CHS
0DD0  3C                         INR A               INCREMENT CHANNEL COUNT
0DD1  32 5F 3E                   STA DACCH           STORE BACK IN RAM
0DD4  C3 90 0D                   JMP REZRL1          LOOP BACK UNTIL DONE
                        ;
                        ;        CARRET              HANG HERE UNTIL A CARRIAGE RETURN IS TYPED
                        ;
0DD7  CD 00 00      E   CARRET   CALL GETCH          GET A CHARACTER FROM THE TERMINAL
0DDA  CD 00 00      E            CALL ECHO           PRINT IT OUT
0DDD  79                         MOV A,C             STICK IT IN A
0DDE  FE 0D                      CPI CR              SEE IF IT WAS A CARRIAGE RETURN
0DE0  C2 D7 0D                   JNZ CARRET          LOOK AGAIN IF NOT
0DE3  C9                         RET                 RETURN IF IT WAS
                        ;
                        ;        DACALB              PROGRAM TO CALIBRATE DAC'S
                        ;
0DE4  3E 77             DACALB   MVI A,077H          VALUE TO RUN RECORDER 0111/0111
0DE6  D3 ED                      OUT PORT2D          RECORDER ON,CALIBRATOR OFF
0DE8  3E 80                      MVI A,PRT10         SET PORT1 FOR OUTPUT
0DEA  D3 F7                      OUT PORT1
0DEC  21 15 3E                   LXI H,PROPA         LOAD ADDRESS OF CALCULATED PROPS
0DEF  0E 08                      MVI C,4*PROPN       NUMBER OF BYTES TO BE ZEROED IN C
0DF1  AF                         XRA A               A REGISTER ZEROED
0DF2  CD 00 00      E            CALL ZERO           ZERO THEM
0DF5  21 09 00          DACCL2   LXI H,POSCHN        SET UP POSITION CHANNEL COUNT
0DF8  22 45 3E                   SHLD POSCH          STORE IN RAM
0DFB  21 59 3E                   LXI H,DAOLD+2*POSCHN
0DFE  22 5B 3E                   SHLD POSNAD         STORED FOR NEW RDGS ADDR
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0E01  21 48 3E              LXI H,DAOLD+1    LO ORDER BYTE OF 1ST RDG
0E04  22 5D 3E              SHLD POSOAD      STORED FOR OLD ADDR RDGS
0E07  21 0F FF              LXI H,0FF0FH     LOAD MAX VALUE IN HL
0E0A  22 61 3E              SHLD THMIN       STORE 4095 AS MINIMUM THICKNESS
0E0D  AF                    XRA A            ZERO ACCUMULATOR
0E0E  32 5F 3E              STA DACCH        ZERO DAC CHANNEL NUMBER
0E11  CD FF 0C     DACAL1   CALL DACON1      CONVERT TO ANALOG & SEND TO RECORDER
0E14  21 18 3E              LXI H,PROPA+3    ADDRESS OF CALIBRATION PROP IN HL
0E17  CD 4E 0E              CALL DACON3      SEND TO CHANNEL 7
0E1A  21 45 3E              LXI H,POSCH      LOAD HL WITH CHANNEL POSITION INDEX
0E1D  35                    DCR M            DECREMENT INDEX
0E1E  F2 11 0E              JP DACAL1        LOOP BACK FOR ALL POSITION CHANNELS
0E21  21 18 3E              LXI H,PROPA+3          PRINT DECIMAL VALUE OF PROPERTIES
0E24  CD 00 00   E          CALL WRIA
0E27  CD 00 00   E          CALL PTOD        POP TOP OF STACK,SET STATUS BITS
0E2A  01 03 05              LXI B,0503H      ON TERMINAL
0E2D  CD 00 00   E          CALL PRINTF
0E30  21 43 12              LXI H,DACMS      DAC CALIB MSG IN HL
0E33  06 07                 MVI B,LDACMS     LENGTH OF MESSAGE IN B
0E35  CD 4D 0F              CALL MSGOUT      PRINT MESSAGE ON TERMINAL
0E38  21 18 3E              LXI H,PROPA+3
0E3B  11 A5 12              LXI D,TENMIL+3   INCREMENT PROPERTY RDGS BY TEN MILS
0E3E  CD 00 00   E          CALL FADDD       ADD 0.01 TO VALUES
0E41  EB                    XCHG             HL ADDRESSES PROPA
0E42  CD 00 00   E          CALL TOS4        SAVE PROPA+0.01 IN RAM
0E45  CD D7 0D              CALL CARRET      HANG UP UNTIL A CR IS TYPED
0E48  C3 F5 0D              JMP DACCL2
                 ;
                 ;          DACON2           2ND DAC PROG.,CAL LACK-OF-PENETRATION
                 ;                           MINIMUM VALUE STORES AS THMIN.
                 ;                           OUTPUT AND RESET WHEN CHANNELS ARE RESET
                 ;
0E4B  21 1C 3E     DACON2   LXI H,PROPA+7    ADDR OF 2ND PROPERTY TO BE CALCULATED
0E4E  11 9D 12     DACON3   LXI D,DAFAC2+3   DE CONTAIN 2ND CONVERSION FACTOR ADDR
0E51  CD 00 00   E          CALL FMULB       FLOATING MULTIPLICATION PERFORMED
0E54  CD 00 00   E          CALL FIXS        CONVERTED NO FIXED
0E57  CD 00 00   E          CALL PTOS        SAVE A COPY OF NEW RDG ON APSTACK
0E5A  21 62 3E              LXI H,THMIN+1    ADDR OF MINIMUM RDG IN HL
0E5D  CD 00 00   E          CALL SSUBA       CUR VAL-THMIN ON APSTACK
0E60  DB 7E                 IN APDATA        HI ORDER AP BYTE IN A
0E62  FE 80                 CPI 080H         IF HI BYTE.GE.80H,CUR VAL.LT.THMIN
0E64  DB 7E                 IN APDATA        FLUSH LOW BYTE
0E66  D4 00 00   E          CNC TOS2         COPY NEW MIN INTO THMIN IF NEW VAL LESS
0E69  3A 45 3E              LDA POSCH        LOAD A WITH POSITION CHANNEL NO.
0E6C  3D                    DCR A            DECREMENT A
0E6D  F0                    RP               RETURN IF POS;POSCH WASN'T ZERO
0E6E  21 61 3E              LXI H,THMIN      ADDR OF MIN THICKNESS INTO HL
0E71  7E                    MOV A,M          HI ORDER BYTE LOADED INTO A
0E72  D3 F6                 OUT PORT1C       OUTPUTTED TO PORT1C.DAC LINES
0E74  FE 04                 CPI 04H          COMPARE TO 00.0/0100,SET ALARM
0E76  DC 7A 0D              CC ALARM         IF L-O-P .LT.50 MILS.
0E79  23                    INX H            INCREMENT COUNTER
0E7A  7E                    MOV A,M          LO ORDER BYTE FROM MEM
0E7B  D3 F4                 OUT PORT1A       LATCHED ON PORT1A,ADC LINES
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0E7D  3E 07                   MVI A,007H        VALUE FOR ADC CH 7
0E7F  D3 F5                   OUT PORT1B        CONTROL LINES SET FOR DAC
0E81  3E 60                   MVI A,060H        STROBE DACS LO.THEN HI
0E83  D3 EE                   OUT PORT2C        DAC LOAD ON PORT2C
0E85  3E 70                   MVI A,070H        TAKE 0111/0000 HI
0E87  D3 EE                   OUT PORT2C
0E89  C9                      RET               RETURN TO CALLING ROUTUNE
                    ;         DACONS            PROGRAM TO DRIVE ACDDACS
                    ;                           FOR WELD REPAIR INSPECTION
                    ;
0E8A  21 24 3E      DACONS    LXI H,PROPA+15    LAST BYTE OF CAL PROP=PROPA+4*PROPN+7
0E8D  0E 04                   MVI C,PROPN+2     REG C CONTAINS NO OF PROPS FOR SQRWLD
0E8F  06 00                   MVI B,00H         REG BC CONTAINS PROP NO INDEX
0E91  11 9D 12      DALPS1    LXI D,DAFAC2+3    DE CONTAINS CONVERSION FACTOR INDEX ***
0E94  CD 00 00   E            CALL FMULB        FLOATING MULTIPLY PERFORMED
0E97  CD 00 00   E            CALL FIXS         CONVERTED TO FIXED NO
0E9A  21 0D 12                LXI H,DACOF+11    LOAD ADDR OF OFFSETS (START AT 7TH) IN HL
0E9D  09                      DAD B             DACOF+11+2*PROPN IN HL
0E9E  09                      DAD B             STORED AS PROPN1,PROPN2,... VAL*01000
0E9F  CD 00 00   E            CALL SADDA        SUBTRACT OFFSET
0EA2  DB 7E                   IN APDATA         HI ORDER BYTE FROM APSTACK TO A REG
0EA4  FE 80                   CPI 080H          IF HI BYTE.GE. 80H NUMBER IS NEG
0EA6  D2 C9 0E                JNC DTMINS        SET DATA TO MINIMUM VALUE (0)
0EA9  FE 10                   CPI 010H          IF HI BYTE.GE. 10,NUMBER.GT.4095
0EAB  D2 D1 0E                JNC DTMAXS        SET DATA TO 4095 (0000/1111 1111/1111)
0EAE  D3 F6         DALPS2    OUT PORT1C        OUTPUT TO DAC LINES
0EB0  DB 7E                   IN APDATA         LOW ORDER BYTE LOADED FROM APSTACK
0EB2  D3 F4                   OUT PORT1A        OUTPUT TO LOW ORDER DAC LINES
0EB4  79                      MOV A,C           LOAD CH NO IN A
0EB5  3D                      DCR A             CH COUNT STARTS AT 0
0EB6  C6 80                   ADI 080H          ADD 1000/000,E1,83048 SELECTED,TR HI
0EB8  D3 F5                   OUT PORT1B        CONTROL LINES SET FOR DAC
0EBA  3E 60                   MVI A,060H        STROBE DACS LO.THEN HI
0EBC  D3 EE                   OUT PORT2C        DAC LOAD ON 2C
0EBE  3E 70                   MVI A,070H        TAKE 0111/0000 HI
0EC0  D3 EE                   OUT PORT2C
0EC2  EB                      XCHG              EXCHANGE HL&DE(FMULB EXCHANGED ONCE)
0EC3  2B                      DCX H             HL DECREMENTED FOR NEXT PROPERTY
0EC4  0D                      DCR C             PROPERTY NUMBER COUNTER DECREMENTED
0EC5  C2 91 0E                JNZ DALPS1        LOOP BACK IF NOT DONE
0EC8  C9                      RET               RETURN IF DONE
0EC9  DB 7E         DTMINS    IN APDATA         CLEAR LOW ORDER BYTE OUT OF AP
0ECB  AF                      XRA A             ZERO ACCUMULATOR
0ECC  D3 7E                   OUT APDATA        ZERO 2ND BYTE IN APSTACK
0ECE  C3 AE 0E                JMP DALPS2        GO BACK AND OUTPUT ZERO
0ED1  DB 7E         DTMAXS    IN APDATA         CLEAR LOW ORDER BYTE OUT OF AP
0ED3  3E FF                   MVI A,0FFH        SET ACC ALL ONES
0ED5  D3 7E                   OUT APDATA        SET 2ND BYTE IN APSTACK TO ONES
0ED7  C3 AE 0E                JMP DALPS2        GO BACK AND OUTPUT MAX VALUE(4095)
                    ;
                    ;         OUTLIF            PROGRAM TO OUTPUT LIFTOFF
                    ;                           EVERY F TIMES.BELL RINGS IF LIFTOFF
                    ;                           IS BELOW LIFMIN.
                    ;
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                      ;OUTLIF    LHLD CONTR       COUNT NUMBER LOADED INTO HL
                      ;          MOV A,H          LAST BYTE OF COUNT NO LOADED INTO ACC
                      ;          ANI 0FH          DUMP 4 HI ORDER BITS
                      ;          RNZ              RETURN IF NOT ZERO
                      ;          LXI H,PROPA+11   ADDR OF LIFTOFF IN HL
                      ;
                      ;          RDSTD            PROGRAM READS NOMINAL TUBE STD
                      ;                           STORES DATA IN RAM AT VOLNEW.SETS VSTBYT=A
                      ;
0EDA  3E 99            RDSTD     MVI A,PRT1I      LOAD PROGRAM WORD FOR A&C INPUT,B OUTPUT
0EDC  D3 F7                      OUT PORT1        SEND TO PORT 1
0EDE  3E 90                      MVI A,090H       LOAD PROGRAM WORD,A=INPUT,B&C=OUTPUT
0EE0  D3 EF                      OUT PORT2        SEND TO PORT2.
0EE2  3E 70                      MVI A,070H       SET MAG TAPE READ,WRITE,DAC LATCH HI
0EE4  D3 EE                      OUT PORT2C       LEAVE STROBE LINES HI
0EE6  3E 07                      MVI A,07H        SET CALIBRATOR RELAYS FOR PROBE RDGS
0EE8  D3 ED                      OUT PORT2B       SET CALIBRATOR ADDRESSES
0EEA  01 08 00                   LXI B,0008       LOAD DELAY FOR DC
0EED  CD 00 0B                   CALL DELAY       DELAY FOR 150 MS TO ALLOW RDGS TO SETTLE
0EF0  CD 00 0B                   CALL DELAY       DELAY FOR 150 MS TO ALLOW RDGS TO SETTLE
0EF3  06 80                      MVI B,080H       MAKE 128 READINGS OF THE STANDARDS
0EF5  0E 06                      MVI C,06H        READ 6 CHANNELS
0EF7  CD AE 0A                   CALL SMDAT       DATA SUMMED & STORED
0EFA  0E 06                      MVI C,06         6 RAW DATA WORDS WILL BE FLOATED & CONVRTD
0EFC  11 40 3E                   LXI D,VOLNEW+14H
0EFF  21 32 3C                   LXI H,RAWDA+17H  HL=LAST RAW DATA VALUE,LAST BYTE
0F02  CD 00 00   E     RDSTDL    CALL FLTDA       FLOAT DOUBLE WORD
0F05  E5                         PUSH H           STORE ADDR ON STACK
0F06  21 51 12                   LXI H,CALSFR+3   ADDR OF CALIBRATION STANDARD FACTOR LOADED
0F09  CD 00 00   E               CALL FMULA       FPSTACK =VOLNEW
0F0C  EB                         XCHG             ADDR OF VOLNEW IN HL
0F0D  CD 00 00   E               CALL TOS4        STORED IN RAM
0F10  11 F9 FF                   LXI D,0FFFFH-6   SUBTACT 6 FROM HL
0F13  19                         DAD D            HL= ADDR OF NEXT VOLNEW WORD
0F14  EB                         XCHG             STORED IN DE
0F15  E1                         POP H
0F16  2B                         DCX H            HL ADDR NEXT RAW DATA WORD
0F17  0D                         DCR C            DECREMENT C COUNTER
0F18  C2 02 0F                   JNZ RDSTDL
0F1B  01 04 08                   LXI B,0804H      B.C=XXXX.XXXX PRINT FORMAT
0F1E  11 01 06                   LXI D,0601H      PRINT 6 PER LINE,1 LINE
0F21  21 2C 3E                   LXI H,VOLNEW     PRINT VALUES READ FOR VOLNEW ON TERM
0F24  CD 00 00   E               CALL FPRNT
0F27  3E AA                      MVI A,0AAH
0F29  32 44 3E                   STA VSTBYT       SET VSTBYT=AA,SHOW THAT STANDARD HAS BEEN
0F2C  C3 00 00   E               JMP GETCM        RETURN TO MONITOR
                      ;
                      ;          PCALP            PROGRAM TO PRINT CALCULATED
                      ;                           PROPERTIES
                      ;
0F2F  2A 19 3C         PCALP     LHLD CONTR       LOAD COUNT NUMBER FROM RAM
0F32  7C                         MOV A,H          MOVE TO ACCUMULATOR
0F33  CD 00 00   E               CALL NMOUT       PRINT HI LEN BYTE
0F36  7D                         MOV A,L          MOVE LOW BYTE TO ACC
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0F37  CD 00 00    E             CALL NMOUT      PRINT OUT
0F3A  0E 20                     MVI C,020H      LOAD A SPACE
0F3C  CD 00 00    E             CALL CO         PRINT A SPACE
0F3F  21 15 3E                  LXI H,PROPA     1ST PROP CAL IN HL
0F42  16 02                     MVI D,PROPN     LOAD NUMBER PER LINE INTO D
0F44  1E 01                     MVI E,01        LOAD 1 LINE INTO C
0F46  01 04 08                  LXI B,0804H     LOAD FORMAT IN BC
0F49  CD 00 00    E             CALL FPRNT      PRINT PROPN NOS IN F8.4 FORMAT
0F4C  C9                        RET             RETURN TO CALLING PROGRAM
                   ;
                   ;  MSGOUT     ROUTINE TO PRINT ASCII ON TTY
                   ;             ADDR OF MESSAGE IN HL, LENGTH IN CHARS IN B
                   ;
0F4D  4E           MSGOUT       MOV C,M         GET NEXT CHAR
0F4E  CD 00 00    E             CALL CO
0F51  23                        INX H           POINT TO NEXT CHAR
0F52  05                        DCR B           UPDATE BYTE COUNTER
0F53  C2 4D 0F                  JNZ MSGOUT      KEEP GOING UNTIL B=0
0F56  C9                        RET             RETURN TO CALLER
                   ;
                   ;
                   ;            WRTAP           PROGRAM TO WRITE DATA ON MAG TAPE
                   ;            DATA IS WRITTEN FROM BC THROUGH DE ON THE TAPE
                   ;                            USE DAC LOAD & 8205 CHIP ADDR.
0F57  3E 86        WRTAP        MVI A,086H      SELECT TAPE DRIVE,SET UP FOR WRITE
0F59  D3 F5                     OUT PORT1B      SEND TO PORT 1B
0F5B  2A 63 3E                  LHLD BYCNT      LOAD BYTE COUNT FOR MAG TAPE IN HL
0F5E  0A           WRTLP        LDAX B          LOAD BYTE ADDR BY BC INTO A
0F5F  D3 F4                     OUT PORT1A      SEND OUT TO TAPE DATA
0F61  CD B2 0F                  CALL STBTAP     STROBE ANOTHER BYTE OUT TO TAPE
0F64  D2 5E 0F                  JNC WRTLP       LOOP BACK IF NOT DONE
0F67  22 63 3E                  SHLD BYCNT      STORE BYTE COUNT BACK IN RAM
0F6A  C9                        RET             RETURN TO CALLING ROUTINE WHEN DONE
                   ;
                   ;            RDTAP           PROGRAM TO READ DATA FROM TAPE INTO RAM
                   ;                            FROM BC THROUGH DE
                   ;
0F6B  2A 63 3E     RDTAP        LHLD BYCNT      GET BYTE COUNT FOR MAG TAPE INTO HL
0F6E  DB DC        RDTAPL       IN PORT3A       READ DATA FROM TAPE
0F70  02                        STAX B          STORE A IN RAM ADDR BY BC
0F71  CD B2 0F                  CALL STBTAP     STROBE TAPE TO READ
0F74  D2 6E 0F                  JNC RDTAPL      LOOP BACK IF NOT DONE
0F77  22 63 3E                  SHLD BYCNT      STORE BYTE COUNT IN RAM
0F7A  C9                        RET             RETURN TO CALLING ROUTINE WHEN DONE
                   ;
                   ;            WRTAPF          FAST VERSION OF WRITE TAPE,USED FOR MAIN R
                   ;
0F7B  3E 86        WRTAPF       MVI A,006H      SELECT TAPE DRIVE,SET UP FOR WRITE
0F7D  D3 F5                     OUT PORT1B      SEND TO PORT 1B
0F7F  2A 63 3E                  LHLD BYCNT      LOAD BYTE COUNT FOR MAG TAPE IN HL
0F82  0A           WRTLPF       LDAX B          LOAD BYTE ADDR BY BC INTO A
0F83  D3 F4                     OUT PORT1A      SEND OUT TO TAPE DATA
0F85  CD B2 0F                  CALL STBTAP     STROBE ANOTHER BYTE OUT TO TAPE
0F88  0A                        LDAX B          LOAD BYTE ADDR BY BC INTO A
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0F89  D3 F4                  OUT PORT1A       SEND OUT TO TAPE DATA
0F8B  CD B2 0F               CALL STBTAP      STROBE ANOTHER BYTE OUT TO TAPE
0F8E  03                     INX B            INCREMENT BC COUNTER TWICE,SKIP
0F8F  03                     INX B            TWO RAM LOCATIONS
0F90  D2 82 0F               JNC WRTLPF       LOOP BACK IF NOT DONE
0F93  22 63 3E               SHLD BYCNT       STORE BYTE COUNT BACK IN RAM
0F96  C9                     RET              RETURN TO CALLING ROUTINE WHEN DONE
                    ;
                    ;        RDTAPF           FAST VERSION OF READ TAPE,USED FOR MAIN RU
                    ;
0F97  2A 63 3E      RDTAPF   LHLD BYCNT       GET BYTE COUNT FOR MAG TAPE INTO HL
0F9A  DB DC         RDTFL    IN PORT3A        READ DATA FROM TAPE
0F9C  02                     STAX B           STORE A IN RAM ADDR BY BC
0F9D  CD B2 0F               CALL STBTAP      STROBE TAPE TO READ
0FA0  DB DC                  IN PORT3A        READ DATA FROM TAPE
0FA2  02                     STAX B           STORE A IN RAM ADDR BY BC
0FA3  AF                     XRA A            ZERO A,WILL ZERO NEXT 2 RAM LOCS
0FA4  03                     INX B            INCREMENT BC COUNTER
0FA5  02                     STAX B           ZERO RAM LOCATION
0FA6  03                     INX B            INCREMENT BC COUNTER
0FA7  02                     STAX B           ZERO RAM LOCATION
0FA8  CD B2 0F               CALL STBTAP      STROBE TAPE TO READ
0FAB  D2 9A 0F               JNC RDTFL        LOOP BACK IF NOT DONE
0FAE  22 63 3E               SHLD BYCNT       STORE BYTE COUNT IN RAM
0FB1  C9                     RET              RETURN TO CALLING ROUTINE WHEN DONE
                    ;
                    ;        STBTAP           STROBE TAPE TO READ OR WRITE,CARRY SET WHE
                    ;
0FB2  AF            STBTAP   XRA A            STROBE RAC LINE LO,THEN HI
0FB3  D3 EE                  OUT PORT2C
0FB5  3E 10                  MVI A,10H
0FB7  D3 EE                  OUT PORT2C
0FB9  23                     INX H            ADD ONE BYTE TO THE BYTE COUNT
0FBA  03                     INX B            INCREMENT BC COUNTER
0FBB  7B                     MOV A,E          TEST TO SEE IF BC.GT.DE
0FBC  91                     SUB C            SUBTRACT BC FROM DE,GET A BORROW WHEN
0FBD  7A                     MOV A,D          BC.GT.DE(CARRY IS SET)
0FBE  98                     SBB B
0FBF  C9                     RET
                    ;
                    ;        RWCLTP           READS RAW DATA FROM MAG TAPE &
                    ;                         CALCULATES PROPS, THEN DISPLAYS THEM ON
                    ;                         THE TERMINAL
                    ;
0FC0  3E 88         RWCLTP   MVI A,PRT1D      SET PORTS FOR DAC OUTPUT
0FC2  D3 F7                  OUT PORT1        SEND CONTROL WORD TO PORT 1
0FC4  3E 05                  MVI A,05H        SELECT TAPE DRIVE,SET UP FOR READ
0FC6  D3 F5                  OUT PORT1B       SEND TO PORT 1B
0FC8  21 00 00               LXI H,0000H      INIT BYTE COUNT SO WE CAN READ AN INTEGER
0FCB  22 63 3E               SHLD BYCNT       NUMBER OF BUFFERS AND KEEP THE EOF'S STRAI
0FCE  21 E6 11               LXI H,TAPMP      ADDRESS OF TAPE PROMPT MESSAGE
0FD1  06 1C                  MVI B,LTAPPR     LENGTH OF PROMPT MESSAGE
0FD3  CD 4D 0F               CALL PROMPT      PRINT PROMPT
0FD6  CD 9F 11      FILEHL   CALL RDASID      READ TITLE FROM TAPE(1ST LINE)
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                               ;
                               ;       FILEPR          FILE PROCESSOR PROGRAM SKIPS TO GIVEN RECO
                               ;                       STARTS PROCESSING THE FILE
                               ;
0FD9  21 01 12         PROPPR         LXI H,PROPR      PROMPT FOR PROPERTY TO BE DISPLAYED
0FDC  06 22                           MVI B,LPROPR     LENGTH OF PROMPT
0FDE  CD 4D 0F                        CALL MSGOUT
0FE1  0E 01                           MVI C,01H
0FE3  CD 00 00    E                   CALL GETNM       GET HEX  NO FROM TERMINAL
0FE6  E1                              POP H            RESTORE PROP NO TO HL
0FE7  22 6A 3E                        SHLD NPROP       STORE PROPERTY NO TO BE CALCULATED IN RAM
0FEA  01 99 3D                        LXI B,CALRD      LOAD ADDR OF CALB RDGS IN BC
0FED  11 F8 3D                        LXI D,CALRD+05FH 60H BYTES OF CALB RDGS TO BE STORED
0FF0  CD 6B 0F                        CALL RDTAP       DATA FROM BC TROUGH DE STORED
0FF3  CD 88 0B                        CALL PRCLB       PRINT CALIBRATION READINGS
0FF6  01 35 3C                        LXI B,CRFRA      ADDRESS OF CORRECTION FACTORS IN BC
0FF9  11 64 3C                        LXI D,CRFRA+02FH LAST CRFRA ADDR IN DE
0FFC  CD 6B 0F                        CALL RDTAP       CORRECTION FACTORS FROM RECALIB ON TAPE
0FFF  21 35 3C                        LXI H,CRFRA      WILL PRINT OUT CORRECTION FACTORS,OFSET,SL
1002  11 06 02                        LXI D,0206H      PRINT 2 PER LINE,6 LINES
1005  01 06 0A                        LXI B,0A06H      LOAD FIXED FORMAT,10 DIGITS,6 AFTER DEC
1008  CD 00 00    E                   CALL FPRNT       PRINT IN FIXED FORMAT
100B  21 01 00                        LXI H,00001H     SET COUNT NO TO 1
100E  22 19 3C                        SHLD CONTN       SET IN RAM
1011  01 00 38                        LXI B,TAPDAT     WE WILL DUMP 1ST BLOCK OF
1014  11 79 38                        LXI D,TAPDAT+079H DATA FROM TAPE SINCE IT
1017  CD 6B 0F                        CALL RDTAP       HAS THE WRONG COUNT NO.
101A  21 45 3E         RESTR1         LXI H,POSCH      LOAD HL WITH POS CHAN ADDR
101D  CD 69 10                        CALL RESET1      START WITH POSCH SET TO POSCHN
1020  01 1B 3C         CALTL          LXI B,RAWDA      LOAD STARTING ADDR INTO BC
1023  AF                              XRA A            ZERO ACCUMULATOR
1024  02                              STAX B           ZERO 1ST RAW DATA BYTE
1025  03                              INX B            MOVE TO 2ND RAW DATA BYTE
1026  02                              STAX B            ZERO IT
1027  03                              INX B            MOVE TO 3RD RAW DATA ADDRESS
1028  11 32 3C                        LXI D,RAWDA+17H  STOP AFTER ALL RAW RDGS
102B  CD 97 0F                        CALL RDTAPF      READ RAW DATA FROM TAPE INTO RAM
102E  CD 7F 08                        CALL FLTCOR      FLOAT AND CORRECT RAW READINGS
1031  3A 6A 3E                        LDA NPROP        LOAD NO OF PROP TO BE CALCULATED
1034  CD 38 0A                        CALL POLSM       CAL PROP,VALUE ON APSTACK
1037  21 15 3E                        LXI H,PROPA      WRITE PROPERTY AT 1ST PROPA LOC IN RAM
103A  CD 00 00    E                   CALL TOS4        STORE TOP OF APSTACK IN RAM
103D  CD FF 0C                        CALL DACON1      SEND PROPERTY TO 5 CHANNEL DAC,STRIP CHART
1040  3E 05                           MVI A,05P        SELECT TAPE DRIVE,SET UP FOR READ
1042  D3 F5                           OUT PORT18       SEND TO PORT 18
1044  21 45 3E                        LXI H,POSCH      LOAD HL WITH CHANNEL POSITION ADDR
1047  35                              DCR M            DECREMENT CHANNEL POSITION INDEX IN MEM
1048  FC 69 10                        CM RESET1        RESET POS CH,INR COUNT NO.
                       ;              CALL MCALF       PRINT PROPERITES ON TERMINAL
104B  C3 20 10                        JMP CALTL        STAY IN LOOP UNTIL DONE
104E  01 99 3D         CALTC          LXI B,CALRD      LOAD ADDRESS OF CALIBRATION RDGS IN BC
1051  11 F8 3D                        LXI D,CALRD+05FH 60 BYTES OF CALB RDGS TO BE STORED
1054  CD 6B 0F                        CALL RDTAP       DATA FROM BC TROUGH DE STORED
1057  CD 88 0B                        CALL PRCLB       PRINT CALIBRATION READINGS
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105A  CD 36 11                   CALL DUMPUF      FINISH OUT CURRENT BUFFER AND EOF BUF
105D  21 01 00                   LXI H,0001       LOAD 0001 INTO HL
1060  22 63 3E                   SHLD BYCNT       STORE IN BYTE COUNT
1063  CD 36 11                   CALL DUMPUF      READ EOF BUFFER
1066  C3 00 00     E             JMP GETCH        RETURN TO MONITTOR
                          ;
1069  36 09               RESET1 MVI M,POSCHN     RESET POSITION CHANNEL NO
106B  2A 19 3C                   LHLD CONTN       LOAD COUNT NUMBER FROM RAM
106E  23                         INX H            INCREMENT COUNT NUMBER
106F  E5                         PUSH H           STORE COUNT NUMBER ON STACK
1070  01 19 3C                   LXI B,CONTN      LOAD COUNT NO ADDR INTO BC
1073  11 1A 3C                   LXI D,CONTN+1    END OF COUNT NO IN DE
1076  CD 6B 0F                   CALL RDTAP       READ COUNT NO FROM TAPE
1079  2A 19 3C                   LHLD CONTN       LOAD TAPE COUNT NUMBER FROM RAM
107C  D1                         POP D            COUNT NO FROM RAM IN DE
107D  7A                         MOV A,D          MOVE HI BYTE OF RAM CT NO TO A
107E  BC                         CMP H            COMPARE TO H,HI BYTE FROM TAPE
107F  C2 98 10                   JNZ STOP         ENTER STOP ROUTINE IF.NE.
1082  7B                         MOV A,E          MOVE LO BYTE FROM RAM TO A
1083  BD                         CMP L            COMPARE TO L,LO BYTE FROM TAPE
1084  C2 98 10                   JNZ STOP         GO TO STOP ROUTINE IF.NE.
1087  21 59 3E                   LXI H,DAOLD+2*POSCHN
108A  22 5B 3E                   SHLD POSNAD      STORED FOR NEW RDGS ADDR
108D  21 48 3E                   LXI H,DAOLD+1    LO ORDER BYTE OF 1ST RDG
1090  22 5D 3E                   SHLD POSOAD      STORED FOR OLD ADDR RDGS
1093  AF                         XRA A            ZERO ACCUMULATOR
1094  32 5F 3E                   STA DACCH        ZERO DAC CHANNEL NUMBER
1097  C9                         RET
                          ;
                          ;      STOP             ROUTINE TO STOP TAPE IF COUNT NOS
                          ;                       DID NOT MATCH
                          ;
1098  C1                  STOP   POP B            POP STACK-GET SET TO STOP
1099  23                         INX H            INCREMENT TAPE CT NO,SEE IF AT END
109A  7A                         MOV A,D          MOVE HI BYTE OF RAM CT NO TO A
109B  BC                         CMP H            COMPARE TO H,HI BYTE FROM TAPE
109C  C2 A7 10                   JNZ STOP1        ENTER STOP ROUTINE IF.NE.
109F  7B                         MOV A,E          MOVE LO BYTE FROM RAM TO A
10A0  BD                         CMP L            COMPARE TO L,LO BYTE FROM TAPE
10A1  C2 A7 10                   JNZ STOP1        GO TO STOP ROUTINE IF.NE.
10A4  C3 4E 10                   JMP CALTC        WE WERE AT END OF TAPE-RD CALIB
10A7  21 23 12            STOP1  LXI H,STPMS      ABNORMAL TAPE DATA MESSAGE
10AA  06 20                      MVI B,LSTPMS     LENGTH OF MESSAGE
10AC  CD 4D 0F                   CALL MSGOUT
10AF  C3 00 00     E             JMP GETCH        RETURN TO MONITOR
                          ;
                          ;      RESTR            ATTEMPTS TO START READING TAPE AGAIN
                          ;                       AFTER AN ERROR AND HALT
                          ;
10B2  3E 88               RESTR  MVI A,PRT1C      SET PORTS FOR DAC OUTPUT
10B4  D3 F7                      OUT PORT1        SEND CONTROL WORD TO PORT 1
10B6  3E 90                      MVI A,090H      LOAD PROGRAM WORD,A=INPUT,B&C=OUTPUT
10B8  D3 EF                      OUT PORTC       SEND TO PORTC.
10BA  3E 07                      MVI A,007H       LOAD 0000/0111 INTO A,CHART OFF.
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10BC  D3 ED                 OUT PORT2B          TURN CALIBRATOR RELAYS OFF
10BE  3E 70                 MVI A,070H          SET MAG TAPE READ,WRITE,DAC LATCH HI
10C0  D3 EE                 OUT PORT2C          LEAVE STROBE LINES HI
10C2  3E 93                 MVI A,PRT3          LOAD WORD FOR A OUT, B INPUT,C I/O
10C4  D3 DF                 OUT PORT3
10C6  3E 05                 MVI A,05H           SELECT TAPE DRIVE,SET UP FOR READ
10C8  D3 F5                 OUT PORT1B          SEND TO PORT 1B
10CA  01 00 30              LXI B,TAPDAT        ADDRESS OF FIRST BYTE IN BC
10CD  11 E7 39              LXI D,TAPDAT+9E7H   ADDRESS OF LAST BYTE TO BE READ
10D0  CD 6B 0F              CALL RDTAP          READ 488 BYTES OF DATA INTO RAM
10D3  21 00 30              LXI H,TAPDAT        SET UP HL TO CONTAIN 1ST BLOCK
10D6  01 7A 30              LXI B,TAPDAT+07AH   BC ADDR OF NEXT BLOCK
10D9  11 F4 30              LXI D,TAPDAT+0F4H   DE ADDR OF 3RD DATA BLOCK
10DC  AF                    XRA A               ZERO ACCUMULATOR
10DD  32 6C 3E              STA RCNT            STORE RDG COUNT NO. IN RAM
10E0  0A          SRLP      LDAX B              LOAD LO BYTE AT BC INTO A
10E1  3D                    DCR A               LOW BYTE SHOULD BE ONE GREATER THAN L
10E2  BE                    CMP M               COMPARE TO LO BYTE AT HL
10E3  C2 14 11              JNZ INCRM           JUMP AROUND IF LO.NE.LO-1
10E6  1A                    LDAX D              LOAD LO BYTE ADDR BY DE INTO A
10E7  3D                    DCR A               LO BYTE AT DE SHOULD BE 2 GT HL
10E8  3D                    DCR A
10E9  BE                    CMP M               SEE IF LO BYTES .EQ.
10EA  C2 14 11              JNZ INCRM           JUMP AROUND IF LO.NE.LO-2
10ED  23                    INX H               LO BYTES CHECKED,LOOK AT HI BYTES
10EE  03                    INX B
10EF  13                    INX D
10F0  0A                    LDAX B              MOVE BYTE AT BC ADDR INTO A
10F1  BE                    CMP M               COMPARE BYTE AT ADDR BC TO ADDR HL
10F2  C2 17 11              JNZ INCRM1          JUMP AROUND IF HI BYTE .NE.
10F5  1A                    LDAX D              LOAD BYTE ADDR BY DE INTO A
10F6  BE                    CMP M               COMPARE HI BYTE ADDR BY DE TO ADDR HL
10F7  C2 17 11              JNZ INCRM1          JUMP AROUND IF HI BYTE .NE.
10FA  67                    MOV H,A             HI ORDER BYTE COUNT IN H
10FB  1B                    DCX D               BACK UP FOR LOW ORDER BYTE
10FC  1A                    LDAX D              LOAD ACC WITH LOW ORDER BYTE
10FD  6F                    MOV L,A             STORE IN L
10FE  23                    INX H               INCREMENT COUNT-THERE ARE 4 COUNTS IN RAM
10FF  22 19 3C              SHLD CONTN          STORE IN RAM
1102  01 00 30              LXI B,TAPDAT        WILL READ TAPE UNTIL WE GET TO NEXT CONTN
1105  3A 6C 3E              LDA RCNT            NUMBER OF RDGS NEEDED IN A
1108  11 00 30              LXI D,TAPDAT        DE SAME AS BC
110B  83                    ADD E               A CONTAINS OFFSET ADDR FOR DE
110C  3D                    DCR A               DECREMENT A
110D  5F                    MOV E,A             DE CONTAINS RDGS TO BE MADE
110E  F4 6B 0F              CP RDTAP            MAKE REQUIRED NO OF TAPE RDGS
1111  C3 1A 10              JMP RESTR1          JUMP INTO CALCULATION LOOP
                  ;
                  ;         INCRM               SUBROUTINE TO INCREMENT ADDRESSES
1114  23          INCRM     INX H               INCREMENT HL,BC,DE TO POINT TO NEXT BYTES
1115  03                    INX B
1116  13                    INX D
1117  3A 6C 3E    INCRM1    LDA RCNT            ENTER HERE IF WE HAVE ALREADY INCREMENTED
111A  3C                    INR A               ADVANCE READING COUNTER
```

