NUREG/CR-1007
BNL-NUREG-51044

120555031837 2 AN
US NRC
SECY PUBLIC DOCUMENT ROOM
BRANCH CHIEF
HST LOBBY
WASHINGTON DC 20555

Doc. Control Desk 016

EVALUATION OF SELECTED SIGNAL PROCESSING METHODS FOR THE CHARACTERIZATION OF STEAM GENERATOR EDDY CURRENT SIGNALS

S.D. Brown and D.T. Hayford
Battelle
Columbus Laboratories

Date Published - August 1979

PREPARED FOR THE CORROSION SCIENCE GROUP
DEPARTMENT OF NUCLEAR ENERGY
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

Sponsored by the U.S. Nuclear Regulatory Commission
Division of Engineering Standards
Under Contract No. EY-76-C-02-0016

8004100025

NUREG/CR-1007
BNL-NUREG-51044
AN

EVALUATION OF SELECTED SIGNAL PROCESSING METHODS FOR THE CHARACTERIZATION OF STEAM GENERATOR EDDY CURRENT SIGNALS

S.D. Brown and D.T. Hayford
Battelle
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Manuscript Completed - April 30, 1979
Date Published - August 1979

PREPARED FOR THE CORROSION SCIENCE GROUP
DEPARTMENT OF NUCLEAR ENERGY
BROOKHAVEN NATIONAL LABORATORY
UPTON, NEW YORK 11973

SPONSORED BY
U.S. NUCLEAR REGULATORY COMMISSION
DIVISION OF ENGINEERING STANDARDS
UNDER CONTRACT NO. EY-76-C-02-0016
NRC FIN NO. A-30119

NOTICE

Available from
National Technical Information Service
Springfield, Virginia 22161

FOREWORD

Recent experience with the formation of small volume but fairly deep defects in once through steam generators (OTSG), particularly adjacent to the upper most support plates, has led to the need for further information on how well the eddy current technique for inservice inspection can measure the depth of these defects. In contrast to the rather large volume phosphate wastage defects or the rather long stress corrosion cracks that have occurred in sludge pile areas, these defects tend to be rather small in volume and located very close to a tube support plate or tube sheet. Signals from the support plate or tube sheet, therefore, can distort or even mask the signals obtained from defects during a routine inservice inspection. They do not, however, prevent determination that there is a small defect present, in most cases, especially where the defect is large enough to have some safety significance. As part of the BNL Technical Assistance program for the Division of Engineering Standards of the U.S. Nuclear Regulatory Commission, we have conducted an investigation at Battelle-Columbus Laboratories of the ability of eddy current inspections to determine the size and depth of these defects. The following report represents the results of their work, and an attempt by them to develop a simple signal subtraction method that is capable of eliminating the signals from the tube support plate and, therefore, give better definition to the portion of the eddy current signal from the defect.

This is the third report in a series by the Fabrication and Quality Assurance Section of Battelle-Columbus Laboratories in the area of detectability of defects in PWR steam generator tubing by eddy current techniques. The first report, reference 1, represented a measurement of the statistical reliability of the eddy current technique for detecting signals from various types of defects, simulating those that had been observed in PWR steam generator tubing up to that time. The second report, reference 2, dealt with the detectability of dents in the steam generator tubing, the detectability of magnetite deposits in the crevice between the tube and the tube support plate, and most importantly, the detectability of defects in steam generator tubing in areas that have been dented. Work is continuing at Battelle-Columbus on still a fourth phase of this program, which is an evaluation of the accuracy of the detection of steam generator defects using multi-frequency eddy current inspection methods.

The data in the present report should be of use to the Nuclear Regulatory Commission in assessing reliability of the eddy current inspection data on OTSG's and especially to the Office of Standards Development in their continuing assessment of the need for an improved basis for determining the reliability of inservice inspection, of nuclear steam generators, and the acceptability of these steam generators for continued service.

John R. Weeks, Leader
Corrosion Science Group
Brookhaven National Laboratory

REFERENCES

1. J.H. Flora, S.D. Brown, and J.R. Weeks, "Evaluation of the Eddy Current Method of Inspecting Steam Generator Tubing," BNL-NUREG-50512-R, Sept. 30, 1976.
2. S.D. Brown and J.H. Flora, "Evaluation of the Eddy Current Method for the Inspection of Steam Generator Tubing - Denting," BNL-NUREG-50743, Sept. 30, 1977.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF TABLES

FINAL REPORT

on

EVALUATION OF SELECTED SIGNAL PROCESSING METHODS FOR THE CHARACTERIZATION OF STEAM GENERATOR EDDY CURRENT SIGNALS

to

BROOKHAVEN NATIONAL LABORATORY
Upton, New York

April 30, 1979

by

S. D. Brown and D. T. Hayford

BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

EVALUATION OF SELECTED SIGNAL PROCESSING METHODS FOR THE CHARACTERIZATION OF STEAM GENERATOR EDDY CURRENT SIGNALS

by

S. D. Brown and D. T. Hayford

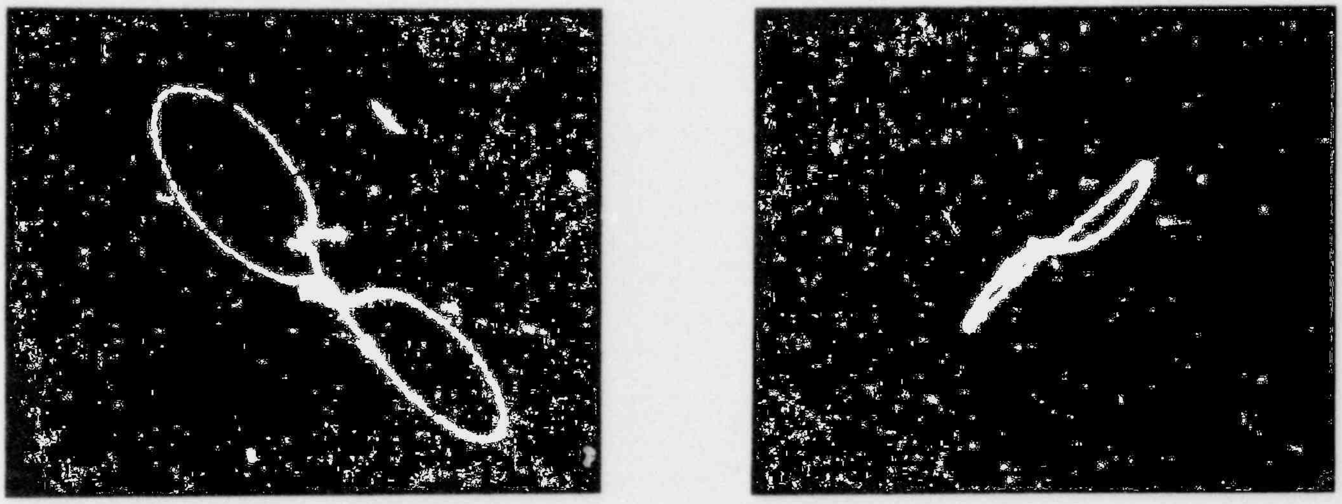
INTRODUCTION

Operating experience with once through steam generators (OTSG) has accumulated to the extent that secondary-side tube degradation has been observed in several operational units. Analysis of eddy current data from OTSG inservice inspections and the visual examination of pulled tubes (Oconee) would suggest that degradation is concentrated near the tube sheet or tube supports in tubes adjacent to open lanes and is of relatively small volume. This is in contrast with the recirculating steam generators where most of the tube defects are of relative large volume, i.e., wastage (here we exclude denting), and occur primarily in the sludge zone (0-10") above the tube sheet. (Palisades, Point Beach, Robinson, and Ginna are exceptions in that wastage or other large volume defects have been confirmed or are suspected at some tube support plate intersections.)

For the OTSG units, the occurrence of small volume defects in proximity to the tube sheet or tube support places a greater emphasis on the need for the development of specialized eddy-current inservice inspection methods since the tube sheet and tube support are extraneous test variables and can preclude defect detection and affect the reliable estimation of defect depth.