```
1111B  32 6C 3E                 STA RCNT       STORE BACK IN RAM
111E  FE 7A                     CPI 07AH       COMPARE TO 122 (07AHEX)
1120  CA D2 10                  JZ RESTR       JUMP TO RESTART PROG TO READ MORE DATA
1123  C3 E0 10                  JMP SRLP       GO BACK TO SEARCH LOOP
                      ;
                      ;         RDCHRS         PROGRAM TO READ IN ASCII CHARACTERS
                      ;                        LAST 4 CHRS IN HLDE,LAST IN E
                      ;
1126  65              RDCHRS    MOV H,L        SAVE PRIOR CHARACTERS
1127  6A                        MOV L,D
1128  53                        MOV D,E        4TH CHARACTER FROM LAST IN H,LAST IN E
1129  59                        MOV E,C
112A  CD 00 00     E            CALL GETCH     GET CHARACTER FROM TERMINAL
112D  CD 00 00     E            CALL ECHO      PRINT CHARACTER ON TERMINAL
1130  FE 0A                     CPI LF         COMPARE CHARACTER TO LINE FEED
1132  C2 26 11                  JNZ RDCHRS     GO BACK & GET NEXT CHARACTER
1135  C9                        RET            A CR WAS DETECTED,RETURN TO CALLING ROUTIN
                      ;
                      ;         DUMPBF         DUMP REST OF BUFFER TO MAKE 4096
                      ;                        WILL STROBE READ IF PORT1B=05,WRITE=086H
                      ;
1136  2A 63 3E        DUMPBF    LHLD BYCNT     LOAD BYTE COUNT INTO HL
1139  7D              FINBUF    MOV A,L        SEE IF BYTE COUNT (LO 9 BITS) IS 512D
113A  FE 00                     CPI 00H
113C  C2 43 11                  JNZ TOG2
113F  7C                        MOV A,H        CHECK HI BIT TOO
1140  E6 0F                     ANI 0FH        DUMP HI ORDER BITS
1142  C8                        RZ             RETURN TO CALLER IF A MULTIPLE OF 4096
1143  AF              TOG2      XRA A          NOW TOGGLE IN ANOTHER BYTE
1144  D3 EE                     OUT PORT2C
1146  3E 10                     MVI A,10H
1148  D3 EE                     OUT PORT2C
114A  23                        INX H          INCREMENT BYTE COUNT BY ONE
114B  C3 39 11                  JMP FINBUF     GO BACK AND CHECK COUNT AGAIN
                      ;
                      ;         WEOF           TOGGLE RAC LINE LOW,THEN BACK HI
                      ;                        TO WRITE AN END OF FILE ON THE TAPE
                      ;
114E  3E 05           WEOF      MVI A,005H     SELECT TAPE DRIVE,SET UP TO WRITE
1150  D3 F5                     OUT PORT1B     END OF FILE.SEND TO PORT 1B
1152  01 01 00                  LXI B,0001     LOAD BIG DELAY IN BC
1155  CD 00 00                  CALL DELAY
1158  AF                        XRA A          STROBE RAC LINE LO,THEN HI
1159  D3 EE                     OUT PORT2C
115B  CD 00 00                  CALL DELAY     ALLOW TIME FOR EOF TO BE WRITTEN
115E  3E 10                     MVI A,10H
1160  D3 EE                     OUT PORT2C
1162  C9                        RET            RETURN TO CALLING ROUTINE
                      ;
                      ;         STOGNF         STROBE GO TO NEXT FILE
                      ;
1163  3E 00           STOGNF    MVI A,00       STROBE GO TO NEXT FILE LINE LO
1165  D3 DE                     OUT PORT3C     OUTPUT TO PORT3C
1167  3E 20                     MVI A,020H     LEAVE LINE HI
```