Figure 1 shows eddy-current signal patterns which result from a support plate and simulated high-cycle fatigue (HCF) crack separately and the composite signal which results when the HCF crack is placed in close proximity to a support plate edge. As can be seen, the composite signal is distorted, precluding the reliable estimation of defect depth.

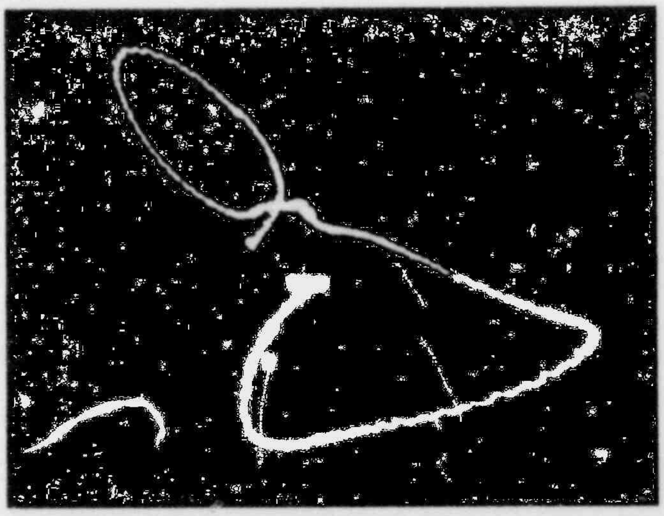
The inability of conventional single frequency eddy current inservice inspection techniques to measure reliably the depth of small volume defects in



Tube Support

Simulated HCF

↔ Wobble



= 675 KHz

Tube Support + HCF

Figure 1. Distorted support plate signal resulting from small volume defect in proximity to broached support plate

close proximity to the tube sheet and support plate has been recognized by the OTSG vendor (Babcock and Wilcox). The B&W Lynchburg Research Center has been using, since September, 1976, a proprietary computer subtraction technique for the off-line analysis of steam generator eddy current data in which a reference support signal is subtracted from a composite defect/support plate signal. Elimination of the extraneous support plate signal would then allow for a more reliable estimation of defect depth. Other inservice equipment vendors have also introduced specialized signal analysis to subtract extraneous signals.

Zetec has recently introduced the ML-2 digital signal analyzer for the subtraction of an extraneous test variable. The signal analyzer performs the same function as a computer subtraction program but is hard-wired implemented in a readily portable instrument package. CONAM has introduced a similar analog version.

The primary objective of this program was to implement a digital computer subtraction technique and evaluate the method using eddy current data derived from models of observed inservice defects. The Zetec ML-2 signal analyzer was also briefly examined. A secondary objective was to investigate the multifrequency aspects of eddy current inspection with regards to the detection and characterization of signal types.

SUMMARY

Digital subtraction techniques, in which a reference support plate signal is subtracted from a distorted support plate signal with the defect signal remaining as the resultant, have been examined by implementing computer programs on a PDP 11/40 and also using a commercially available signal analyzer. The average absolute error in measuring defect depth was found to be 6 percent when compared with the analog estimated depth for the defect scanned free of the extraneous support plate. When compared to the actual defect depth, the average absolute error was 14 percent.

Multifrequency eddy currents, in which a coil is excited at more than one frequency, offers advantages in characterizing certain primary or secondary side tube conditions. The use of more than one inspection frequency can provide additional information in the characterization of laminated support plates, tube dings and magnetic tube deposits.

OTSG DEFECT TYPES

Specific causative factors which give rise to particular OTSG defect types are discussed in References 1 and 2. Actual OTSG defect types which have been observed based on the visual examination and metallurgical analysis of pulled tubes are summarized in Table 1. All of the defect types in Table 1 occur near the tubesheet or support plate. Pitting has also been observed in straight sections of tubing away from the influence of either the tubesheet or support plate.

Examples of OTSG defect types as observed on tubes pulled from Oconee units are shown in Figure 2 and 3. Figure 2a shows fretting wear on the steam generator tube as a result of tube contact with the broached support plate land area. Figure 2b illustrates the so-called "candleflame" defect which has occurred at the edge of the broached support plate. Figure 3a shows an example of pitting. Figure 3b illustrates an example of a high cycle fatigue crack. These cracks have been observed below the upper tubesheet and near the upper support plates.

EXPERIMENTAL INVESTIGATION

Defect Fabrication

In order to duplicate realistically the eddy current signatures for typical OTSG defect types, simulated defects were fabricated in the laboratory. Conventional electrodischarge machining (EDM) methods were used. Care was taken to model the size and shape of the simulated defect to that which has been observed from the visual and metallographic examinations of pulled tubes. OTSG defect types selected for consideration for this program included fretting, pitting, dings, high-cycle fatigue cracks, multiple scalloping and the candleflame. Photographic examples of typical simulated defects are shown in Figure 4. Detailed measurements on simulated flaws used in this study as well as specimen identification number are summarized in Table 2.

Eddy Current Data Collection

The experimental objectives were basically twofold: (1) to examine the multifrequency aspects of steam generator tubing inspection, and (2) after implementing a digital computer subtraction technique, collect eddy current data from

TABLE 1. SUMMARY OF OTSG DEFECT TYPES

Defect Type	Location
• High-cycle fatigue crack	In proximity to upper tube sheet and upper support plates
• Pitting	Straight sections of tube and within the broached support plate
• Candle-flame	In proximity to broached support plate
• Multiple scallop	In proximity to broached support plate
• Fretting	At broached support plate land contact area
• Ding	At edge of support plates at land contact region. Also a tube sheet
• Serpentine depression	At upper tube sheet

~5X

(a) Fretting Wear at 15th Tube Support Plate

(b) Candleflame

Figure 2. OTSG tubing degradation

~20X

(a) Pitting at a 15th Tube Support plate land contact area

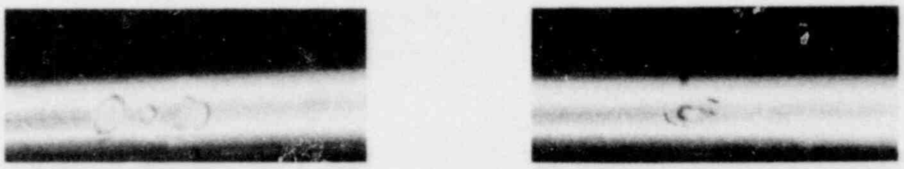
20X

(b) Through-wall crack

Figure 3. OTSG tubing degradation

(a) Tube ding

(b) Fretting



(c) Multiple scalloping

(d) Candleflame

(e) High-cycle fatigue

(f) Pitting

Figure 4. Examples of OTSG simulated tube defects

TABLE 2. SUMMARY OF DEFECT DIMENSIONS

			Dimensions		
Defect Type	Specimen No.	Geometry	Maximum Depth, percent of wall	Length of Diameter	Width, inches
Simple Pitting	A	See Figure 4f	66	0.014 inches	--
	B	Ditto	54	0.022 "	--
	C	"	42	0.013 "	--
	D	"	21	0.005 "	--
Multiple Scalloping	E	See Figure 4c	54	0.221 inches	0.223
	F	Ditto	52	0.175 "	0.239
	G	"	41	0.106 "	--
High-Cycle Fatigue	H	See Figure 4e	89	360 degrees	0.003-0.010
	I	Ditto	32	217 "	0.007
	J	"	12	174 "	0.004
Candle Flame	L	See Figure 4d	55	0.224 inches	0.086
	M	Ditto	44	0.210 "	0.086
	N	"	41	0.211 "	0.075
	O	"	16	0.196 "	0.076
Fretting	P	See Figure 4b	34	1.5 inches	0.135
	Q	Ditto	19	1.5 "	0.135
	R	"	5	1.5 "	0.135

OTSG defect types located in proximity to tube supports which in turn would be processed using the subtraction technique and assess the capability of the technique in providing estimates of defect depth.