```
1169  D3 DE                     OUT PORT3C
116B  C9                        RET               RETURN TO CALLING ROUTINE
                        ;
                        ;       WRITE ID ON TERMINAL AND TAPE
                        ;
116C  21 D8 11          WRTID:  LXI H,MID1        GET ADDR OF 1ST ID REQUEST MSG
116F  06 0D                     MVI B,LMID1       GET # OF CHARS IN MSG
1171  CD 4D 0F                  CALL MSGOUT       PRINT IT ON TTY
1174  3E 06                     MVI A,006H        SELECT TAPE ONLY
1176  D3 F5                     OUT PORT1B
1178  3E 01                     MVI A,01H
117A  D3 EE                     OUT PORT2C        LEAVE REC HI
117C  CD 80 11                  CALL GETID
117F  C9                        RET
                        ;
                        ;  GETID  ROUTINE TO READ CHARS FROM TTY AND PRINT
                        ;         THEM AT THE CURRENT POSITION ON THE MAG TAPE.
                        ;         <CR> TERMINATES.
                        ;
1180  2A 63 3E          GETID   LHLD BYCNT        LOAD BYTE COUNT IN HL
1183  CD 00 00      E   GETID0  CALL GETCH
1186  CD 00 00      E           CALL ECHO         PRINT IT ON TTY
1189  79                        MOV A,C           GET ID CHAR INTO A
118A  D3 F4                     OUT PORT1A        PUT IT ON TAPE WRITEDATA PORT
118C  3E 00                     MVI A,00H         STROBE REC LO THEN HI
118E  D3 EE                     OUT PORT2C
1190  3E 10                     MVI A,10H
1192  D3 EE                     OUT PORT2C
1194  23                        INX H             INCREMENT RECORD BYTE COUNT
1195  3E 0D                     MVI A,0DH
1197  B9                        CMP C             WAS LAST CHAR A <CR>?
1198  C2 83 11                  JNZ GETID0        NO-GET ANOTHER CHAR
119B  22 63 3E                  SHLD BYCNT        STORE BYTE COUNT BACK IN RAM
119E  C9                        RET               YES-RETURN TO CALLER
                        ;
                        ;  READID  ROUTINE TO READ IDENTIFICATION DATA FROM TAPE
                        ;          AND PRINT IT ON THE TTY
                        ;
119F  CD 00 00      E   READID  CALL CROUT        MAKE FORMAT LOOK NICE
11A2  CD 00 00      E           CALL CROUT        TWO LINE FEEDS
11A5  2A 63 3E          RD0:    LHLD BYCNT        LOAD BYTE COUNT INTO HL
11A8  23                        INX H             INCREMENT BYTE COUNT
11A9  22 63 3E                  SHLD BYCNT        STORE BACK IN RAM
11AC  DB DC                     IN PORT3A         READ A CHAR FROM TAPE
11AE  4F                        MOV C,A
11AF  CD 00 00      E           CALL CO           OUTPUT IT TO TTY
11B2  FE 0D                     CPI CR            WAS IT A <CR>?
11B4  CA C3 11                  JZ RETRN          YES-FINISH UP & RETURN
11B7  53                        MOV D,E           LAST TWO CHARACTERS BEFORE CR SAVED IN DE
11B8  59                        MOV E,C           CHARACTER JUST PRINTED MOVED TO E
11B9  AF                        XRA A             NO-READ ANOTHER CHAR
11BA  D3 EE                     OUT PORT2C        STROBE RAC LO THEN HI
11BC  3E 10                     MVI A,10H
11BE  D3 EE                     OUT PORT2C
```

```
11C0  C3 A5 11               JMP RDO
11C3  EB           RETRN     XCHG             MOVE COIL NO TO HL SO IT CAN BE SAVED
11C4  22 66 3E               SHLD COILNT      SAVE COIL NO FROM TAPE
11C7  7D                     MOV A,L          MOVE LAST BYTE TO ACC
11C8  E6 0F                  ANI 0FH          ONLY LOOK AT FIRST 4 BITS
11CA  07                     RLC              MULTIPLY BY 2, GET OFFSET FROM ORG
11CB  C6 10                  ADI 10H          ADD ORG, WE HAVE HI BYTE OF CALD ADDR
11CD  32 2B 3E               STA CLBADR       STORE THIS HI BYTE
11D0  AF                     XRA A            LO-READ ANOTHER CHAR
11D1  D3 EE                  OUT PORT2C       STROBE KAC LO THEN HI
11D3  3E 10                  MVI A,10H
11D5  D3 EE                  OUT PORT2C
11D7  C9                     RET              RETURN TO CALLER
                   ;
                   ;  DATA STORAGE FOR MESSAGES
                   ;
11D8  0D 0A 45 4E  MID1      DB  CR,LF,'ENTER ID: '
11DC  54 45 52 20
11E0  49 44 3A 20
11E4  20
000D               LMID1     EQU $-MID1       LENGTH OF MESSAGE MID1
11E5  0D 0A 53 57  TAPPR     DB  CR,LF,'SWITCH TAPE TO READ,ONLINE'
11E9  49 54 43 48
11ED  20 54 41 50
11F1  45 20 54 4F
11F5  20 52 45 41
11F9  44 2C 4F 4E
11FD  4C 49 4E 45
001C               LTAPPR    EQU $-TAPPR      LENGTH OF TAPE PROMP MESSAGE
1201  0D 0A 44 49  PROPR     DB  CR,LF,'DISP 0.LOP 1.IDEF 2.LOFF 3.ODEF '
1205  53 50 20 30
1209  2E 4C 4F 50
120D  20 31 2E 49
1211  44 45 46 20
1215  32 2E 4C 4F
1219  46 46 20 33
121D  2E 4F 44 45
1221  46 20
0022               LPROPR    EQU $-PROPR      LENGTH OF PROPERTY PROMPT
1223  0D 0A 54 41  STPMS     DB  CR,LF,'TAPE ERROR - DO MANUAL RESTART'
1227  50 45 20 45
122B  52 52 4F 52
122F  20 2D 20 44
1233  4F 20 4D 41
1237  4E 55 41 4C
123B  20 52 45 53
123F  54 41 52 54
0020               LSTPMS    EQU $-STPMS      LENGTH OF STOP PROMPT
                   ;
1243  20 4D 49 4C  DACMS     DB ' MILS',CR,LF
1247  53 0D 0A
0007               LDACMS    EQU $-DACMS
124A  71 A0 CA 00  CALFK     DB 071H,0A0H,0CAH,0H   ;CALIB CON FAC =5/(4095*10E-4)
124E  70 A0 6A 00  CALSFR    DB 070H,0A0H,06AH,0H   ;CALIB STD FAC =5/(4095*128)
```