The collection of the initial eddy current data was accomplished using conventional ISI analog instrumentation techniques. The equipment complement included an EM-3300 eddy current instrument, a Teac FM-2300 two-channel magnetic tape recorder, a Brush 220 strip chart recorder and a Zetec probe pusher/puller. A Zetec 520 LC probe was used. Tube lengths were mounted vertically in a small laboratory mockup in order to approximate actual inservice probe dynamics. Guidelines for the establishment of initial eddy current instrumentation settings and the construction of appropriate phase angle versus depth calibration curves were based on the ASME Section XI procedure. Support plate subtraction was accomplished using eddy current data at 675 KHz. This frequency in the thinner OTSG tube wall (0.037 inch) gives a phase angle spread comparable to 400 KHz in the thicker wall (0.050 inch) U-bend generator tubing.

Basis for the Development of Computer Subtraction Software

The major assumption behind the use of computer subtraction to eliminate the effects of support plates on eddy current defect signals is that the composite signal from a support plate in conjunction with a defect is the linear combination of the signals from each alone. In equation form,

$$\begin{aligned} X_{comp} &= X_{sp} + X_d \\ Y_{comp} &= Y_{sp} + Y_d \end{aligned} \tag{1}$$

where the X_i and Y_i are the inphase and quadrature components of the eddy current signals from the composite, the support alone, and the defect alone, respectively. It is then possible to find the eddy current signal from the defect alone by subtracting the support plate signal from the composite signal obtained during the inservice inspection of a steam generator. Hence,

$$\begin{aligned} X_d &= X_{comp} - X_{sp} \\ Y_d &= Y_{comp} - Y_{sp} \end{aligned} \tag{2}$$

Ideally, we would subtract the same support plate signal as is contained in the composite signal; practically, this is impossible. Most support plate signals, however, resemble each other enough so that one may be substituted for another. Conversely, a number of reference support plates could be kept on file to find the best match to the support plate signal contained in the composite.

The X_i and Y_i in Equation 2 are all explicit functions of the position along a tube; they are, at best, only implicit functions of time, the defining relationship being the velocity at which the eddy current probe traverses the tube. However, it is only practical to measure them as functions of time, with the proviso that the probe speed remain constant.

Before the subtraction of the support plate signal from the composite signal can take place, the X and Y components of each signal must be lined up in time. Usually, one lobe of the tube support in the composite is unaffected. As long as the velocity of the probe remains the same when measuring the composite signal and the reference support signal, it is possible to line up the undistorted lobes to effect a good cancellation of the support in the defect area. If probe velocity varies between the reference support signal and the composite, then appropriate scaling must be performed prior to alignment.

Two types of alignment schemes were considered. The first used a cross-correlation technique to decide when the undistorted lobes were aligned. For continuous functions, the cross-correlation between them is defined as

$$C(\tau) = \int f_1(t) f_2(t - \tau) dt$$

which is a maximum when τ is suitably chosen and occurs when f_1 and f_2 are aligned, where $f_1(t)$ and $f_2(t - \tau)$ are the reference and distorted plate signals, respectively, and τ is the time shift between them.

A visual alignment approach, wherein the operator moved the composite signal back and forth until he was satisfied with the cancellation, was also implemented. The visual technique was nearly as accurate as cross-correlation technique when the probe speed was constant; thus the latter was eliminated in favor of the visual alignment.

Software Description

Two major programs were written in the investigation of support plate suppression by computer subtraction. The first, called BNL1, performed the analog-to-digital conversions necessary to digitize the various composite and support plate signals. The second, named BNL3, performed the actual reference support plate subtraction. Both programs were written in Fortran for operation on a DEC PDP 11/40. Various subroutines were also written to perform many of actual functions of BNL1 and BNL3. These were written in either Fortran or DEC assembly language. Copies of all programs are included in the Appendix.

The flexibility and ease of operation of these two programs was greatly enhanced by two BCL-developed features - the command interpreter and the file-directory handler. The command interpreter is a subroutine (COMMAND) which allows the computer operator to control the function of the computer by entering easy-to-remember four-letter symbols. The subroutine would examine the entry, and, if from the correct list, would direct the computer to the proper segment. If the entry is not from the correct list, the subroutine would prompt the operator for a correct entry by printing out the correct list. After the computer performs each segment, as directed by the interpreter, the program control would return to the interpreter to await the next command.