```
                             ;
                             ;            SLOPE EXPONENTS WAS 077H BUT THE NO OF RDGN,NRDG,
                             ;            HAS BEEN DIVIDED INTO SLOPE,OR N SUB FROM EXPT,WHERE
                             ;            2**N=NRDG
1252  00 00 00 00            CRFRO         DB 0,0,0,0,077H,0A0H,0AH,0 ;1ST OFS=0,1ST,SLP=5/4095*NRDG
1256  77 A0 0A 00
125A  00 00 00 00                          DB 0,0,0,0,077H,0A0H,0AH,0 ;2ND OFS=0,2ND,SLP=5/4095*NRDG
125E  77 A0 0A 00
1262  00 00 00 00                          DB 0,0,0,0,077H,0A0H,0AH,0 ;3RD OFS=0,3RD,SLP=5/4095*NRDG
1266  77 A0 0A 00
126A  00 00 00 00                          DB 0,0,0,0,077H,0A0H,0AH,0 ;4TH OFS=0,4TH,SLP=5/4095*NRDG
126E  77 A0 0A 00
1272  00 00 00 00                          DB 0,0,0,0,077H,0A0H,0AH,0 ;5TH OFS=0,5TH,SLP=5/4095*NRDG
1276  77 A0 0A 00
127A  00 00 00 00                          DB 0,0,0,0,077H,0A0H,0AH,0 ;6TH OFS=0,6TH,SLP=5/4095*NRDG
127E  77 A0 0A 00
1282  01 99 01 99            DACOF         DB 1,099H,1,099H,1,099H ;DAC OFFSET,1ST,2ND,3RD.VAL*DAFAC
1286  01 99
1288  01 99 01 99                          DB 1,099H,1,099H,1,099H ;DAC OFFSET,4TH,5TH,6TH
128C  01 99
128E  01 99 01 99                          DB 1,099H,1,099H,1,099H ;DAC OFFSET,7TH,8TH,9TH
1292  01 99
1294  01 99                                DB 1,099H          10TH
1296  0F 9F F6 00            DAFAC         DB 0FH,09FH,0F6H,0H   ;D TO A FACTOR = 40959
129A  10 9F F6 00            DAFAC2        DB 10H,09FH,0F6H,0H   ;2ND DAC FACOR=81909
129E  01 06 16 20            SPEEDS        DB 01H,06H,016H,020H ;SPEEDS FOR PUSH/PULL SLOWEST FIRST
12A2  7A A3 D7 0C            TENMIL        DB 07AH,0A3H,0D7H,0CH ;0.01
                                           ORG 1800H          START DATA AT 1800 IN FOURTH PROM.
                             ;  SET NCOED IN TUBFIT=DEC VAL OF ADDR OF 1ST CAL0 VALUE
1800                         CAL0          DS 060H             INITIAL CALIBRATION READINGS
1860                         VOLSTD        DS 018H             INITIAL READINGS ON NOMINAL TUBE STANDARD
1878                         COEDT         DS 114H            ;PROPERTY COEFICIENTS,276 BYTES.
                                                              ;LAST PROPERTY SET IN TUBFIT IS FIRST
                                                              ;ON CRT AND GRAPH-FIRST IN LAST OUT.
198C                                        END
```

ASSEMBLER ERRORS =   0

SYMBOL TABLE

A	0007	ADBUS	0AF4	ADRDG	0ADC	ALADD	3E68
ALARM	0D7A	APDATA	007E	APSTS	007F	B	0000
BYCNT	3E63	C	0001	CAL0	1800	CALFR	124A
CALID	0B0A	CALL2	0B72	CALLP	0D15	CALPR	0898
CALPRL	08A6	CALPRO	0898	CALRD	3D99	CALSFR	124E
CALTC	104E	CALTL	1020	CARRET	0DD7	CHALP	0B1F
CHANO	3C11	CHCLP	0B42	CHLOP	0AC5	CHSD	E 0000
CHSDA	E 0001	CHSF	E 0002	CHSFA	E 0003	CHSS	E 0004
CHSSA	E 0005	CLOADR	3E2B	CO	E 0060	COEDT	1070
COEOF	003D	COILNT	3E66	CONTN	3C19	COPDT	E 0058
CORLP	0A95	COS	E 0006	COSA	E 0007	CR	000D
CRFAC	0A0F	CRFRA	3C35	CRFRO	1252	CROUT	E 0057
D	0002	DACAL1	0E11	DACALB	0DE4	DACCH	3E5F
DACCL2	0DF5	DACMS	1243	DACOF	1282	DACOFS	3C65
DACON1	0CFF	DACON2	0E4D	DACON3	0E4E	DACONS	0E0A
DACSET	0D76	DADD	E 0008	DADDA	E 0009	DADDB	E 000A
DAFAC	1296	DAFAC2	129A	DALP2	0D34	DALPS1	0E91
DALPS2	0EAE	DAOLD	3E47	DDIV	E 000B	DDIVA	E 000C
DDIVB	E 000D	DECNO	E 000E	DELAY	0B00	DMUL	E 000F
DMULA	E 0010	DMULB	E 0011	DMUU	E 0012	DMUUA	E 0013
DMUUB	E 0014	DSPAD	3C12	DSUB	E 0015	DSUBA	E 0016
DSUBB	E 0017	DTMAX	0D6D	DTMAXS	0ED1	DTMIN	0D65
DTMINS	0EC9	DUMPDF	1136	E	0003	ECHO	E 0062
EPRNT	E 005C	EXP	E 0018	EXP10	E 001A	EXPA	E 0019
FADD	E 001B	FADDA	E 001C	FADDB	E 001D	FDIV	E 001E
FDIVA	E 001F	FDIVB	E 0020	FILECT	3E65	FILENL	0FD6
FINBUF	1139	FIXD	E 0021	FIXDA	E 0022	FIXS	E 0023
FIXSA	E 0024	FLTCOR	007F	FLTD	E 0025	FLTDA	E 0026
FLTS	E 0027	FLTSA	E 0028	FMUL	E 0029	FMULA	E 002A
FMULB	E 002B	FPRNT	E 005D	FSUB	E 002C	FSUBA	E 002D
FSUBB	E 002E	GETCH	E 0063	GETCM	E 0059	GETHX	E 0064
GETID	1180	GETID0	1183	GETHM	E 005F	H	0004
INCRM	1114	INCRM1	1117	L	0005	LPACMS	0007
LF	000A	LMID1	000D	LN	E 002F	LNA	E 0030
LOG	E 0031	LOGA	E 0032	LOPSM	0A84	LPROPR	0D22
LSTPMS	0020	LTAPPR	0D1C	M	0006	MAIND	0D42
MDAD	E 0033	MEMORY	M 0000	MID1	11D8	MSGOUT	0F4D
NCALC	0004	NCHA	0006	NNOUT	E 0061	NPROP	3E6A
NRDG	0001	PCAL1	3C15	PCAL2	3C16	PCAL3	3C17
PCAL4	3C18	PCALN	3C14	PCALP	0F2F	POLLP	0A02
POLSM	0A38	POPD	E 0034	POPS	E 0035	PORT1	00F7
PORT1A	00F4	PORT1B	00F5	PORT1C	00F6	PORT2	00EF
PORT2A	00EC	PORT2B	00ED	PORT2C	00EE	PORT3	00DF
PORT3A	00DC	PORT3B	00DD	PORT3C	00DE	POSCH	3E45
POSCHN	0009	POSNAD	3E5D	[illegible]	[illegible]	[illegible]	0D08
PRINT	E 005A	PRINTF	E 005B	[illegible]	[illegible]	[illegible]	0002
PROPPR	0FD9	PROPR	[illegible]	PRT11	[illegible]	PRT10	[illegible]
PRT3	0093	PRTSU	[illegible]	[illegible]	[illegible]	[illegible]	E 003C
PTOS	E 0037	PUPI	E [illegible]	[illegible]	E [illegible]	[illegible]	E 003A
PWRB	E 003B	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
RD0	11A6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
RDSTD	0EDA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
RDTAPL	0F6E	RDTFL	0F9A	READID	115F	RECAL	0B99
RECL2	0BAC	RECL3	0CB9	RECL4	0C97	RECL5	0CEB
RECLP	0DA1	RECNO	3E60	RESET	0F57	RESET1	1059
RESTR	10B2	RESTR1	101A	RETRN	11C3	REZRL1	0D90
REZRO	0D00	RUNM	08CD	[illegible]	[illegible]	RUNMS	099E
RUNMS1	09D5	RWCLTP	0FC8	SADD	E [illegible]	SADDA	E 003D
SADDB	E 003E	SDIV	E 003F	SDIVA	E [illegible]	SDIVB	E 0041
SIN	E 0042	SINA	E 0043	SMCLP	[illegible]	SMDAT	0ADE
SMLOP	0ABE	SMUL	E 0044	SMULA	E 0045	SMULB	E 0046
SMUU	E 0047	SMUUA	E 0048	SMUUB	E [illegible]	SP	0000
SPEEDO	129E	SQRT	E 004A	SQRTA	E [illegible]	[illegible]	1CE0
SSUB	E 004C	SSUBA	E 004D	SSUBB	E [illegible]	STACK	E 0000
[illegible]	1163	STBTAP	[illegible]	STOP	[illegible]	STOP1	1097
STOPR	092C	STPMS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SUMXY	3E09	SUMY	[illegible]	[illegible]	[illegible]	[illegible]	E 004F
TANA	E 0050	TAPDAT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
THMIN	3E61	TOG2	[illegible]	[illegible]	E [illegible]	[illegible]	E [illegible]
TRACT	3C10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
VSTDYT	[illegible]	UEOF	[illegible]	[illegible]	E [illegible]	[illegible]	E [illegible]
WRTAP	0F57	WRTAPF	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
WRTLPF	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
YBAR	3E11	ZERO	E [illegible]				

Appendix F

PROCEDURE FOR PERFORMING THE AUTOMATED MULTIFREQUENCY EDDY-CURRENT INSPECTION OF THE SHEATH WELD ON THE SUPERCONDUCTOR CABLE

This procedure describes the techniques used to perform the eddy-current inspection of the sheath weld on the production line as the superconductor cable is being fabricated. The procedure provides guidelines for the necessary steps and the order of performance required to set up and calibrate the equipment, verify the test sensitivity, and perform the inspection to evaluate the quality of the gas tungsten arc weld in the steel sheath for the superconductor cable for the Fusion Energy Program. The procedure was written with the assumption that the operator is familiar with the test equipment and its operation.

1. EQUIPMENT

Multifrequency eddy-current instrument
Eddy-current probe and cable
Probe drive mechanism
Transceiver unit
Video terminal and keyboard
Remote control box (RCB)
Six-channel analog recorder
Magnetic tape recorder
Assorted nonconducting shims in the 25- to 250-μm (0.001- to 0.010-in.) range
Reference standards
Isolation transformer

2. ELECTRICAL POWER

2.1 Before connecting power to the eddy-current instrument, make sure that the three toggle switches on the phase calibrator module are in the "down" position (i.e., "MAG-LO," "PH-LO," and "OPERATE" positions), and make sure that an eddy-current probe is connected to the correct jacks on the calibrator module.

2.2 Connect electrical power to *all* instruments [eddy current (only on isolation transformer), two recorders, transceiver, video terminal, and probe drive mechanism], turn the equipment on, and allow at least 4 h for the instruments to warm up and stabilize.

3. DURING THE WARM-UP PERIOD

3.1 Check all cables and electrical connections to make sure that they are correct (see Fig. F.1).

3.2 Check the switches on all modules and instruments to assure they are in the normal position, per Tables F.1 and F.2.

3.3 Place standard tube 1 (with inner surface defects) in the probe drive unit. [Under normal conditions the probe has a 88.9-μm-thick (0.0035-in.) tape on face.] Place a 76.2-μm-thick (0.0030-in.) nonconducting shim between the probe face and the tube and mechanically adjust the lift-off. Connect hold-down spring to V-block.

3.4 Turn on the probe drive mechanism and let it run for a brief period to assure that it operates freely and correctly.

3.5 *Display Raw Readings.* Set the remote control box (RCB) function switch to position 3. When the cursor symbol appears on the video display, press the "reset" switch on the RCB. The statement "NDT COMP9" should appear on the video display. Next, press the "interrupt" switch on the RCB, and the raw readings will be continuously displayed on the video terminal. Check the raw readings to see if any are either zero or 4.999. If so, there is probably something wrong with the eddy-current instrument, and it should be corrected before proceeding. Press the "reset" switch on the RCB to stop the readings, and go to the next step.

3.6 *Check the analog recording system.* Set the (RCB) function switch to position 7. Press a chart speed switch to start the analog recorder chart drive. Use a slow chart speed (5 mm/s or less). Press the "interrupt" switch on the RCB and set all recorder pens to the zero reference value on each chart scale by use of zero adjustments on the recorder. The zero reference value for the five defect channels is 10 minor divisions to the left of the right-hand chart margin. [Each minor division represents 51 μm (0.0020 in.). The chart range is −0.51 to +2.03 mm (−0.020 to +0.080 in.).] The zero reference value for the lack-of-penetration channel is the right-hand chart margin. [Each minor division

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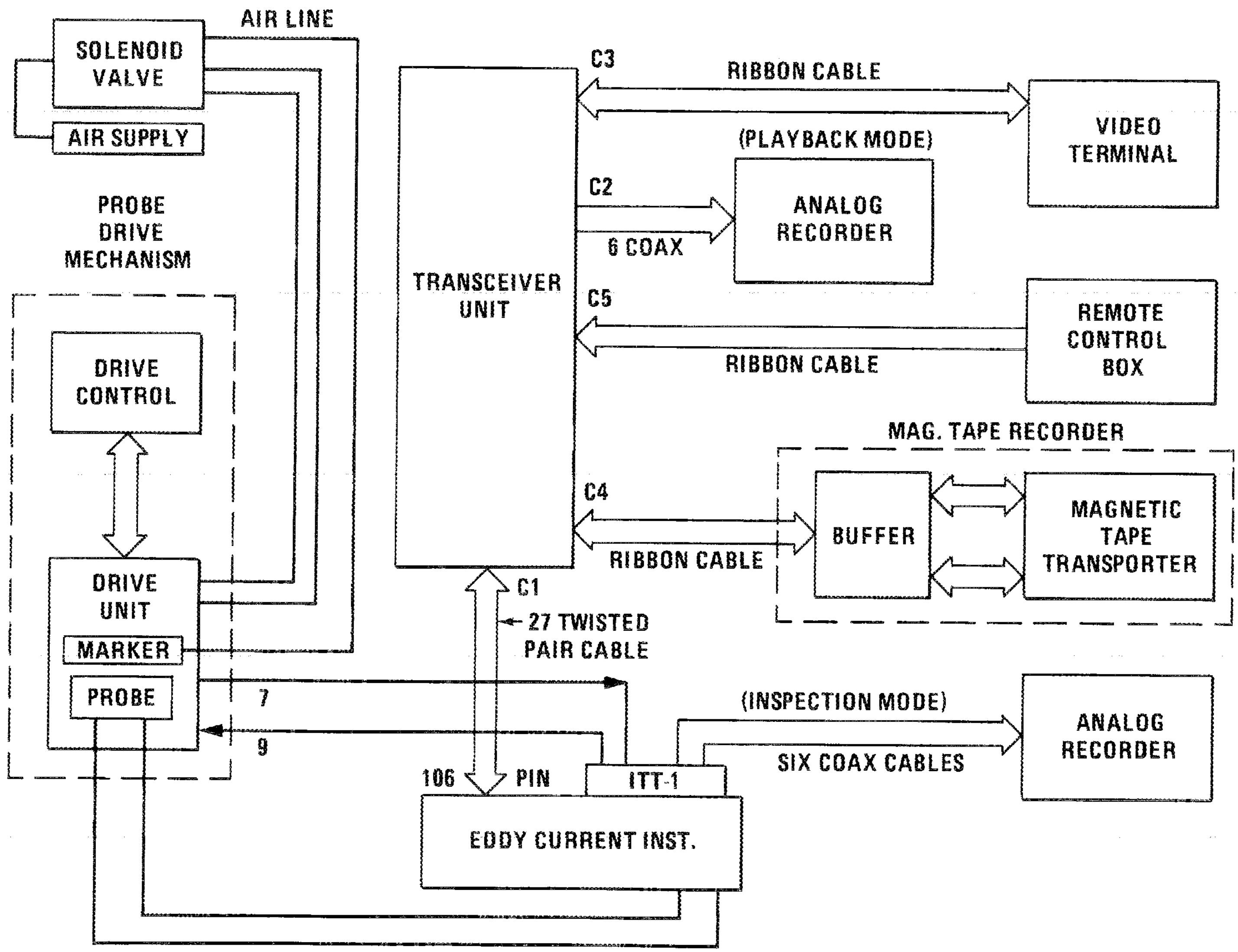

Fig. F.1. Block diagram of instruments showing cable connections.

Table F.1. Normal instrument settings

Instrument	Modular[a] position	Switch identity	Correct switch setting
Eddy-Current Instrument		Power on-off	
Power Oscillator	M1	High frequency (top)	500 kHz
		Median frequency (middle)	100 kHz
		Low frequency (bottom)	20 kHz
Bandpass Amplifier	M4	Low frequency	20 kHz
	M6	Mid frequency	100 kHz
	M8	High frequency	500 kHz
Discriminators[b]	M3	Coarse lift-off	518
	M3	Coarse balance	714
	M5	Coarse lift-off	512
	M5	Coarse balance	682
	M7	Coarse lift-off	507
	M7	Coarse balance	920
Analog Recorder		Power on-off	
		Sensitivity — coarse	100 mV/div
		Sensitivity — fine	Maximum CW
		Chart speed	5 mm/div
Probe Drive Control		Power on-off	
		Speed adjustment	124–128
		Scale selector (torque/speed)	Speed
		Direction (CW/stop/CCW)	CW

[a]The eddy-current instrument chassis has 10 modular positions. They are identified as M1 to M10 from right to left when facing the instrument. The computer module occupies two positions, M9 and M10.

[b]Adjustments of the lift-off and balance controls on the discriminators may sometimes be necessary to calibrate the eddy-current instrument. These adjustments should be made by using only the fine controls (screwdriver adjustments). If a change in the coarse control setting becomes necessary, notify your supervisor.

Table F.2. Instrument switches and functions

Instrument	Switch	Position(s)	Function and comments
Eddy Current Control Module	Function	0–9	Selects correct PROM to match the eddy-current probe (00 for 454, 01 for 460, and 02 for 459)
	Interrupt		DO NOT USE
	Reset		DO NOT USE
Magnetic Tape Recorder			
Transporter	Power	On-Off	
Transporter	Load	On-Off	Used to load tape
Transporter	On-Line	On-Off	Use for recording and reading
Transporter	Rewind	On-Off	Used to rewind tape
Transporter	Write ring		See Appendix A
Buffer	Power	On-Off	
Buffer	EOF	On-Off	See Appendix A
Buffer	Mode	Record	Used to record data
Buffer	Mode	Read	Used to read tape
Buffer	Mode	Continuous	DO NOT USE
Buffer	Mode	Remote	DO NOT USE
Transceiver	Power	On-Off	
	Selector	DX	Select external computer, used to record data (in eddy-current instrument)
	Selector	Local	Select internal computer, used to read tape
	Function	0–9	Always set on 1
Video Terminal	Power	On-Off	Located in back of instrument
	Keyboard		Transmits information and commands to computer

represents 51 μm (0.0020 in.). The chart range is 0 to 2.54 mm (0 to 0.1 in.).] The actual value recorded on each recorder channel is also displayed on the video monitor. After zeroing all pens, press the "return" key on the keyboard. All recorder pens should step five minor chart divisions to the left on the respective chart scales, representing an increase of 0.25 mm (0.010 in.). Press the "return" key a total of eight times, representing an increase of 2.03 mm (0.080 in.). All five defect channel recorder pens should now be at the left margin of their respective chart scales. If any of these recorder pens are not at the left margin, check the recorder sensitivity adjustments for that recorder channel (see Table F.1). Note the variable sensitivity adjustment must be set at maximum (fully clockwise) for that recorder channel to be calibrated. Press the "return" key twice more to check the calibration on the lack-of-penetration channel. [If the incremented steps between zero and maximum are not linear (i.e., five divisions per step), something is wrong with the recorder.] Press the "reset" switch on the RCB to stop this check, press the "STOP" switch on the analog recorder, and go to the next step.

3.7 Check the magnetic tape recorder according to the procedure described in Supplement 1.

4. AFTER THE EDDY-CURRENT TEST SYSTEM HAS COMPLETED A 4-h WARM-UP PERIOD, COMPLETE THE FOLLOWING CHECKOUT SEQUENCE

4.1 Set the transceiver selector switch to "DX." Set the transceiver function switch to "1."

4.2 *Check the analog recording system.* Set the (RCB) function switch to position 7. Press a chart speed switch to start the analog recorder chart drive. Use a slow chart speed (5 mm/s or less). Press the "interrupt" switch on the RCB and set all recorder pens to the zero reference value on each chart scale by use of zero adjustments on the recorder. The zero reference value for the five defect channels is 10 minor divisions to the left of the right-hand chart margin. [Each minor division represents 51 μm (0.0020 in.). The chart range is −0.51 to +2.03 mm (−0.020 to +0.080 in.).] The zero reference value for the lack-of-penetration channel is the right-hand chart margin. [Each minor division represents 51 μm (0.0020 in.).] The chart range is 0 to 2.54 mm (0 to 0.1 in.). The actual value recorded on each recorder channel is also displayed on the video monitor. After zeroing all pens, press the "return" key on the keyboard. All recorder pens should step five minor chart divisions to the left on the respective chart scales, representing an increase of 0.25 mm (0.010 in.). Press the "return" key a total of eight times, representing an increase of 2.03 mm (0.080 in.). All five defect channel recorder pens should now be at the left margin of their respective chart scales. If any of these recorder pens are not at the left margin, check the recorder sensitivity adjustments for that recorder channel (see Table F.1). Note that the variable sensitivity adjustment must be set at maximum (fully clockwise) for that recorder channel to be calibrated. Press the "return" key twice more to check the calibration on the lack-of-penetration channel. [If the incremented steps between zero and maximum are not linear (i.e., five divisions per step), something is wrong with the recorder.] Press the "reset" switch on the RCB to stop this check, press the "STOP" switch on the analog recorder, and go to the next step.

4.3 *Perform and Display Calibration.* Set the RCB function switch to position 5. Press the "interrupt" switch on the RCB. You should hear relays clicking, and about 10 s later the computer will display four lines of data on the video monitor. Let the display repeat about four or five times and press the "reset" switch on the RCB to stop. Evaluate the data. High magnitudes (columns 1, 3, and 5) should be 4.50 ± 0.02 V. High phases (even columns) should be 4.00 ± 0.02 V, except PH3 = 4.50 V. The phase difference between high magnitude and low magnitude readings on the first two lines of phase data should be less than ±10 mV. *If not, refer to the instrument calibration procedure.* (*Important*: Do not leave the calibration system running for long periods of time because the relays could be damaged.)

4.4 *Read Reference Standard.* [The probe should have the 88.9-μm-thick (0.0035-in.) Teflon tape on its face.] Using the square tube standard D, position the probe over the reference reading mark [centered over the weld and 76.2 mm (3 in.) from the end toward defect 1].

Select a lift-off shim to obtain a Mag 2 reading within ±0.1 V of the Mag 2 reading in Table F.3 (readings from nominal tube sample, third column) for the coil being used. This is done in the function 3 position of the RCB. Example: Probe 454-00 should read 3.6 V (3.5 ± 0.1 V) with a 0.102-mm (0.004-in.) shim. Press reset on RCB.

Select function 2 on the RCB. Using the shim size determined above, hold the probe over the reference reading mark with the shim between the probe face and sample. Press the "interrupt" switch on the RCB. One line of data should be shown on the video display. Press the "interrupt" switch again and another line of data will appear. Repeat until at least five lines of data are obtained or until the last two lines of data agree to within ±2 mV. Check the Mag 2 reading (third column) and compare with the Mag 2 reading for the nominal tube sample for the probe being used. See Table F.3.

4.5 Place probe in scanning fixture with a 76.2-µm-thick (0.003-in.) shim between the probe and tube and the shim not touching the nylon V-block. Fix the probe at this lift-off and remove the 76.2-µm (0.003-in.) shim. Record the last set of readings obtained in the test log book. Press the "reset" switch on the RCB to return the computer to normal operation.

4.6 *Display Raw Readings*. Set the remote control box (RCB) function switch to position 3. Press the "reset" switch" on the RCB. The statement "NDT COMP9" should appear on the video display. Next, press the "interrupt" switch on the RCB, and the raw readings will be continuously displayed on the video terminal. Check the raw readings to see if any are either zero or 4.999. If so, check the eddy-current probe to see if it is properly seated on the standard test tube. If it is, something is probably wrong with the eddy-current instrument, and it should be corrected before you proceed. Press the "reset" switch on the RCB to stop the readings and go to the next step.

4.7 *Main Running Loop*. Calibration and test data are recorded during this sequence, which is described in general as follows:

a. Precalibration — Run each of the round calibration standards and record the data on the analog recorder and magnetic tape.

Table F.3. Eddy-current probe, PROM code, and calibration readings

	Average and standard deviations of calibration readings (V) for each frequency					
	20 kHz		100 kHz		500 kHz	
	MAG1	PHA1	MAG2	PHA2	MAG3	PHA3
	Probe 454, code 00					
	4.5004	4.0004	4.5022	3.9945	4.5023	4.4958
S.D.	0.0000	0.0000	0.0000	0.0023	0.0000	0.0032
	2.4591	3.9989	2.3132	3.9933	2.4104	4.4956
S.D.	0.0023	0.0032	0.0000	0.0000	0.0016	0.0045
a	4.2220	2.5743	3.5361	2.8298	3.6230	1.0296
	Probe 460, code 01					
	4.4977	4.0047	4.4985	4.0118	4.5007	4.4878
S.D.	0.0045	0.0032	0.0032	0.0032	0.0000	0.0064
	2.4601	4.0047	2.3095	4.0103	2.4042	4.4864
S.D.	0.0016	0.0032	0.0000	0.0045	0.0000	0.0064
a	4.3142	3.0158	3.8659	2.9747	3.7303	1.0510
	Probe 459, code 02					
	4.4974	4.0006	4.4976	4.0110	4.5197	4.4953
S.D.	0.0045	0.0045	0.0000	0.0084	0.0032	0.0084
	2.4592	3.9997	2.3090	4.0176	2.4158	4.4947
S.D.	0.0000	0.0032	0.0016	0.0055	0.0016	0.0084
a	4.5155	2.9760	4.1346	2.9136	4.1158	0.9058

[a]Readings from nominal tube sample.

b. Perform Test on Sheath Weld — Record the data on both analog and magnetic tape recorders.

c. Postcalibration — Check the calibration standard and record the data on both analog and magnetic tape recorders.

These steps are described in detail in the following sections.

5. PRECALIBRATION

5.1 Install a new magnetic tape on the tape transporter and label the trailing end of the BOT marker with "1."

5.2 Place the inner surface calibration standard (tube 1) in the probe drive unit and center the probe over the area marked "start."

5.3 Operate the "reset" switch on the RCB. (Check for the correct coefficient code on the control module.)

5.4 Set the RCB function switch to Ø. Switch the magnetic tape recorder buffer to "record" and place the transporter "on line."

5.5 Operate the "interrupt" switch on the RCB. The instruction "enter ID" will appear on the video display. Enter the following information from the keyboard: PRE-CAL, standard number, date, superconductor number, probe number, and code.

5.6 Operate the 5-mm/s chart speed switch on the analog recorder.

5.7 Press the "return" key on the keyboard. The eddy-current computer will perform a recalibration and display the raw magnitude and phase readings along with the calculated coefficients on the video terminal. At the end of the display, the computer enters the "running" mode, and the eddy-current system starts recording data. Raw data are presented to the magnetic tape recorder, and calculated data are presented to the analog (strip-chart) recorder. (The data will be recorded only if the respective recorder is activated.)

5.8 Start the probe drive mechanism.

5.9 Using a slow and steady speed, manually pull the standard tube through the probe drive unit. Maintain the alignment of the weld on top of the tube and centered under the eddy-current probe.

5.10 Observe the analog recorder as you pull the standard tube through the drive unit. All five defect channel recorder pens should write between 5 and 25 minor divisions [−0.25 to +0.76 mm (−0.010 to +0.030 in.)] to the left of the right-hand margin on the recorder chart except when defect indications are obtained. (Inside-surface defects are recorded on the analog recorder.) Note: Signals greater than 0.76 mm (0.030 in.) (15 divisions) on the recorder chart should operate the indication marker that identifies the area on the superconductor sheath where the indication is located.

5.11 Identify this recording on the analog recorder as the "Precalibration Test" and record the date, the examiner's initials, and the identification of the superconductor sheath being examined.

5.12 When the precalibration of tube 1 is complete:

a. Set the RCB function switch to 1.
b. Stop the analog chart recorder and the probe drive mechanism.
c. After the EOF on the buffer illuminates, switch the magnetic tape recorder to "off line." Operate reset on the RCB.
d. Add a new BOT marker at "tape cleaner" and the outside edge of the tape. Turn the transporter off, rewind the tape reel about 1 turn, and turn the transporter on. Operate the "load" switch; the transporter should advance the tape to the new BOT marker. Label the BOT marker "A," and repeat steps 5.3 through 5.12 using the inner surface standard. Be sure to add a new BOT marker after standard A. Remove the tape reel and label as follows: "Standard Readings for Conductor Identity ____, Date ____, and Probe Identity ____."

6. PERFORM THE TEST

6.1 Place the probe drive unit on the superconductor cable, position the drive unit against the stop on the mill, and reconnect V-block and spring.

6.2 Turn on the probe drive mechanism and let it run for a brief period to assure that it operates freely and correctly.

6.3 Operate the "reset" switch on the RCB.

6.4 Set the RCB function switch to Ø.

6.5 Prepare magnetic tape recorder:

a. Install a new tape reel.

b. Verify "write" enable.

c. Check for correct "BOT" position.

d. Set selector switch on buffer to "record."

e. Set transporter to "on line" and verify.

Note: Never operate a "reset" switch when the magnetic tape recorder is on-line and in the "record" mode.

6.6 Operate the "interrupt" switch on the RCB. The instruction "enter ID" will appear on the video display, and the EOF enable indicator will go out.

6.7 Type in the test identification (ID) on the keyboard as follows and in order: (date, AIRCO + tube number, and eddy-current probe serial number and PROM coefficient code).

Probe serial number	454	460	459
PROM coefficient code	00	01	02

6.8 Manually hold the eddy-current probe off the tube until the plug at the start of the superconductor is about 0.30 m (12 in.) away from the first drive unit rollers. Then seat the probe holder and

a. turn on the probe drive control,

b. press the "return" key on the keyboard,

c. operate the 5-mm/s chart speed switch on the analog recorder.

The eddy-current computer will perform a recalibration and display the magnitude and phase readings along with the calculated coefficients on the video terminal.

At the end of the display, the computer enters the "running" mode, and the eddy-current system starts recording data. Raw data are recorded on the magnetic tape recorder, and calculated data are recorded on the analog (strip-chart) recorder.

6.9 Observe the analog recorder. All six recorder pens should write on scale on the recorder chart. If the pen on one of the defect channels goes off scale and stays, press the "zero" switch on the RCB to bring all defect channels back to the zero reference line on the recorder. Record the time of this "zero" shift along with the operator's initials on the analog recorder chart and in the eddy-current log book.

6.10 Observe the equipment as the test is being conducted to make sure that all systems operate correctly. Watch for probe wear. Check both recorders periodically to see that they are recording properly and that the recorder pens remain on scale. If test indications are obtained, check the indication marker to see that it correctly identifies the area on the sheath. Record any unusual events (such as power outages and equipment breakdowns) on the chart and in the log book.

6.11 When the test is complete, do the following:

a. Set the RCB function switch to 1.
b. Turn off the analog recorder drive and probe drive mechanism.
c. Remove the probe drive unit from the superconductor cable.

6.12 Check the magnetic tape recorder; the end-of-file (EOF) indicator should be lit.

a. If the EOF indicator stays lit, you are ready to perform a post-calibration test (step 7.0).
b. If the EOF indicator does *not* stay lit, there may be problems with the recorder or eddy-current computer, or both. In either case, make a record in the log book.
c. Rewind the tape, remove it, label the tape reel, and remove the write ring.

7. POSTCALIBRATION

7.1 Replace the calibration tape made in step 5.

7.2 Advance the tape beyond the second BOT marker. Turn the recorder "off," then "on," and operate the "load" switch. The transporter should advance the tape to the third BOT marker and stop.

7.3 Repeat the calibration steps described in Section 5.

7.4 Place the calibration standard (identity) in the probe drive unit, and center the probe over the area marked "start."

7.5 Set the RCB function switch to Ø.

7.6 Operate the "interrupt" switch on the RCB. The instruction "enter ID" will appear on the video display.

7.7 Type in the test identification (ID) on the keyboard as follows and in order: (date, AIRCO + tube number, and eddy-current probe serial number). Note: Do *not* operate a "reset" switch when the magnetic tape recorder is "on-line" and in the "record" mode.

7.8 Operate the 5-mm/s chart speed switch on the analog recorder.

7.9 Press the "return" key on the keyboard. The eddy-current computer will perform a recalibration and display the raw magnitude and phase readings along with the calculated coefficients on the video terminal similar to step 4.7 of this procedure. At the end of the display, the computer enters the "running" mode and the eddy-current system starts recording data.

7.10 Start the probe drive mechanism.

7.11 Using a slow and steady speed, manually pull the standard tube through the probe drive mechanism. Maintain the alignment of the weld on top of the tube and centered under the eddy-current probe.

7.12 Observe the analog recorder as you pull the standard tube through the drive unit. All five defect channel recorder pens should write between 5 and 25 minor divisions [−0.25 to +0.76 mm (−0.010 to +0.030 in.)] to the left of the right-hand margin on the recorder chart except when defect indications are obtained. If not, recheck the recorder calibration and zero reference settings.

7.13 Identify this recording on the analog recorder as the "Postcalibration Test" and record the date, the examiner's initials, and the identification of the superconductor sheath being examined.

8. WHEN THE POSTCALIBRATION TEST IS COMPLETE, DO THE FOLLOWING

8.1 Set the RCB function switch to 1.

8.2 Stop the analog recorder drive and the probe drive mechanism.

8.3 Check the magnetic tape recorder. The EOF indicator should be lit. If it is, proceed to the next step. If it does not light, wait a brief period. If it still does not light, check for problems and mention this in the log book.

8.4 Operate "rewind" switch on transporter. At this point, either remove or read the tape per instructions in Supplement 1. To remove the tape, operate the "rewind" switch again and remove the tape reel when rewinding is complete. Remove the "write" ring from the tape reel and save. Place a protective collar over the tape reel. Identify the tape reel.

If there are no more tests to perform, turn all power off and secure the equipment.

Supplement 1 (to Appendix F)

TAPE RECORDER OPERATION

1. GENERAL

The read and record operations of this tape recorder are performed with the aid of computers. The read computer is located in the transceiver unit, while the record computer is in the eddy-current instrument. In order to read a tape, the read computer must have the same program (EPROM 0800 and 1000) in it that was in the record computer when the tape was written. Do not operate the "reset" switch on the remote control box (RCB) or the control module in the eddy-current instrument if the transporter is "on-line" and the buffer mode switch is on "record." This causes the record computer to lose synchronization with the tape position. The tape beyond the point where the "reset" switch is operated cannot be read from this tape recorder.

2. LOAD TAPE ON THE TRANSPORTER

2.1 Turn on the power to the transport and buffer. A 30-min warm-up period is recommended.

2.2 Remove write ring if reading a prerecorded tape.

2.3 Install the write ring if writing on a prerecorded tape or leave the write ring in place if writing on a new tape. (The write ring is a plastic insert on the back of the reel.)

2.4 Seat the tape reel on the supply hub, push the hub in, and thread the tape as shown on the transporter. The power to the transporter should be on and the "load" lamp out when the tape is being threaded.

2.5 Operate the "load" switch to advance the tape to the beginning of tape (BOT) marker. The BOT marker is a piece of reflective tape, 25 by 6 mm (1 × 1/4 in.), on the outside edge of the tape.

2.6 The "write enable" or "write ring" lamp will be on if the write ring is in place.

3. RECORDING ON TAPE

3.1 Do not operate the "reset" switch on the RCB or on the control module in the eddy-current instrument if the transporter is "on line" and the buffer mode switch is on "record."

3.2 Set the selector switch on the transceiver unit to "DX."

3.3 Operate the "reset" switch on the RCB (transporter "off line").

3.4 Set the function switch on the RCB to "Ø."

3.5 Select "record" on the buffer mode switch.

3.6 Set the function switch on the control module in the eddy-current instrument according to the eddy-current probe being used (see Table F.3).

3.7 Operate the "on line" switch on the transporter. The EOF switch should illuminate, the "on line" light should illuminate, and the tape should advance smoothly. If all three actions do not occur, operate "rewind" and try again. This indicates that the EOF is enabled, both buffers are empty, and the tape recorder is ready to receive data.

3.8 Operate the "INT" switch on the RCB. The EOF enable should go out, and "enter ID" will be printed on the video display.

3.9 Type one space, then enter the correct test identification data and probe serial number.

3.10 Operate the keyboard "return" key when you are ready to start recording on the tape. The record computer in the eddy-current instrument will be acquiring and recording the data. The transporter should advance the tape in smooth rhythmic steps.

3.11 To stop the test, select "1" on the RCB. The computer will fill the last buffer and transfer the buffer contents onto the tape. The EOF enable will illuminate to indicate that both buffers are empty. The computer will then issue a write end-of-file (WRT EOF) command. The tape recorder will record an EOF. The EOF enable light will go out, the tape will advance, and EOF enable will illuminate again, and verify will be indicated with a period followed by the cursor on the video display. The tape recorder will stop and await further instructions.

3.12 Operate the "on line" switch to "off line."

4. REWIND TAPE

4.1 Operate the "rewind" switch. The transporter will rewind the tape until the BOT marker is located and then stop.

4.2 Operate the "rewind" switch again. The transporter will rewind the remaining portion of the tape and stop.

4.3 Pull the supply hub out to unlock the reel and remove the tape.

4.4 Place the protective collar around the reel.

4.5 Identify the reel.

4.6 Remove the write ring.

5. READ TAPE

5.1 Equipment required:

a. Transporter

b. Buffer

c. Terminal

d. Transceiver unit

e. Strip-chart recorder

5.2 Remove the strip-chart recorder cable from the eddy-current instrument and connect to C2 of the transceiver unit.

5.3 Remove the write ring from the reel.

5.4 Seat the reel on the supply hub, push the hub in, and thread the tape as shown on the transporter. The power to the transporter should be on and the "load" lamp out when the tape is being threaded.

5.5 Operate the "load" switch on the transporter to advance the tape to the beginning of tape (BOT) marker.

5.6 Select "local" on the transceiver unit selector switch.

5.7 Set the function switch on the transceiver unit to "1."

5.8 Operate the "reset" switch on the transceiver unit. "NDT COMP9" should be displayed on the terminal.

5.9 Operate the "INT" switch on the transceiver unit. The following will be displayed on the video screen: "switch tape to read, on line."

5.10 Select "read" on the buffer mode switch.

5.11 Operate the "on line" switch on the transporter. The "on line" light should illuminate. The tape should advance smoothly.

5.12 Respond to statement printed on the CRT. Type in one of four codes — Ø, 1, 2, 3 — and operate the return key on the keyboard.

5.13 The tape will be read, and calculated data will be recorded on the strip-chart recorder.

5.14 To prevent damage to the tape, remove it from the transporter and replace the protective collar.

5.15 Turn off equipment.

Appendix G

PROCEDURE TO CHECK DIGITAL RECORDING SYSTEM

This procedure describes the operation of the digital recording system for the superconductor sheath weld inspection and describes the steps necessary to check the operation of the system before performing the eddy-current inspection. The computer program CHECK associated with this test is described in Appendix H. The procedure is self-explanatory but should be read completely before attempting the check.

1.0 GENERAL

The following is a description of the digital recording system and the steps necessary to check the operation of the system.

Refer to Fig. G.1, block diagram of the digital recording system. Each multifrequency eddy-current (MFEC) test system has two identical microcomputer circuit boards, one located in the control module of the eddy-current instrument and one in the transceiver unit. A computer program designed to check the operation of the digital recording system is stored on PROM chips in each microcomputer circuit board. The two PROM chips are identical and interchangeable.

Initiation of the program starts a counting program in each computer that counts (in hexadecimal) from 0000 to FFFF. The four-digit hexadecimal number that is generated is described in Fig. G.2. The low byte (X_1 and X_2) represent the count (from 00 to FF), and the high byte (X_3 and X_4) represent the number of times the count has been repeated.

The low byte is transmitted through the transceiver unit and through the "write" portion of the logic package to the tape transporter, where it is stored on magnetic tape. When the tape is played back, the data bytes are transmitted from the magnetic tape through the "read" portion of the logic package to the computer board located in the transceiver.

The computer program in the transceiver unit generates a four-digit hexadecimal count identical to the one generated by the control module microcomputer. When the data bytes stored on magnetic tape are received by the computer in the transceiver unit, they will be compared with the

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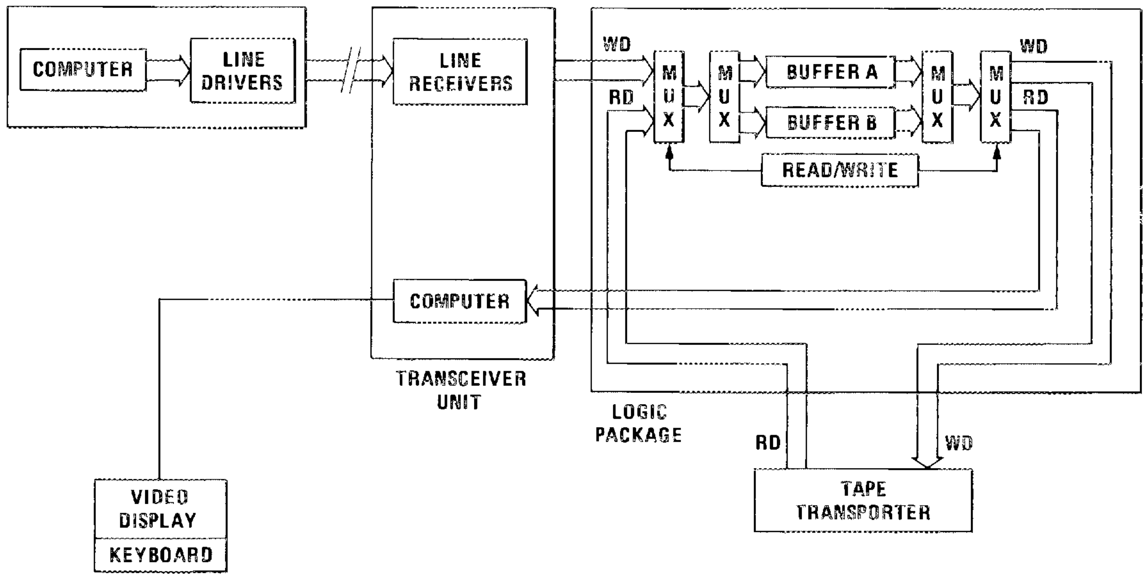

Fig. G.1. Block diagram of the digital recording system.

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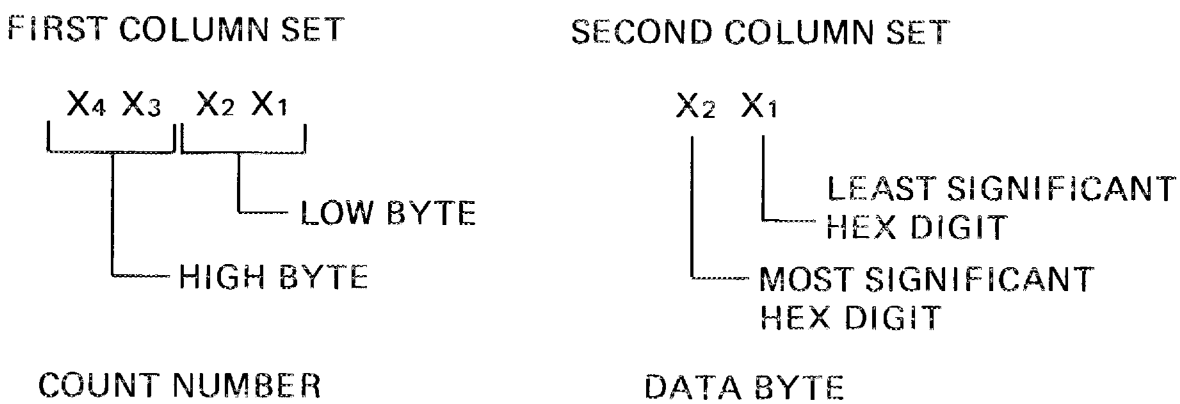

Fig. G.2. Video display of the hexadecimal numbers.

corresponding low byte generated by the count program in the transceiver microcomputer, and either one or two columns of data will be displayed on the video terminal.

If the two bytes are identical, then only the one column set of four hex numbers (the transceiver computer count number) will be displayed on the video terminal. If the received byte is not identical with the low byte generated by the transceiver computer, a second column set of two hex digits (the data byte) will be displayed on the video terminal. The appearance of the second column set of data is a positive indication that something is wrong in the digital recording system. The manner in which the numbers are presented in the second column set of data provides information that can be used to determine the general location of the problem.

To use the information presented in the second column set, the operator must understand hexadecimal and binary numbers and have a general knowledge of how the recording system works. The following is a brief description of how the system works (refer to Fig. G.1).

The data bytes (X_1 and X_2) are transmitted from the control module over the respective data lines (Fig. G.3) to the two recorder buffers, A and B. The same buffers are used to "write" data on the magnetic tape and to "read" data off the tape. The two buffers are like one-way streets, and data always travel through the buffers in the same direction whether the recorder is reading or writing.

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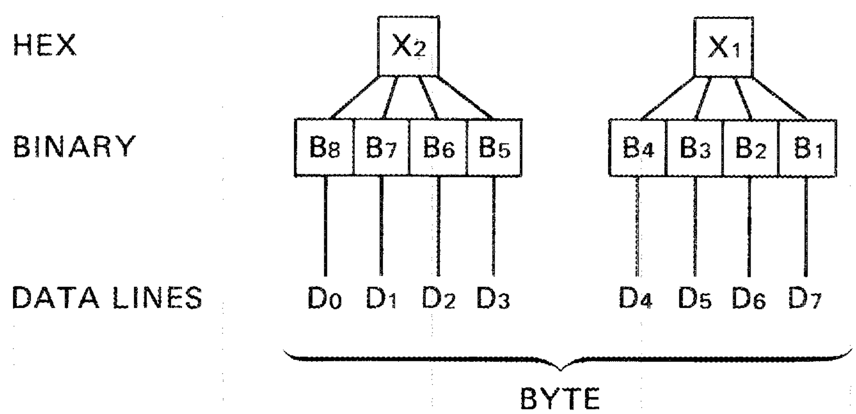

Fig. G.3. Eight data lines used to transmit two hexadecimal digits.

A single buffer has a limited capacity for data. When a buffer is filled with data, it must dump those data onto the next process in the system before it can accept more data. If only one buffer is used, no data can be transferred into or out of the recorder while the buffer is dumping. If two buffers are used, then one buffer can be receiving data while the other is dumping, and the recording process is continuous. The multiplexers select which buffer receives data according to the amount of data received. The program always starts with buffer A; when that buffer is filled, the multiplexer will switch to buffer B. By the time buffer B is filled, buffer A will be ready to receive data. Each buffer can hold 4K of memory (OFFF in hexadecimal). Table G.1 shows the four-digit hexadecimal count and which buffer will be used. If one of the buffers is not operating, for example, then all the data bytes transmitted through that buffer will be incorrect and will differ from the count number. Incorrect hex numbers will be printed in the second column set on the video display.

Table G.1. Recorder buffers used for particular sets of hexadecimal numbers

Hexadecimal count	Buffer used	Hexadecimal count	Buffer used
0000–0FFF	A	8000–8FFF	A
1000–1FFF	B	9000–9FFF	B
2000–2FFF	A	A000–AFFF	A
3000–3FFF	B	B000–BFFF	B
4000–4FFF	A	C000–CFFF	A
5000–5FFF	B	D000–DFFF	B
6000–6FFF	A	E000–EFFF	A
7000–7FFF	B	F000–FFFF	B

Four binary digits are required to express each hexdigit (see Fig. G.3); therefore, eight data lines are required to transmit one data byte through the recording system. These data lines are fixed (hard wired) and will always represent the same binary digit; therefore, if a particular binary digit is missing in the output data, we can trace it back to a particular data line, and this will help locate the problem.

By examination of the data in the second column set displayed on the video screen, the operator can determine if the digital recording system is operating properly or not, and, if not, he can determine whether the problem is in one of the buffers or a data line and can isolate which buffers or which data line is not operating properly. In addition, the program will let the operator know if the problem is caused by an operator error.

2. EQUIPMENT REQUIRED

Eddy-current instrument
Transceiver unit
Remote control box (RCB)
Tape transporter
Tape buffer logic package
Video terminal

3. INITIAL SETUP

3.1 Apply power to the equipment.

3.2 Operate the select switch to "DX" on the transceiver unit.

3.3 Operate the reset switch on the RCB and verify response (NDT-COMP9) on the video terminal.

4. SET UP TAPE RECORDER

4.1 Select a new reel of magnetic tape, make sure the write ring is properly in place, and install the reel on the transporter.

4.2 Operate the select switch to "record" on the buffer logic package.

4.3 Operate the "load" switch on the transporter (tape will advance to BOT marker).

4.4 Verify that the "WRITE ENABLE" lamp is illuminated.

4.5 Operate the "ON LINE" switch on the transporter and verify that the EOF lamp on the buffer logic package is illuminated.

5. STORE THE DATA ON MAGNETIC TAPE

5.1 Type G154A and carriage return on the keyboard. The EOF lamp should go out; the terminal will display the prompt "Hit carriage return to start."

5.2 Respond to the prompt on the video terminal (type a carriage return). The transporter should begin advancing tape in rhythmic steps and will continue for 1 to 2 min. Data generated by the counting program in the control module computer are stored on the magnetic tape. When this program loop is completed, the transporter will stop advancing and the EOF lamp on the buffer will illuminate. The line "rewind, SW to local, read, G158F, on line, CR to start" will be displayed on the terminal. *Do not respond at this time; go to the next step.*

6. IDENTIFY AND REWIND THE TAPE

6.1 Operate the "EOF" switch on the buffer logic package. This will write an "END OF FILE" mark on the magnetic tape, and the tape will be advanced a short length. Operate the "EOF" switch again to place a second "END OF FILE" mark on the tape.

6.2 Operate the "ON LINE" switch on the transporter to "OFF LINE."

6.3 Install a BOT marker on the outer edge of the tape in the area near the tape cleaner.

6.4 Operate the "REWIND" switch on the transporter.

6.5 Identify the BOT marker at the start of the record.

7. PLAY THE TAPE BACK AND CHECK THE DIGITAL RECORDING SYSTEM

7.1 Operate the select switch to "READ" on the buffer logic package.

7.2 Operate the select switch to "LOCAL" on the transceiver unit.

7.3 Operate the "RESET" switch on the transceiver unit and verify response (NDT-COMP9) on the video terminal.

7.4 Type G158F and a carriage return on the keyboard.

7.5 Operate the "ON LINE" switch on the transporter.

7.6 Press the "CARRIAGE RETURN" key on the keyboard. A check of the digital recording system will begin. A column set of four hexadecimal numbers counting from 0000 to FFFF will be displayed on the video terminal. The total display will take about 9 min. The count can be stopped by pressing any character on the keyboard and can be resumed by pressing the "CARRIAGE RETURN" key.

The manner in which these data are displayed on the video terminal lets the operator know whether the digital recording system is operating properly or not. If the digital recording is not operating properly, a second column set of two hexadecimal numbers will be displayed on the video terminal. Perform the following data checks in the order listed to localize the problem area.

CHECK 1: LOOK FOR THE SECOND COLUMN OF NUMBERS

If only one column set of four hexadecimal numbers is displayed, and the numbers count from 0000 to FFFF, the digital recording system is operating properly and is ready for use.

All other checks apply to conditions under which a second column set of two hexadecimal numbers is printed out on the video terminal and some problem exists.

CHECK 2: EXAMINE THE LEAST SIGNIFICANT HEX DIGIT (LSHD) (RIGHT NUMBER) IN THE SECOND COLUMN SET

a. If the LSHD (X_1) in the second column set increases consecutively from 0 to F, and the number is one higher than the respective hex digit in the first column set, the problem is operational. Return to step 3.2 of this procedure and repeat the procedure.

b. If the LSHD in the second column set does not increase consecutively or if certain numbers are skipped, determine which numbers are skipped and go to check 3.

NOTE: If the data byte is properly transmitted through the digital recording system and if it properly matches the low byte in the count generated by the transceiver, no data will be displayed in the second column set. This will be true for all or part of the data transmitted.

CHECK 3: EXAMINE THE MOST SIGNIFICANT HEX DIGIT (MSHD) (LEFT NUMBER) IN COLUMN 2

a. Determine whether the MSHD (X_2) in the second column set matches the corresponding hex digit (X_2) in the first column set; also determine if any digits are skipped.

b. Arbitrarily select two or three values of X_2 and X_1 from the first column set and the second column set and write them down on a sheet of paper.

c. Convert the two sets of hex numbers into their binary equivalents in the manner shown in Fig. G.3.

d. Examine the binary digits to see if one or more remain set at 0 or 1 throughout the count. Also determine if that digit can explain the difference in the count between the two column sets. If so, the problem is in the data line corresponding to that binary digit (Fig. G.3).

CHECK 4: CHECK THE BUFFERS

If one of the buffers is bad, the data in the second column set will be discontinuous, and large sets of numbers will appear to be missing. The missing numbers will correspond to the good buffer. (If data are properly transmitted through the digital recording system, no values will appear in the second column set.) The bad buffer can be determined by relating the hex digit (X_4) in the second column set to the corresponding hex digit (X_4). If X_4 in the second column set is zero or an even number (hexadecimal), the problem is in buffer A. If X_4 is an odd number, the problem is in buffer B.

To check the buffers, let the data count run long enough to make sure that some numbers are (or are not) getting through each buffer.

If any numbers get through a particular buffer, that buffer can be assumed to be operating properly.

Appendix H

PROGRAM CHECK

The program CHECK (written in machine language) generates counting programs in the two microcomputers located in the control module and the transceiver units of the MFEC instrument. Each counting program generates a set of hexadecimal numbers from 0000 to FFFF. The hex numbers generated in the control module microcomputer are transmitted through the transceiver unit and tape buffers to the tape transporter, where they are recorded by the magnetic tape recorder. The numbers are then read back from the magnetic tape through the tape buffers and transceiver unit and are compared with the number set generated by the transceiver unit microcomputer. The results of the comparison are displayed on the video terminal. If the two sets of hex numbers are exactly identical, then only one column set of four numbers (0000 to FFFF) will be displayed. If the two sets of numbers are not identical, a second column set of two numbers (00 to FF) will be displayed. This procedure provides a means to check the operation of the digital recording system, including the magnetic tape recorder. The procedure that outlines the steps required to perform this system check is provided in Appendix G.

```
                          TITLE 'COMPS CHECKOUT PROGRAM VERSION 12 APRIL 84'
                          LIST   B,G,O,T
            ;             HLIST   I,M,S
                          ORG 2000H         START PROGRAM IN 5TH PROM.
            ; SYMBOL DEFINITIONS
            ;
            ;  DEFINE PORT ADDRESSES
            ;  NORMAL COMPS PORT ADDRESSES
            ;
            ;PORT1        EQU 0F7H          PORT 1 CONTROL WORD ADDRESS
            ;PORT1A       EQU 0F4H          PORT1A ADDRESS
            ;PORT1B       EQU 0F5H          PORT1B ADDRESS
            ;PORT1C       EQU 0F6H          PORT1C ADDRESS
            ;PORT2        EQU 0EFH          PORT 2 CONTROL WORD ADDRESS
            ;PORT2A       EQU 0ECH          PORT2A ADDRESS
            ;PORT2B       EQU 0EDH          PORT2B ADDRESS
            ;PORT2C       EQU 0EEH          PORT3C ADDRESS
            ;PORT3        EQU 0DFH          PORT 3 CONTROL WORD ADDRESS
            ;PORT3A       EQU 0DCH          PORT3A ADDRESS
            ;PORT3B       EQU 0DDH          PORT3B ADDRESS
            ;PORT3C       EQU 0DEH          PORT3C ADDRESS
            ;APDATA       EQU 07EH          ARITHMETIC PROCESSOR DATA PORT
            ;USSTS        EQU 0FCH           USART CONTROL/STATUS ADDRESS
            ;
            ;  PORT ADDRESSES FOR COMPSO WITH GPIB BOARD
            ;
00CF        PORT1        EQU 0CFH          PORT 1 CONTROL WORD ADDRESS
00CC        PORT1A       EQU 0CCH          PORT1A ADDRESS
00CD        PORT1B       EQU 0CDH          PORT1B ADDRESS
00CE        PORT1C       EQU 0CEH          PORT1C ADDRESS
00D7        PORT2        EQU 0D7H          PORT 2 CONTROL WORD ADDRESS
00D4        PORT2A       EQU 0D4H          PORT2A ADDRESS
00D5        PORT2B       EQU 0D5H          PORT2B ADDRESS
00D6        PORT2C       EQU 0D6H          PORT2C ADDRESS
00EE        APDATA       EQU 0EEH          ARITHMETIC PROCESSOR DATA PORT
00EF        APSTAT       EQU 0EFH          ARITHMETIC PROCESSOR STATUS PORT
00C6        USSTS        EQU 0C6H           USART CONTROL/STATUS ADDRESS
00E7        RTCCTL       EQU 0E7H           REAL TIME CLOCK CONTROL
00E4        RTCCT0       EQU 0E4H           REAL TIME CLOCK COUNTER 0
00E5        RTCCT1       EQU 0E5H           REAL TIME CLOCK COUNTER 1
00E6        RTCCT2       EQU 0E6H           REAL TIME CLOCK COUNTER 2,USED FOR BAUD RA
            ;            GPIB ADDRESS AND MASK DEFINITIONS
00D8        BUSPRT       EQU 0D8H           BASE ADDR OF GPIB BUSS
00D8        BUSIN        EQU 0D8H           DATA IN FROM BUSS ADDR
00D8        BUSOUT       EQU BUSIN          DATA OUT TO BUSS ADDR
00D9        S1           EQU 0D9H           INTERRUPT STATUS REGISTER1 ADDR
00D9        INTE1        EQU 0D9H           INTERRUPT ENABLE REGISTER 1 ADDR
0002        BOM          EQU 02             BYTE OUT INTR MASK,BYTE
            ;                               SHOULD BE WRITTEN IN BUSOUT
0001        BIM          EQU 01             BYTE IN INTR MASK,BYTE SHOULD
            ;                               BE READ FROM BUSIN REGISTER
0010        ENDMK        EQU 10H            END INTERRUPT MASK
0080        CPT          EQU 80H            COMMAND PASS THROUGH MASK
            ;            REG #2 INTERRUPTS
```