The file-directory handler is actually a group of subroutines (ATTIN, ATTOUT, DIROPN, DIRCLD) which greatly simplify reading data from and writing data to the system disk. Each time the operator attempts to save the digitized data generated by BNL1, the file-directory handler would look up the next unused name and print it out to the operator. The operator has the choice of storing the data under that name, or may use some other name. However, if the operator always follows the suggestion of the file-directory handler, inadvertent elimination of old data by storing new data under the same name is prevented. In the same way, a second operator could never erase data stored by the first operator if the computer's suggestions are always followed.

These two features have provided programs with a great deal of flexibility but which are nearly foolproof and can be used by operators with relatively little training or experience.

The hardware used for the off-line analysis of the eddy current data is shown in Figure 5. The equipment outlined by the dashed line shows the conventional analog instrumentation used for the collection of the initial eddy current data. Once the analog eddy current data were acquired they could be played back through a signal conditioner (scaling resistor) and digitized using an A/D converter for the subsequent routing into the PDP-11/40 computer memory.

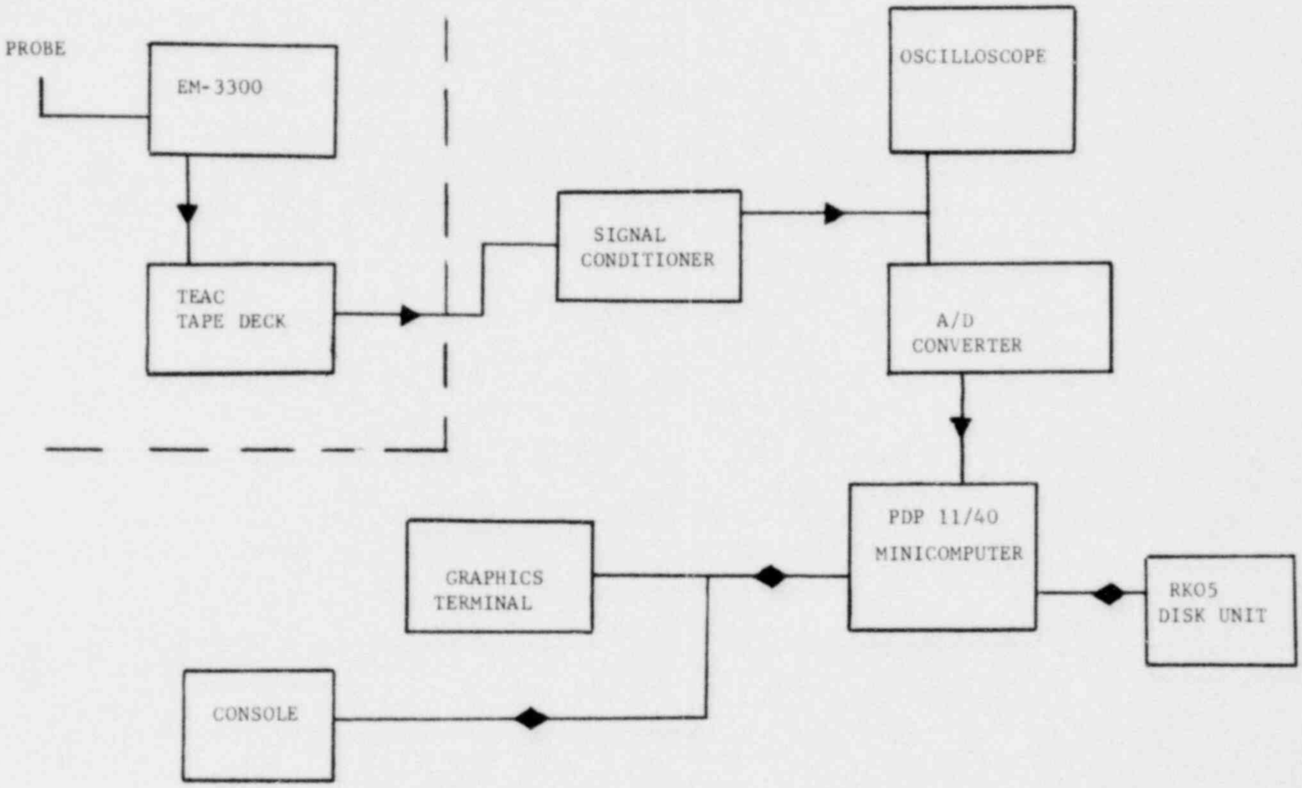


Figure 5. Computer subtraction system block diagram

The RK05 disk unit stored the original BNL1/BNL3 programs, auxiliary peripheral programs, as well as processed data. The data console allows for the operator to interact with the various programs via the graphics terminals which provide for the display of data in their various stages of processing.

BNL1 Program

The function of program BNL1 is threefold: to control the system ADC's that digitize the eddy current data, to display the captured data so that the operator may perform certain simple operations on it, and, finally, to save the captured data on the system disk. The flow chart for BNL1 is given in Figure 6, where the underlined words indicate the command, recognized by the command interpreter, for performing each function. The purpose of each command is detailed below.