```
00DA        INTE2     EQU 0DAH           INTERRUPT REGISTER 2 ADDR
            ;         REG #4 ADDRESS MODE CONSTANTS
00DC        ADRMD     EQU 0DCH            ADDRESS MODE REGISTER ADDR
0080        TON       EQU 080H            TALK ONLY,NOT LISTEN  MODE
0040        LON       EQU 040H            LISTEN ONLY,NOT TALK MODE
00C0        TLON      EQU 0C0H            TALK AND LISTEN ONLY MODE
0001        MODE1     EQU 01H             MODE 1 ADDRESSING
            ;         REG #4 (READ) ADDRESS STATUS REGISTER
00DC        ADRST     EQU ADRMD           ADDRESS STATUS REGISTER ADDR
0020        EOIST     EQU 20H             END OR IDENTIFY MASK
0002        TA        EQU 02H             TALKER ADDR OR ACT;SER POLL-TADS TACS SPAS
0004        LA        EQU 04H             LISTENER ADDRESSED OR ACTIVE-LADS OR LACS
0001        MJMN      EQU 01H             MAJOR OR MINOR TALKER/LISTENER,1=MINOR
            ;         REG #5(WRITE) AUXILLARY MODE REGISTER
00DD        AUXMD     EQU 0DDH            AUXILLARY MODE REG ADDR
0022        CLKRT     EQU 022H            CLOCK SET FOR 2MHZ
0003        FNHSK     EQU 03H             FINISH HANDSHAKE AUX COMMAND
0006        SDEOI     EQU 06H             SEND END OR IDENTIFY WITH NEXT BYTE
0080        AXRA      EQU 080H            WRITE DDDDD INTO AUX REGISTER A
0001        HOHSK     EQU 01H             HOLD OFF HANDSHAKE ON ALL BYTES
0002        HOEND     EQU 02H             HOLD OFF HANHSHAKE ON END BYTE
0003        CAHCY     EQU 03H             CONTINIOUS ACCEPTOR HANDSHAKE CYCLING
0004        EDEOS     EQU 04H             END ON EOS RECEIVED DAT REG MATCHES EOS RE
0008        EOIS      EQU 08H             OUTPUT EOI ON EOS SENT
0040        EOSBC     EQU 40H             EOS FUNCTIONS AS FULL 8-BIT REG
000F        VSCMD     EQU 0FH             VALID COMMAND PASS THROUGH
0007        IVCMD     EQU 07H             INVALID COMMAND PASS THROUGH
00A0        AXRB      EQU 0A0H            AUXILLARY REG B PATTERN
0001        CPTEN     EQU 01H             COMMAND PASS THROUGH ENABLE
            ;         REG #5(READ)
00DD        CPTRG     EQU 0DDH            ADDR TO READ COMMAND PASS THROUGH
            ;         REG #6 (WRITE) ADDRESS 0/1 REG CONSTANTS
00DE        ADR01     EQU 0DEH            COMP 9 GPIB ADDRESSES
0060        DTDL1     EQU 060H            DISABLE MAJOR TALKER/LISTENER
00E0        DTDL2     EQU 0E0H            DISABLE MINOR TALKER/LISTENER
0005        ADRTL     EQU 05H             TALKER LISTENER ADDRESS SET TO 5
            ;         REG #7 EOS-END OF SEQUENCE CHARACTER REG
00DF        EOSR      EQU 0DFH            FLAGS END OF BLOCK BY CHAR IN REG
            ;
            ;  SYMBOL DEFINITIONS
            ;
000D        CR        EQU 0DH             CARRIAGE RETURN DEFINED
000A        LF        EQU 0AH             LINE FEED DEFINED
0070        DISBLK    EQU 0070H           JUMP INTO DISPLAY DATA ROUTINE
0F6B        RDTAP     EQU 0F6BH           ADDRESS OF READ TAPE ROUTINE
            ;
            ;  MATH SUBROUTINES FOR THE COMP 9 ARE STORED AS PUBLIC.ANY ROUTINE
            ;  CAN BE CALLED USING AN 'EXTRN' STATEMENT.
            ;
             EXTRN        ACOS,ASIN,ATAN,ATANA,BIDEC,BIDECF
             EXTRN        CHSD,CHSDA,CHSF,CHSFA,CHSS,CHSSA,COS,COSA
             EXTRN        DADD,DADDA,DADDB,DDIV,DDIVA,DDIVB,DECNO
             EXTRN        DMUL,DMULA,DMULB,DMUU,DMUUA,DMUUB,DSUB,DSUBA,DSUBB
             EXTRN        EXP,EXPA,EXP10,FADD,FADDA,FADDB,FDIV,FDIVA,FDIVB
```

```
                          EXTRN     FIXD,FIXDA,FIXS,FIXSA,FLTD,FLTDA,FLTS,FLTSA
                          EXTRN     FMUL,FMULA,FMULB,FSUB,FSUBA,FSUBB,LN,LNA,LOG,LOGA
                          EXTRN     MDAD,NOP,POPD,POPS,PTOD,PTOS,PUPI,PWR,PWRA,PWRB
                          EXTRN     SADD,SADDA,SADDB,SDIV,SDIVA,SDIVB,SIN,SINA
                          EXTRN     SMUL,SMULA,SMULB,SMUU,SMUUA,SMUUB,SQRT,SQRTA
                          EXTRN     SSUB,SSUBA,SSUBB,TAN,TANA,TOS1,TOS2,TOS4
                          EXTRN     WRT1,WRT2,WRT4,XCHD,XCHS
                          EXTRN     CROUT,COPDT,GETCM,PRINT,PRINTF,EPRNT,FPRNT,ZERO
                          EXTRN     ECHO,GETCH,CO,NMOUT,ZEROM
                         ;
                         ;          I/O PORTS CHECKOUT ROUTINE
                         ;          TRANSMITT FROM DATA PORT1 TO PORT2,FROM PORT1 TO
                         ;          PORT3,THEN BACK.PRINT OUT MESSAGE IF OK OR ERROR.
                         ;
2000  3E 80              CKPT1A     MVI A,080H        PROGRAM PORT1A FOR ALL TRANSMITT
2002  D3 CF                         OUT PORT1
2004  3E 98                         MVI A,098H        PROGRAM WORD FOR RECEIVE
2006  D3 D7                         OUT PORT2         PORT2 PROGRAMED TO RECIEVE
                         ;          OUT PORT3         PORT3 PROGRAMED TO RECIEVE
2008  16 00                         MVI D,0           D REG ZERUED
200A  06 0C                         MVI B,12          LENGTH OF MESSAGE IN B
200C  7A                 LOP1       MOV A,D           MOVE FROM D REG TO A REG
200D  D3 CC                         OUT PORT1A        OUTPUT TO PORT1A
200F  AF                            XRA A             ZERO ACCUMULATOR
2010  DB D4                         IN PORT2A         INPUT FROM PORT2A
2012  BA                            CMP D             REG A COMPARED TO REG D
2013  C2 62 21                      JNZ E12A          JUMP TO ERROR IF NOT EQUAL
2016  14                            INR D             INCREMENT D REG
2017  C2 0C 20                      JNZ LOP1          LOOP BACK IF NOT DONE
201A  21 AB 22                      LXI H,POK1A       OK MESSAGE FOR PORT1A
201D  CD 58 21                      CALL PRTOK        PRINT MESSAGE
2020  3E 80              CKPT1B     MVI A,080H        PROGRAM PORT1B FOR ALL TRANSMITT
2022  D3 CF                         OUT PORT1
2024  3E 9D                         MVI A,09DH        PROGRAM WORD FOR RECEIVE
2026  D3 D7                         OUT PORT2         PORT2 PROGRAMED TO RECIEVE
2028  16 00                         MVI D,0           D REG ZEROED
202A  06 0C                         MVI B,12          LENGTH OF MESSAGE IN B
202C  7A                 LOP2       MOV A,D           MOVE FROM D REG TO A REG
202D  D3 CD                         OUT PORT1B        OUTPUT TO PORT1B
202F  AF                            XRA A             ZERO ACCUMULATOR
2030  DB D5                         IN PORT2B         INPUT FROM PORT2B
2032  BA                            CMP D             REG A COMPARED TO REG D
2033  C2 6B 21                      JNZ E12B          JUMP TO ERROR IF NOT EQUAL
2036  14                            INR D             INCREMENT D REG
2037  C2 2C 20                      JNZ LOP2          LOOP BACK IF NOT DONE
203A  21 B7 22                      LXI H,POK1B       OK MESSAGE FOR PORT1B
203D  CD 58 21                      CALL PRTOK        PRINT MESSAGE
2040  3E 80              CKPT1C     MVI A,080H        PROGRAM PORT1C FOR ALL TRANSMITT
2042  D3 CF                         OUT PORT1
2044  3E 9D                         MVI A,09DH        PROGRAM WORD FOR RECEIVE
2046  D3 D7                         OUT PORT2         PORT2 PROGRAMED TO RECIEVE
2048  16 00                         MVI D,0           D REG ZEROED
204A  06 0C                         MVI B,12          LENGTH OF MESSAGE IN B
204C  7A                 LOP3       MOV A,D           MOVE FROM D REG TO A REG
```

```
204D  D3 CE                OUT PORT1C      OUTPUT TO PORT1C
204F  AF                   XRA A           ZERO ACCUMULATOR
2050  DB D6                IN PORT2C       INPUT FROM PORT2C
2052  BA                   CMP D           REG A COMPARED TO REG D
2053  C2 74 21             JNZ E12C        JUMP TO ERROR IF NOT EQUAL
2056  14                   INR D           INCREMENT D REG
2057  C2 4C 20             JNZ LOP3        LOOP BACK IF NOT DONE
205A  21 C3 22             LXI H,POK1C     OK MESSAGE FOR PORT1C
205D  CD 58 21             CALL PRTOK      PRINT MESSAGE
2060  3E 80       CKPT2A   MVI A,080H      PROGRAM PORT2A FOR ALL TRANSMITT
2062  D3 D7                OUT PORT2
2064  3E 9B                MVI A,09BH      PROGRAM WORD FOR RECEIVE
                           OUT PORT3       PORT3 PROGRAMED TO RECIEVE
2066  D3 CF                OUT PORT1       PORT1 PROGRAMED TO RECIEVE
2068  16 00                MVI D,0         D REG ZEROED
206A  06 0C                MVI B,12        LENGTH OF MESSAGE IN B
206C  7A          LOP4     MOV A,D         MOVE FROM D REG TO A REG
206D  D3 D4                OUT PORT2A      OUTPUT TO PORT2A
206F  AF                   XRA A           ZERO ACCUMULATOR
2070  DB CC                IN PORT1A       INPUT FROM PORT1A
2072  BA                   CMP D           REG A COMPARED TO REG D
2073  C2 7D 21             JNZ E21A        JUMP TO ERROR IF NOT EQUAL
2076  14                   INR D           INCREMENT D REG
2077  C2 6C 20             JNZ LOP4        LOOP BACK IF NOT DONE
207A  21 F3 22             LXI H,POK2A     OK MESSAGE FOR PORT2A
207D  CD 58 21             CALL PRTOK      PRINT MESSAGE
2080  3E 80       CKPT2B   MVI A,080H      PROGRAM PORT2B FOR ALL TRANSMITT
2082  D3 D7                OUT PORT2
2084  3E 9B                MVI A,09BH      PROGRAM WORD FOR RECEIVE
2086  D3 CF                OUT PORT1       PORT1 PROGRAMED TO RECIEVE
2088  16 00                MVI D,0         D REG ZEROED
208A  06 0C                MVI B,12        LENGTH OF MESSAGE IN B
208C  7A          LOP5     MOV A,D         MOVE FROM D REG TO A REG
208D  D3 D5                OUT PORT2B      OUTPUT TO PORT2B
208F  AF                   XRA A           ZERO ACCUMULATOR
2090  DB CD                IN PORT1B       INPUT FROM PORT1B
2092  BA                   CMP D           REG A COMPARED TO REG D
2093  C2 86 21             JNZ E21B        JUMP TO ERROR IF NOT EQUAL
2096  14                   INR D           INCREMENT D REG
2097  C2 8C 20             JNZ LOP5        LOOP BACK IF NOT DONE
209A  21 FF 22             LXI H,POK2B     OK MESSAGE FOR PORT2B
209D  CD 58 21             CALL PRTOK      PRINT MESSAGE
20A0  3E 80       CKPT2C   MVI A,080H      PROGRAM PORT2C FOR ALL TRANSMITT
20A2  D3 D7                OUT PORT2
20A4  3E 9B                MVI A,09BH      PROGRAM WORD FOR RECEIVE
20A6  D3 CF                OUT PORT1       PORT1 PROGRAMED TO RECIEVE
20A8  16 00                MVI D,0         D REG ZEROED
20AA  06 0C                MVI B,12        LENGTH OF MESSAGE IN B
20AC  7A          LOP6     MOV A,D         MOVE FROM D REG TO A REG
20AD  D3 D6                OUT PORT2C      OUTPUT TO PORT2C
20AF  AF                   XRA A           ZERO ACCUMULATOR
20B0  DB CE                IN PORT1C       INPUT FROM PORT1C
20B2  BA                   CMP D           REG A COMPARED TO REG D
20B3  C2 8F 21             JNZ E21C        JUMP TO ERROR IF NOT EQUAL
```

```
2086  14                   INR D          INCREMENT D REG
2087  C2 AC 20             JNZ LOP6       LOOP BACK IF NOT DONE
208A  21 0D 23             LXI H,POK1C    OK MESSAGE FOR PORT1C
208D  CD 58 21             CALL PRTOK     PRINT MESSAGE
                ;CKPT2A;    MVI A,[illegible]   PROGRAM PORT2A FOR ALL TRANSMITT
                ;          OUT PORT1
                ;          MVI A,[illegible]   PROGRAM WORD FOR RECEIVE
                ;          OUT PORT1      PORT1 PROGRAMED TO RECIEVE
                ;          OUT PORT2      PORT2 PROGRAMED TO RECIEVE
                ;          MVI D,0        D REG ZEROED
                ;          MVI B,12       LENGTH OF MESSAGE IN B
                ;LOP7        MOV A,D        MOVE FROM D REG TO A REG
                ;          OUT PORT2A     OUTPUT TO PORT2A
                ;          XRA A          ZERO ACCUMULATOR
                ;          IN PORT1A      INPUT FROM PORT1A
                ;          CMP D          REG A COMPARED TO REG D
                ;          JNZ E31A       JUMP TO ERROR IF NOT EQUAL
                ;          INR D          INCREMENT D REG
                ;          JNZ LOP7       LOOP BACK IF NOT DONE
                ;          LXI H,POK3A    OK MESSAGE FOR PORT3A
                ;          CALL PRTOK     PRINT MESSAGE
                ;CKPT3B      MVI A,[illegible]   PROGRAM PORT3B FOR ALL TRANSMITT
                ;          OUT PORT3
                ;          MVI A,[illegible]   PROGRAM WORD FOR RECEIVE
                ;          OUT PORT1      PORT1 PROGRAMED TO RECIEVE
                ;          MVI D,0        D REG ZEROED
                ;          MVI B,12       LENGTH OF MESSAGE IN B
                ;LOP8        MOV A,D        MOVE FROM D REG TO A REG
                ;          OUT PORT3B     OUTPUT TO PORT3B
                ;          XRA A          ZERO ACCUMULATOR
                ;          IN PORT1B      INPUT FROM PORT1B
                ;          CMP D          REG A COMPARED TO REG D
                ;          JNZ E31B       JUMP TO ERROR IF NOT EQUAL
                ;          INR D          INCREMENT D REG
                ;          JNZ LOP8       LOOP BACK IF NOT DONE
                ;          LXI H,POK3B    OK MESSAGE FOR PORT3B
                ;          CALL PRTOK     PRINT MESSAGE
                ;CKPT3C      MVI A,[illegible]   PROGRAM PORT3C FOR ALL TRANSMITT
                ;          OUT PORT3
                ;          MVI A,[illegible]   PROGRAM WORD FOR RECEIVE
                ;          OUT PORT1      PORT1 PROGRAMED TO RECIEVE
                ;          MVI D,0        D REG ZEROED
                ;          MVI B,12       LENGTH OF MESSAGE IN B
                ;LOP9        MOV A,D        MOVE FROM D REG TO A REG
                ;          OUT PORT3C     OUTPUT TO PORT3C
                ;          XRA A          ZERO ACCUMULATOR
                ;          IN PORT1C      INPUT FROM PORT1C
                ;          CMP D          REG A COMPARED TO REG D
                ;          JNZ E31C       JUMP TO ERROR IF NOT EQUAL
                ;          INR D          INCREMENT D REG
                ;          JNZ LOP9       LOOP BACK IF NOT DONE
                ;          LXI H,POK3C    OK MESSAGE FOR PORT3C
                ;          CALL PRTOK     PRINT MESSAGE
20C0  C3 C3 20             JMP RAMCK      CHECK RAM
```