DAT: Initialize all buffer and array sizes to work with a total of 0.5 second of data; used to capture composite and support plate signals. (Default value)

STD: Same as DAT, but a total of 0.3 second. Used mainly to store ASME standards for display purposes.

DIGI: Begin the digitizing process. When the command is entered, the ADC's are enabled, with a sampling rate of 4 KHz. The x-channel (ADC channel 2) is sampled first, followed almost immediately by the y-channel (ADC channel 3). After the first 0.5 second (0.3 if STD is in effect), the data buffers are filled; however, the last 0.5 second (0.3 second) of data is always retained in the buffers. The ADC's are disabled by typing a carriage return and the last 0.5 (0.3) second of data is displayed on the graphics terminal.

WIND: Bracket the desired data with a window. Since we must allow time for the operator to react and turn off the ADC's we must actually digitize more data than necessary. Storing and processing this extra data are inefficient, so we allow the operator to indicate which part of the data he wishes to retain. The starting point of the window is controlled by voltage fed into the ADC (channel 0). The length of the window is controlled by voltage fed into the ADC (channel 0). The length of the window is controlled by the DAT or

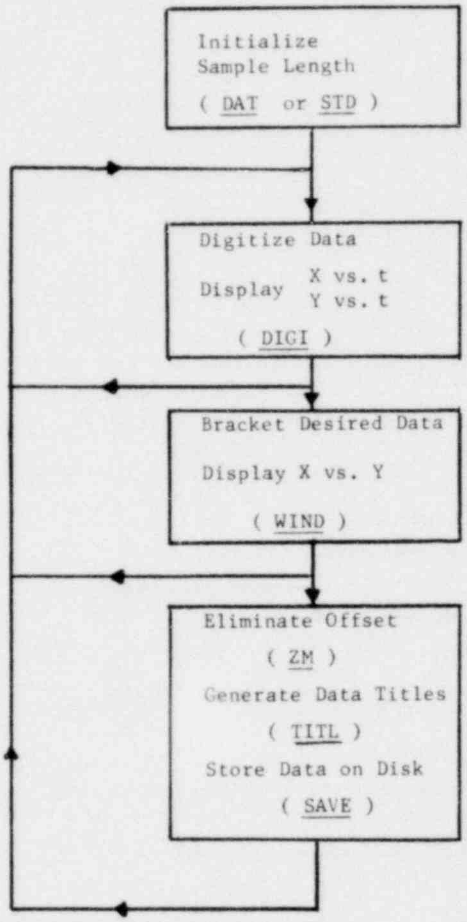


Figure 6. BNL 1 program flow diagram

STD option in effect (0.25 second for DAT, 0.15 second for STD). Pressing a carriage return locks the window in its last position. At this time, the x-t and y-t data may be plotted as x-y data.

ZM: Allows the operator to shift the x-t and y-t data up and down so that the bracketed data has a zero mean.

TITL: Allows the operator to read the current titles. The titles are stored with the data to permanently identify it. Alternatively, the operator may change the titles, if necessary.