```
                           ;            RAMCK             CHECK ALL RAM IN MEMORY
                           ;                              ERROR PRINTED OUT ONLY IF BAD
                           ;
                           ;
20C3   1E 00               RAMCK        MVI E,0           ZERO ALL RAM
20C5   21 00 08                         LXI H,0800H       FIRST HEX ADDRESS TO BE ZEROED IN HL
20C8   01 D5 38                         LXI B,038D5H      MAXIMUM ADDRESS TO BE TESTED
20CB   CD 00 00       E                 CALL ZEROM        ZERO RAM FROM 800 TO 3FE0H
20CE   21 00 08                         LXI H,0800H       HL SET AT STARTING ADDRESS
20D1   3E 00               MNXT         MVI A,0           A REG ZEROED
20D3   BE                  LOPM         CMP M             COMPARE ACCUMULATOR TO MEMORY
20D4   C2 3A 21                         JNZ MERR          JUMP TO MEMORY ERROR IF NOT EQUAL
20D7   3C                               INR A             INCREMENT ACCUMULATOR
20D8   CA DF 20                         JZ NXTM           JUMP TO NEXT MEMORY IF ACCUMULATOR ZERO
20DB   34                               INR M             JUMP BACK TO TEST SAME MEM LOC AGAIN
20DC   C3 D3 20                         JMP LOPM          JUMP BACK TO TEST SAME RAM WITH NEXT NO
20DF   23                  NXTM         INX H             INCREMENT HL TO POINT TO NEXT MEM LOC
20E0   3E D5               HLTS         MVI A,0D5H        TEST TO SEE IF HL.GT.38D5
20E2   95                               SUB L             SUBTRACT HL FROM 3FE0.IF NEG GET A BORROW
20E3   3E 38                            MVI A,038H        WHEN HL.GT.38D5,CARRY SET
20E5   9C                               SBB H             JUMP BACK TO MONITOR WHEN DONE
20E6   D2 D1 20                         JNC MNXT          JUMP TO NEXT RAM TEST
20E9   21 05 22                         LXI H,RAMCP       ADDR OF RAM TEST COMPLETE MSG
20EC   06 13                            MVI B,19          B REG LOADED FOT 19 CHARACTERS
20EE   CD 58 21                         CALL PRTOK        PRINT OUT MESSAGE
20F1   C3 F4 20                         JMP MATHC         CHECK OUT AM9511 MATH PACK
                           ;
                           ;            MATHC             PROGRAM CHECKS OUT 9511 MATH PACK
                           ;
20F4   CD 00 00       E    MATHC        CALL CROUT
20F7   CD 00 00       E                 CALL PUPI         PUSH PI ON STACK
20FA   CD 00 00       E                 CALL PTOD         PUSH TOP OF STACK DOUBLE
20FD   CD 00 00       E                 CALL FMUL         PI*PI ON TOP OF STACK
2100   CD 00 00       E                 CALL PTOD         PI*PI,PI*PI ON TOS ,NEXT ON STACK
2103   CD 00 00       E                 CALL FADD         2*PI*PI ON TOS
2106   CD 00 00       E                 CALL SQRT         PI*SQRT(2) ON TOS
2109   CD 00 00       E                 CALL COS          COS((PI*SQRT(2)) ON TOS
210C   CD 00 00       E                 CALL PUPI         ANOTHER COPY OF PI ON TOS
210F   CD 00 00       E                 CALL FSUB         PI-COS((PI*SQRT(2)) ON TOS
2112   CD 00 00       E                 CALL PTOD         TWO COPIES ON TOS
2115   CD 00 00       E                 CALL PRINT        TOP OF STACK PRINTED ON TERMINAL
2118   DB EE                            IN APDATA         READ NO FROM TOS
211A   FE 02                            CPI 002H          COMPARE TO CORRECT EXPONENT
211C   C4 AA 21                         CNZ APUER         CALL APU ERROR IF.NE.02
211F   DB EE                            IN APDATA         READ NEXT NO
2121   FE DA                            CPI 0DAH          COMPARE TO CORRECT EXPONENT
2123   C4 AA 21                         CNZ APUER         CALL APU ERROR IF.NE.DA
2126   DB EE                            IN APDATA
2128   FE 1A                            CPI 01AH          COMPARE TO CORRECT EXPONENT
212A   C4 AA 21                         CNZ APUER         CALL APU ERROR IF.NE.1A
212D   DB EE                            IN APDATA
212F   FE 2F                            CPI 02FH          COMPARE TO CORRECT EXPONENT
2131   C4 AA 21                         CNZ APUER         CALL APU ERROR IF.NE.2F
2134   CD 00 00       E                 CALL CROUT
```

```
2137  C3 00 00   E           JMP GETCH
                       ;
                       ;      MERR           MEMORY ERROR ROUTINE-PRINTS CHIP ADDR
                       ;                     IN 1K INCREMENTS & CONTINUES TEST
                       ;
213A  1E 00            MERR   MVI E,0        ZERO E
213C  7C                      MOV A,H        MOVE H TO A
213D  E6 FC                   ANI 0FCH       DUMP 2 LOWER BITS OF H
213F  57                      MOV D,A        RESTORE TO D
2140  21 98 22                LXI H,ERRM     MEMORY ERROR MESSAGE LOADED
2143  06 13                   MVI B,19       19 CHARACTERS WILL BE PRINTED
2145  CD 58 21                CALL PRTOK     CHARACTERS PRINTED
2148  7A                      MOV A,D
2149  CD 00 00   E            CALL NMOUT     NUMBER IN BE PRINTED
214C  7B                      MOV A,E
214D  CD 00 00   E            CALL NMOUT
2150  7A                      MOV A,D        HI ORDER ADDR LOADED BACK IN A
2151  C6 04                   ADI 04H        MEM ADDR INCREASED TO NEXT RAM
2153  67                      MOV H,A        MOVE HI ORDER + 400H BACK IN H
2154  6B                      MOV L,E        HL HAS ADDR OF NEXT RAM
2155  C3 E0 20                JMP HLTS       GO TEST NEXT RAM
                       ;
                       ;      PRTOK          PROGRAM PRINTS MESSAGE ADDRESSED
                       ;                     BY HL THAT IS B CHARACTERS LONG
                       ;
2158  4E               PRTOK  MOV C,M        GET CHARACTER TO BE PRINTED
2159  CD 00 00   E            CALL CO        SEND CHARACTER TO PRINTER
215C  23                      INX H          GO TO NEXT CHARACTER
215D  05                      DCR B          DECREMENT BYTE COUNTER
215E  C2 58 21                JNZ PRTOK      GO BACK FOR NEXT CHARACTER IF NOT DONE
2161  C9                      RET            RETURN TO CALLER IF DONE
2162  21 CF 22         E12A   LXI H,PBD1A    PORT12A BAD ERROR MESSAGE
2165  CD 58 21                CALL PRTOK     PRINT MESSAGE
2168  C3 20 20                JMP CKPT1B     TEST NEXT SET OF PORTS
216B  21 DB 22         E12B   LXI H,PBD1B    PORT12B BAD ERROR MESSAGE
216E  CD 58 21                CALL PRTOK     PRINT MESSAGE
2171  C3 40 20                JMP CKPT1C     TEST NEXT SET OF PORTS
2174  21 E7 22         E12C   LXI H,PBD1C    PORT12C BAD ERROR MESSAGE
2177  CD 58 21                CALL PRTOK     PRINT MESSAGE
217A  C3 60 20                JMP CKPT2A     TEST NEXT SET OF PORTS
217D  21 17 23         E21A   LXI H,PBD2A    PORT21A BAD ERROR MESSAGE
2180  CD 58 21                CALL PRTOK     PRINT MESSAGE
2183  C3 80 20                JMP CKPT2B     TEST NEXT SET OF PORTS
2186  21 23 23         E21B   LXI H,PBD2B    PORT21B BAD ERROR MESSAGE
2189  CD 58 21                CALL PRTOK     PRINT MESSAGE
218C  C3 A0 20                JMP CKPT2C     TEST NEXT SET OF PORTS
218F  21 2F 23         E21C   LXI H,PBD2C    PORT21C BAD ERROR MESSAGE
2192  CD 58 21                CALL PRTOK     PRINT MESSAGE
                       ;      JMP CKPT3A     TEST NEXT SET OF PORTS
2195  21 5F 23         E31A   LXI H,PBD3A    PORT31A BAD ERROR MESSAGE
2198  CD 58 21                CALL PRTOK     PRINT MESSAGE
                       ;      JMP CKPT3B     TEST NEXT SET OF PORTS
219B  21 6B 23         E31B   LXI H,PB[illegible]  PORT31B [illegible] ERROR MESSAGE
219E  CD 58 21                CALL PRTOK     PRINT MESSAGE
```

```
                            ;       JMP CKPT3C       TEST NEXT SET OF PORTS
21A1  21 77 23              E31C    LXI H,PBD3C      PORT31C BAD ERROR MESSAGE
21A4  CD 58 21                      CALL PRTOK       PRINT MESSAGE
21A7  C3 C3 20                      JMP RAMCK        TEST NEXT CIRCUITS
                            ;
21AA  21 75 22              APUER   LXI H,ERAPU      HL LOADED WITH APU ERR MSG ADR
21AD  06 10                         MVI B,016        14 CHARACTERS,CR,LF TO BE PRINTED
21AF  CD 58 21                      CALL PRTOK       MESSAGE PRINTED
21B2  C3 00 00        E             JMP GETCM
                            ;
                            ;       TSTTAP           PROGRAM TO TEST AIRCO TAPE DATA
                            ;
21B5  3E 88                 TSTTAP  MVI A,088H       PORT1 WILL BE SET FOR OUTPUT
21B7  D3 CF                         OUT PORT1        SET PORT1 FOR OUTPUT
21B9  3E 90                         MVI A,090H       PORT2 SET
21BB  D3 D7                         OUT PORT2        CONTROL WORD SENT
21BD  3E 07                         MVI A,07H        CHART OFF SIGNAL
21BF  D3 D5                         OUT PORT2B       TURN OFF CALIBRATOR RELAYS
21C1  3E 70                         MVI A,070H       SET MAG TAPE READ,WRITE,DAC LATCH HI
21C3  D3 D6                         OUT PORT2C       LEAVE STROBE LINES HI
21C5  3E 93                         MVI A,093H       LOAD WORD FOR A OUT,B INPUT,C I/O
                            ;       OUT PORT3
21C7  3E 05                         MVI A,05H        SELECT TAPE DRIVE,SET UP FOR READ
21C9  D3 CD                         OUT PORT1B       SEND TO PORT 1B
21CB  01 00 30              TAP1    LXI B,03000H     BLOCK OF DATA TO BE READ INTO RAM
21CE  C5                            PUSH B           STORE ON STACK
21CF  11 F3 30                      LXI D,030F3H     END OF DATA BLOCK
21D2  D5                            PUSH D           STORE ON STACK
21D3  CD 6B 0F                      CALL RDTAP       READ 244 BYTES OF DATA FROM TAPE
21D6  C3 70 00                      JMP DISBLK       DISPLAY BLOCK OF DATA FROM TAPE
                            ;
                            ;
                            ;       BUFCK            PROGRAM TO CHECK THE BUFFER
                            ;                        IN THE TAPE FORMATTER FOR
                            ;                        WRITES A 64K BLOCK TO TAPE
                            ;                        TAPE SHOULD BE RECORD,ONLINE BEFORE GO
                            ;                        IS TYPED.
                            ;
21D9  21 03 23              BUFWCK  LXI H,TWRP       LOAD ADDR OF PROMPT MSG IN HL
21DC  06 1E                         MVI B,TWRPL      LOAD LENGTH OF PROMPT MSG IN B
21DE  CD 58 21                      CALL PRTOK       PRINT B CHARACTERS,ADDR BY HL
21E1  21 00 00                      LXI H,0H         ZERO BYTE COUNT IN HL
21E4  3E 88                         MVI A,088H       SET PORT1 FOR OUTPUT
21E6  D3 CF                         OUT PORT1        TO MAG TAPE
21E8  3E 90                         MVI A,090H       SET PORT2 FOR OUTPUT
21EA  D3 D7                         OUT PORT2
21EC  3E 86                         MVI A,086H       SELECT TAPE DRIVE
21EE  D3 CD                         OUT PORT1B       SEND TO PORT1B
21F0  3E 07                         MVI A,07H        TURN OFF CHART SIGNAL
21F2  D3 D5                         OUT PORT2B       CALIBRATOR RELAYS
21F4  CD 68 22                      CALL CARRET      HANG HERE UNTIL READY
21F7  7D                    TWLP    MOV A,L          LOAD LOW BYCOUNT FROM HL
21F8  D3 CC                         OUT PORT1A       SEND OUT TO PORT1A
21FA  AF                            XRA A            ZERO A,STROBE RAC LINE
```

```
21FB  D3 D6                    OUT PORT2C      LO,THEN HI
21FD  3E 10                    MVI A,10H
21FF  D3 D6                    OUT PORT2C
2201  0E 20                    MVI C,020H      LOAD ASCII CHARACTER FOR SPACE IN C
2203  CD 00 00   E             CALL CO         PRINT A SPACE
2206  23                       INX H           INCREMENT BYTE COUNT
2207  7C                       MOV A,H         CHECK HI BYTE
2208  FE 00                    CPI 0           BOTH HI & LO BYTE
220A  C2 F7 21                 JNZ TWLP        ZERO WHEN DONE
220D  7D                       MOV A,L         CHECK LO BYTE
220E  FE 00                    CPI 0
2210  C2 F7 21                 JNZ TWLP
                 ;                             WRITE IS DONE,PROMPT FOR READBACK
2213  21 A1 23                 LXI H,TRDP      LOAD ADDR OF TAPE READ PRO MSG
2216  06 32                    MVI B,TRDPL     LENGTH OF MSG IN B
2218  CD 50 21                 CALL PRTOK      PRINT ON TERMINAL
221B  C3 00 00   E             JMP GETCH       RETURN TO MONITOR
                 ;
                 ;             BUFRCK          PROGRAM TO CHECK THE BUFFER
                 ;                             IN THE TAPE FORMATTER FOR READS
                 ;                             OF 64K DATA BLOCK.ERRORS PRINTED
221E  21 01 00   BUFRCK        LXI H,1H        SET BYTE COUNT
2221  3E 88                    MVI A,088H      SET PORT1 FOR OUTPUT
2223  D3 CF                    OUT PORT1       TO MAG TAPE
2225  3E 90                    MVI A,090H      SET PORT2 FOR OUTPUT
2227  D3 D7                    OUT PORT2
2229  3E 07                    MVI A,07H       TURN OFF CHART SIGNAL
222B  D3 D5                    OUT PORT2B      CALIBRATOR RELAYS
222D  3E 93                    MVI A,093H      LOAD WORD FOR A OUT,B IN C I/O
                 ;             OUT PORT3       SEND TO PORT3
222F  3E 05                    MVI A,05H       SELECT TAPE DRIVE,SET UP FOR READ
2231  D3 CD                    OUT PORT1B      SEND TO PORT 1B
2233  CD 68 22                 CALL CARRET     HANG HERE ULTIL READY
2236  CD 00 00   E   TRLP      CALL CROUT      CR,LF
2239  7C                       MOV A,H         MOVE TO ACC TO PRINT
223A  CD 00 00   E             CALL NMOUT      PRINT H
223D  7D                       MOV A,L         MOVE L TO ACC
223E  CD 00 00   E             CALL NMOUT      PRINT L
2241  0E 20                    MVI C,020H      LOAD ASCII CHARACTER FOR SPACE IN C
2243  CD 00 00   E             CALL CO         PRINT A SPACE
                 ;             IN PORT3A       READ BYTE FROM TAPE BUFFER TO ACC
2246  BD                       CMP L           COMPARE TAPE DATA TO BYTE COUNT
2247  C4 00 00   E             CNZ NMOUT       PRINT IT IF.NE.BYTECOUNT
224A  DB C6                    IN USSTS        CHECK USART FOR CHARACTER
224C  E6 02                    ANI 02H
224E  C4 68 22                 CNZ CARRET      HANG FOR CARRIAGE RETURN IF CHARACTER
2251  AF                       XRA A           ZERO ACCUMULATOR
2252  D3 D6                    OUT PORT2C      SEND REC LINE LOW
2254  3E 10                    MVI A,10H       SEND LINE BACK HI
2256  D3 D6                    OUT PORT2C
2258  23                       INX H           INCREMENT BYTE COUNT
2259  7C                       MOV A,H         CHECK HI BYTE
225A  FE 00                    CPI 0           BOTH HI & LO BYTE
225C  C2 36 22                 JNZ TRLP        ZERO WHEN DONE
```

```
225F    7D                          MOV A,L         CHECK LO BYTE
2260    FE 00                       CPI 0
2262    C2 36 22                    JNZ TRLP
2265    C3 00 00      E             JMP GETCM       RETURN TO MONITOR
                             ;
                             ;      CARRET          HANGS PROGRAM HERE UNTIL CR TYPED
                             ;
2268    CD 00 00      E      CARRET CALL GETCH      GET A CHARACTER FROM TERMINAL
226B    CD 00 00      E             CALL ECHO       PRINT IT OUT
226E    79                          MOV A,C         STICK IT IN ACC
226F    FE 0D                       CPI CR          COMPARE TO CARRIAGE RETURN
2271    C2 68 22                    JNZ CARRET      LOOK AGAIN IF NOT CR
2274    C9                          RET             RETURN IF IT WAS
                             ;
2275    0D 0A 45 52          ERAPU  DB CR,LF,'ER IN 9511 APU'
2279    20 49 4E 20
227D    39 35 31 31
2281    20 41 50 55
                             ;
2285    0D 0A 52 41          RAMCP  DB CR,LF,'RAM TEST COMPLETE'
2289    4D 20 54 45
228D    53 54 20 43
2291    4F 4D 50 4C
2295    45 54 45
2298    0D 0A 4D 45          ERRM   DB CR,LF,'MEMORY ERROR AT
229C    4D 4F 52 59
22A0    20 45 52 52
22A4    4F 52 20 41
22A8    54 20 20
22AB    0D 0A 50 4F          POK1A  DB CR,LF,'PORT12A OK'
22AF    52 54 31 32
22B3    41 20 4F 4B
22B7    20 20 50 4F          POK1B  DB '  PORT12B OK'
22BB    52 54 31 32
22BF    42 20 4F 4B
22C3    20 20 50 4F          POK1C  DB '  PORT12C OK'
22C7    52 54 31 32
22CB    43 20 4F 4B
22CF    0D 0A 45 52          PBD1A  DB CR,LF,'ER PORT12A'
22D3    20 50 4F 52
22D7    54 31 32 41
22DB    20 20 45 52          PBD1B  DB '  ER PORT12B'
22DF    20 50 4F 52
22E3    54 31 32 42
22E7    20 20 45 52          PBD1C  DB '  ER PORT12C'
22EB    20 50 4F 52
22EF    54 31 32 43
22F3    0D 0A 50 4F          POK2A  DB CR,LF,'PORT21A OK'
22F7    52 54 32 31
22FB    41 20 4F 4B
22FF    20 20 50 4F          POK2B  DB '  PORT21B OK'
2303    52 54 32 31
2307    42 20 4F 4B
230B    20 20 50 4F          POK2C  DB '  PORT21C OK'
```

```
230F  52 54 32 31
2313  43 20 4F 4B
2317  0D 0A 45 52    PBD2A    DB CR,LF,'ER PORT21A'
231B  20 50 4F 52
231F  54 32 31 41
2323  20 20 45 52    PBD2B    DB '  ER PORT21B'
2327  20 50 4F 52
232B  54 32 31 42
232F  20 20 45 52    PBD2C    DB '  ER PORT21C'
2333  20 50 4F 52
2337  54 32 31 43
233B  0D 0A 50 4F    POK3A    DB CR,LF,'PORT31A OK'
233F  52 54 33 31
2343  41 20 4F 4B
2347  20 20 50 4F    POK3B    DB '  PORT31B OK'
234B  52 54 33 31
234F  42 20 4F 4B
2353  20 20 50 4F    POK3C    DB '  PORT31C OK'
2357  52 54 33 31
235B  43 20 4F 4B
235F  0D 0A 45 52    PBD3A    DB CR,LF,'ER PORT31A'
2363  20 50 4F 52
2367  54 33 31 41
236B  20 20 45 52    PBD3B    DB '  ER PORT31B'
236F  20 50 4F 52
2373  54 33 31 42
2377  20 20 45 52    PBD3C    DB '  ER PORT31C'
237B  20 50 4F 52
237F  54 33 31 43
2383  0D 0A 48 49    TWRP     DB CR,LF,'HIT CARRIAGE RETURN TO START'
2387  54 20 43 41
238B  52 52 49 41
238F  47 45 20 52
2393  45 54 55 52
2397  4E 20 54 4F
239B  20 53 54 41
239F  52 54
001E                 TWRPL    EQU $-TWRP        LENGTH OF PROMPT
23A1  0D 0A 52 45    TRDP     DB CR,LF,'REWIND,SW TO LOCAL,READ,G158F,ONLINE,CR TO START'
23A5  57 49 4E 44
23A9  2C 53 57 20
23AD  54 4F 20 4C
23B1  4F 43 41 4C
23B5  2C 52 45 41
23B9  44 2C 47 31
23BD  35 38 46 2C
23C1  4F 4E 4C 49
23C5  4E 45 2C 43
23C9  52 20 54 4F
23CD  20 53 54 41
23D1  52 54
0032                 TRDPL    EQU $-TRDP        LENGTH OF PROMPT
23D3                          END

ASSEMBLER ERRORS =    0
```

SYMBOL TABLE

A		0007	ACOS	E	0000	ADR01		00DE	ADRMD		00DC
ADRST		00DC	ADRTL		0005	APDATA		00EE	APSTAT		00EF
APUER		21AA	ASIN	E	0001	ATAN	E	0002	ATANA	E	0003
AUXMD		00DD	AXRA		0000	AXRB		00A0	B		0000
BIDEC	E	0004	BIDECF	E	0005	BIM		0001	BOM		0002
BUFRCK		221E	BUFWCK		21D9	BUSIN		00D0	BUSOUT		00D0
BUSPRT		00D8	C		0001	CANCY		0003	CARRET		2268
CHSD	E	0006	CHSDA	E	0007	CHSF	E	0008	CHSFA	E	0009
CHSS	E	000A	CHSSA	E	000B	CKPT1A		2000	CKPT1B		2020
CKPT1C		2040	CKPT2A		2060	CKPT2B		2080	CKPT2C		20A0
CLKRT		0022	CO	E	006A	COPDT	E	0061	COS	E	000C
COSA	E	000D	CPT		0000	CPTEN		0001	CPTRG		00DD
CR		000D	CROUT	E	0060	D		0002	DADD	E	000E
DADDA	E	000F	DADDB	E	0010	DDIV	E	0011	DDIVA	E	0012
DDIVB	E	0013	DECHO	E	0014	DISBLK		0070	DMUL	E	0015
DMULA	E	0016	DMULB	E	0017	DMUU	E	0018	DMUUA	E	0019
DMUUB	E	001A	DSUB	E	001B	DSUBA	E	001C	DSUBB	E	001D
DTDL1		0060	DTDL2		00E0	E		0003	E12A		2162
E12B		216B	E12C		2174	E21A		217D	E21B		2186
E21C		218F	E31A		2195	E31B		2198	E31C		21A1
ECHO	E	0068	EDEOS		0004	ENDMK		0010	EOIS		0008
EOIST		0020	EOSBC		0040	EOSR		00DF	EPRNT	E	0065
ERAPU		2275	ERRM		2290	EXP	E	001E	EXP10	E	0020
EXPA	E	001F	FADD	E	0021	FADDA	E	0022	FADDB	E	0023
FDIV	E	0024	FDIVA	E	0025	FDIVB	E	0026	FIXD	E	0027
FIXDA	E	0028	FIXS	E	0029	FIXSA	E	002A	FLTD	E	002B
FLTDA	E	002C	FLTS	E	002D	FLTSA	E	002E	FMUL	E	002F
FMULA	E	0030	FMULB	E	0031	FNHSK		0003	FPRNT	E	0066
FSUB	E	0032	FSUBA	E	0033	FSUBB	E	0034	GETCH	E	0069
GETCM	E	0062	H		0004	HLTS		20E0	HOEND		0002
HOHSK		0001	INTE1		00D9	INTE2		00DA	L		0005
LA		0004	LF		000A	LN	E	0035	LNA	E	0036
LOG	E	0037	LOGA	E	0038	LON		0040	LOP1		200C
LOP2		202C	LOP3		204C	LOP4		206C	LOP5		208C
LOP6		20AC	LOPN		20D3	M		0006	MATHC		20F4
MDAD	E	0039	MEMORY	M	0000	MERR		213A	MJMN		0001
MNXT		20D1	MODE1		0001	NMOUT	E	0068	NOP	E	003A
NVCMD		0007	NXTM		20DF	PBD1A		22CF	PBD1B		22DB
PBD1C		22E7	PBD2A		2317	PBD2B		2323	PBD2C		232F
PBD3A		235F	PBD3B		236B	PBD3C		2377	POK1A		22AB
POK1B		22B7	POK1C		22C3	POK2A		22F3	POK2B		22FF
POK2C		230B	POK3A		233B	POK3B		2347	POK3C		2353
POPD	E	003B	POPS	E	003C	PORT1		00CF	PORT1A		00CC
PORT1B		00CD	PORT1C		00CE	PORT2		00D7	PORT2A		00D4
PORT2B		00D5	PORT2C		00D6	PRINT	E	0063	PRINTF	E	0064
PRTOK		2150	PSW		0006	PTOD	E	003D	PTOS	E	003E
PUPI	E	003F	PWR	E	0040	PWRA	E	0041	PWRB	E	0042
RAMCK		20C3	RAMCP		2205	RDTAP		0F6B	RTCCT0		00E4
RTCCT1		00E5	RTCCT2		00E6	RTCCTL		00E7	S1		00D3
SADD	E	0043	SADDA	E	0044	SADDB	E	0045	SDEOI		0006
SDIV	E	0046	SDIVA	E	0047	SDIVB	E	0048	SIN	E	0049
SINA	E	004A	SMUL	E	004B	SMULA	E	004C	SMULB	E	004D
SMUU	E	004E	SMUUA	E	004F	SMUUB	E	0050	SP		0006
SQRT	E	0051	SQRTA	E	0052	SSUB	E	0053	SSUBA	E	0054
SSUBB	E	0055	STACK	S	0000	TA		0002	TAN	E	0056
TANA	E	0057	TAP1		21CB	TLON		00C0	TON		0000
TOS1	E	0058	TOS2	E	0059	TOS4	E	005A	TRDP		23A1
TRDPL		0032	TRLP		2236	TSTTAP		21B5	TWLP		21F7
TWRP		2383	TWRPL		001E	USSTS		00C6	VSCMD		000F
WRT1	E	005B	WRT2	E	005C	WRT4	E	005D	XCMD	E	005E
XCHS	E	005F	ZERO	E	0067	ZEROM	E	006C			

Appendix I

PROCEDURE FOR PERFORMING THE MANUAL EDDY-CURRENT INSPECTION OF THE SHEATH WELD ON THE SUPERCONDUCTOR CABLE

This procedure describes the techniques used to perform the manual eddy-current inspection of the sheath weld after the superconductor cable has been fabricated. The procedure provides guidelines for the necessary steps and the order of performance required to set up and calibrate the equipment, verify the test sensitivity, and perform the inspection to evaluate those areas on the sheath weld where indications were obtained during the on-line inspection. This procedure and technique can also be used to determine whether or not the weld repairs were successful. The procedure was written with the assumption that the operator is familiar with the test equipment and its operation.

1.0 EQUIPMENT

Multifrequency eddy-current instrument
Eddy-current probe and cable
Probe holder for manual scanning
Transceiver unit
Video terminal and keyboard
Remote control box (RCB)
Six-channel analog recorder
Assorted nonconducting shims in the 25 to 254 μm (0.001 to 0.010 in.) range
Reference standards
Isolation transformer

2. ELECTRICAL POWER

2.1 Before connecting power to the eddy-current instrument, make sure that the three toggle switches on the phase calibrator module are in the "down" position (i.e., "MAG-LO," "PH-LO," and "OPERATE" positions), and make sure that an eddy-current probe is connected to the correct jacks on the calibrator module.

2.2 Connect electrical power to *all* instruments [eddy current (only on isolation transformer), analog recorder, transceiver, and video terminal], turn the equipment on, and allow at least 4 h for the instruments to warm up and stabilize.

3. DURING THE WARM-UP PERIOD

3.1 Check all cables and electrical connections to make sure they are correct (see Fig. I.1).

3.2 Check the switches on all modules and instruments to assure they are in the normal position, per Tables I.1 and I.2.

3.3 *Check the analog recording system.* Set the RCB function switch to position 7. Press a chart speed switch to start the analog recorder chart drive. Use a slow chart speed (5 mm/s or less). Press the "interrupt" switch on the RCB, and set all recorder pens to the zero reference value on each chart scale using zero adjustments on the recorder. After zeroing all pens, press the "return" key on the keyboard. All recorder pens should step five minor chart divisions to the left on the respective chart scales, representing an increase of 0.25 mm (0.010 in.). Press the "return" key eight times, representing an increase of 2.03 mm (0.080 in.). If any of these recorder pens are not at the left margin, check the recorder sensitivity adjustments for that recorder

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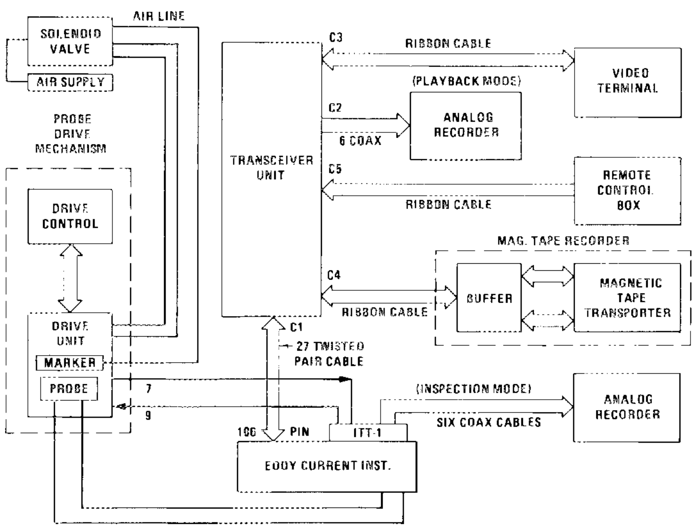

Fig. I.1. Block diagram of the digital recording system.

Table I.1. Normal instrument settings

Instrument	Modular[a] position	Switch identity	Correct switch setting
Eddy-Current Instrument		Power on-off	
Power Oscillator	M1	High frequency (top)	500 kHz
		Median frequency (middle)	100 kHz
		Low frequency (bottom)	20 kHz
Bandpass Amplifier	M4	Low frequency	20 kHz
	M6	Mid frequency	100 kHz
	M8	High frequency	500 kHz
Discriminators[b]	M3	Coarse lift-off	518
	M3	Coarse balance	714
	M5	Coarse lift-off	512
	M5	Coarse balance	682
	M7	Coarse lift-off	507
	M7	Coarse balance	920
Analog Recorder		Power on-off	
		Sensitivity — coarse	100 mV/div
		Sensitivity — fine	Maximum CW
		Chart speed	5 mm/div
Probe Drive Control		Power on-off	
		Speed adjustment	124—128
		Scale selector (torque/speed)	Speed
		Direction (CW/stop/CCW)	CW

[a]The eddy-current instrument chassis has 10 modular positions. They are identified as M1 to M10 from right to left when facing the instrument. The computer module occupies two positions, M9 and M10.

[b]Adjustments of the lift-off and balance controls on the discriminators may sometimes be necessary to calibrate the eddy-current instrument. These adjustments should be made by using only the fine controls (screwdriver adjustments). If a change in the coarse control setting becomes necessary, notify your supervisor.

Table I.2. Instrument switches and functions

Instrument	Switch	Position(s)	Function and comments
Eddy Current Control Module	Function	0–9	Selects correct PROM to match the eddy-current probe (00 for 454, 01 for 460, and 02 for 459)
	Interrupt		DO NOT USE
	Reset		DO NOT USE
Magnetic Tape Recorder			
Transporter	Power	On-Off	
Transporter	Load	On-Off	Used to load tape
Transporter	On-Line	On-Off	Use for recording and reading
Transporter	Rewind	On-Off	Used to rewind tape
Transporter	Write ring		See Appendix A
Buffer	Power	On-Off	
Buffer	EOF	On-Off	See Appendix A
Buffer	Mode	Record	Used to record data
Buffer	Mode	Read	Used to read tape
Buffer	Mode	Continuous	DO NOT USE
Buffer	Mode	Remote	DO NOT USE
Transceiver	Power	On-Off	
	Selector	DX	Select external computer, used to record data (in eddy-current instrument)
	Selector	Local	Select internal computer, used to read tape
	Function	0–9	Always set on 1
Video Terminal	Power	On-Off	Located in back of instrument
	Keyboard		Transmits information and commands to computer

channel (see Table I.1). Note that the variable sensitivity adjustment must be set at maximum (fully clockwise) for that recorder channel to be calibrated. Press the "return" key twice more to check the calibration on channels 1 through 4. [If the incremented steps between zero and maximum are not linear (i.e., five divisions per step), something is wrong with the recorder.] Press the "reset" switch on the RCB to stop this check and press the "STOP" switch on the analog recorder and go to the next step.

4. AFTER THE EDDY-CURRENT TEST SYSTEM HAS COMPLETED A 4-h WARM-UP PERIOD, COMPLETE THE FOLLOWING CHECKOUT SEQUENCE

4.1 Set the transceiver selector switch to "DX." Set the transceiver function switch to "1."

4.2 *Check the analog recording system.* Set the (RCB) function switch to position 7. Press a chart speed switch to start the analog recorder chart drive. Use a slow chart speed (5 mm/s or less). Press the "interrupt" switch on the RCB, and set all recorder pens to the zero reference value on each chart scale using zero adjustments on the recorder. After zeroing all pens, press the "return" key on the keyboard. All recorder pens should step five minor chart divisions to the left on the respective chart scales, representing an increase of 0.25 mm (0.010 in.). Press the "return" key eight times, representing an increase of 2.03 mm (0.080 in.). If any of these recorder pens are not at the left margin, check the recorder sensitivity adjustments for that recorder channel (see Table I.1). Note that the variable sensitivity adjustment must be set at maximum (fully clockwise) for that recorder channel to be calibrated. Press the "return" key twice more to check the calibration on channels 1 through 4. [If the incremented steps between zero and maximum are not linear (i.e., five divisions per step), something is wrong with the recorder.] Press the "reset" switch on the RCB to stop this check and press the "STOP" switch on the analog recorder and go to the next step.

4.3 *Perform and Display Calibration.* Set the RCB function switch to position 5. Press the "interrupt" switch on the RCB. You should hear relays clicking, and about 10 s later the computer will display four lines of data on the video monitor. Let the display repeat about four or five times and press the "reset" switch on the RCB to stop. Evaluate the data.

High magnitudes (columns 1, 3, and 5) should be 4.50 ± 0.02 V. High phases (even columns) should be 4.00 ± 0.02 V, except PH3 = 4.50 V. The phase difference between high-magnitude and low-magnitude readings on the first two lines of phase data should be less than ±10 mV. *If not, refer to the instrument calibration procedure.*

(*Important:* Do not leave the calibration system running for long periods of time because the relays could be damaged.)

4.4 *Read Reference Standard.* [The probe should have the 88.9-μm-thick (0.0035 in.) Teflon tape on its face.] Using the square tube standard D, position the probe over the reference reading mark [centered over the weld and 7.62 cm (3 in.) from the end toward defect number 1]. Select a lift-off shim to obtain a Mag 2 reading within ±0.1 V of the Mag 2 reading in Table I.3 (readings from nominal tube sample, third column) for the coil being used. This is done in the function 3 position of the RCB. Example: Probe 454-00 should read 3.6 V (3.5 ± 0.1 V) with a 101.6-μm (0.004-in.) shim. Press reset on RCB.

Select function 2 on the RCB. Using the shim size determined above, hold the probe over the reference reading mark with the shim between the probe face and sample. Press the "interrupt" switch on the RCB. One line of data should be printed out on the video display. Press the "interrupt" switch again and another line of data will appear. Repeat until at least five lines of data are obtained or until the last two lines of data agree to within ±2 mV. Check the Mag 2 reading (third column) and compare with the Mag 2 reading for the nominal tube sample for the probe being used. See Table I.3.

5. INSPECTION

5.1 Set up eddy-current equipment as just described in steps 1.1 through 4.4 above.

5.2 Place the eddy-current probe in the manual scanning fixture. Adjust the probe position until the Mag 2 reading is the same as in step 4.4. Fix the probe at this lift-off. Press the "reset" switch on the RCB.

Table I.3. Eddy-current probe, PROM code, and calibration readings

	Averages and standard deviations of calibration readings (V) for each frequency					
	20 kHz		100 kHz		500 kHz	
	MAG1	PHA1	MAG2	PHA2	MAG3	PHA3
	Probe 454, code 00					
	4.5004	4.0004	4.5022	3.9945	4.5023	4.4958
S.D.	0.0000	0.0000	0.0000	0.0023	0.0000	0.0032
	2.4591	3.9989	2.3132	3.9933	2.4104	4.4956
S.D.	0.0023	0.0032	0.0000	0.0000	0.0016	0.0045
a	4.2220	2.5743	3.5361	2.8298	3.6230	1.0296
	Probe 460, code 01					
	4.4977	4.0047	4.4985	4.0118	4.5007	4.4878
S.D.	0.0045	0.0032	0.0032	0.0032	0.0000	0.0064
	2.4601	4.0047	2.3095	4.0103	2.4042	4.4864
S.D.	0.0016	0.0032	0.0000	0.0045	0.0000	0.0064
a	4.3142	3.0158	3.8659	2.9747	3.7303	1.0510
	Probe 459, code 02					
	4.4974	4.0006	4.4976	4.0110	4.5197	4.4953
S.D.	0.0045	0.0045	0.0000	0.0084	0.0032	0.0084
	2.4592	3.9997	2.3090	4.0176	2.4158	4.4947
S.D.	0.0000	0.0032	0.0016	0.0055	0.0016	0.0084
a	4.5155	2.9760	4.1346	2.9136	4.1158	0.9058

[a]Readings from nominal tube sample.

5.3. *Display Raw Readings*. Set the RCB function switch to position 3. Press the "reset" switch on the RCB. The statement "NDT COMP9" should appear on the video display. Next, press the "interrupt" switch on the RCB, and the raw readings will be continuously displayed on the video terminal. Check the raw readings to see if any are either zero or 4.999. If so, a problem exists. Check the eddy-current probe to see if it is properly seated on the standard test tube. If it is, something is probably wrong with the eddy-current instrument, and it should be corrected before proceeding. If the readings are all right, press the "reset" switch on the RCB to stop the readings and go to the next step.

6. PRECALIBRATION

6.1 Place the manual scanning fixture on calibration standard D and position the probe over the weld centerline.

6.2 Operate the "reset" switch on the RCB.

6.3 Set the RCB function switch to 6 and check that the PROM setting on the control module is correct for square conductor testing (04 for eddy-current probes 454 and 459 and 05 for probe 460).

6.4 Operate the "interrupt" switch on the RCB. The instruction, "enter ID" will appear on the video display. Enter the following information from the keyboard: probe serial number and coding (e.g., 459-04).

6.5 Operate the 2-mm/s chart speed switch on the analog recorder.

6.6. Press the "return" key on the keyboard. The eddy-current computer will perform a recalibration and display the raw magnitude and phase readings along with the calculated coefficients on the video terminal. At the end of the display, the computer enters the "running" mode.

6.7 Using a slow and steady speed, move the manual scanning fixture and probe along the standard conductor. Maintain the alignment of the weld on top of the tube and centered under the eddy-current probe. Scan each defect by moving the probe back and forth across the defect at least three times.

6.8 Observe the analog recorder as you scan the square standard. The four-channel recorder pens from the left should write between 5 and 25 minor divisions −25 to +76 mm (−0.010 to +0.030 in.) to the left of the right-hand margin on the recorder chart except when defect indications are obtained. The four channels identified from left to right are outside surface defects, lift-off, inside surface defects, and lack of penetration or wall thickness.

6.9 When the calibration is complete, stop the analog chart recorder and identify the recording as the "Precalibration Test." Record the date, the examiner's initials, and the identification of the superconductor sheath being examined on the recording.

7. PERFORM THE TEST

7.1 The eddy-current system is now ready to manually scan conductors. The scanning of a conductor is performed by starting the chart recorder at 2 mm/s and slowly pulling the probe and fixture uniformly along the conductor. The fixture must be kept level with the conductor surface to avoid lift-off effects.

7.2 Three scans of a given area are required: one along the weld centerline, and one at 2.29 mm (0.090 in.) on either side of the weld in the heat-affected zone. Each scan is initiated by starting the chart recorder and terminated by stopping the chart recorder.

7.3. Indications obtained during manual scanning are to be compared with the indications obtained on the calibration standard. Indications of defects exceeding the tolerances defined in Westinghouse Specification 90P744, Spec. 1, Rev. 2, require repair. Areas needing repair are to be indicated on the multifrequency eddy-current report and noted on the conductor inspection follower sheet.

7.4 When all manual scanning has been completed, rescan the calibration standard according to steps 6.7 through 6.9 of this appendix and label as the "Postcalibration."

7.5 After all testing is completed, set the RCB function switch to 5. When the display on the video terminal is completed, press the reset button on the RCB.

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