SAVE: Instructs the computer to save the bracketed data, along with the current titles, on the system disk.

The operation of BNL1 is fairly straightforward, and follows the flow chart directly. The operator starts the program and types either DAT or STD. (DAT is more usual, and is the default option.) He then turns the tape recorder on and plays the tape until it is at some point previous to the location of the data of interest. After typing DIGI, he restarts the tape until the data has shown on the vectorscope screen and then presses the carriage return to stop the digitizer. (The operator has roughly 0.25 second to respond). He is then able to view the captured data on the graphics terminal. If the correct data has been captured, the operator continues on with WIND, ZM, TITL, and ultimately, with SAVE. If the wrong data were captured, or the correct data were only partially captured (generally caused by the operator reacting too slowly) the operator need only rewind the tape, restart the digitizer, and proceed again.

The above process may be repeated as many times as necessary until all the data has been captured.

BNL3 Program

The program BNL3 works with the support plate signals to eliminate the effects of the support plate on eddy current defect signals. The flow chart for this program is shown in Figure 7. As in the previous section, the underlined words refer to the proper command mnemonics.

In this program, the inphase and quadrature x-t and y-t signals are displayed on the graphics terminal in three different displays. A description of each display type is given below.

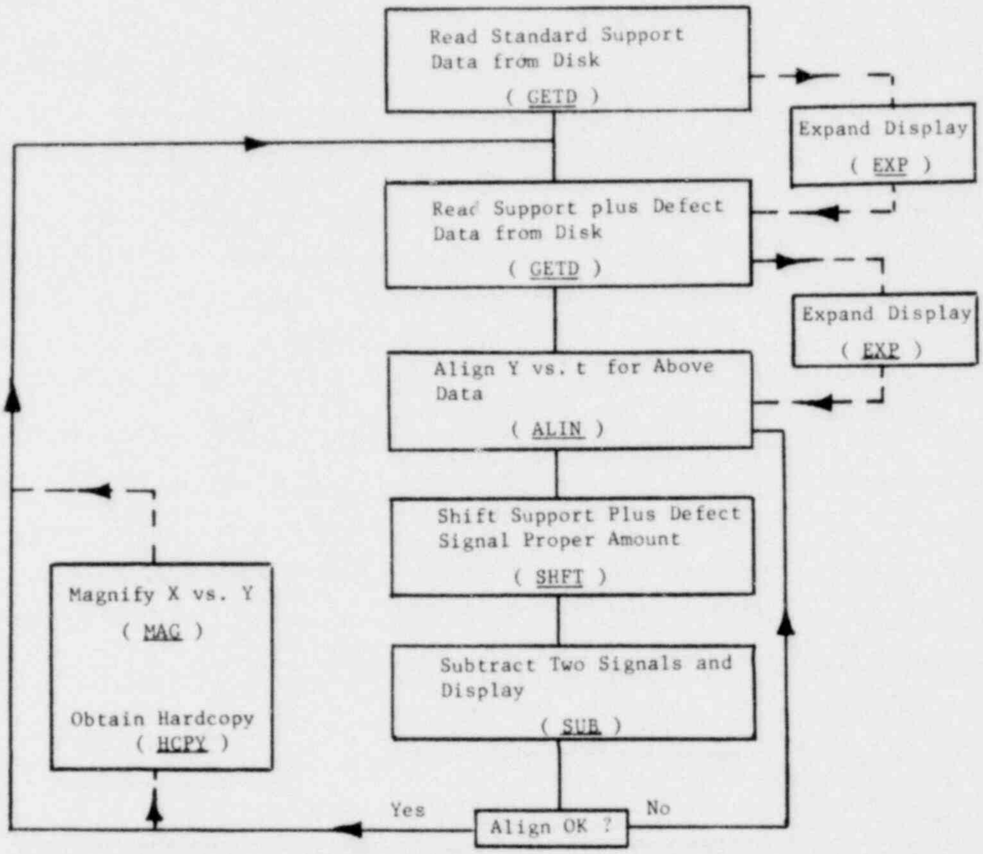


Figure 7. BNL 3 program flow diagram

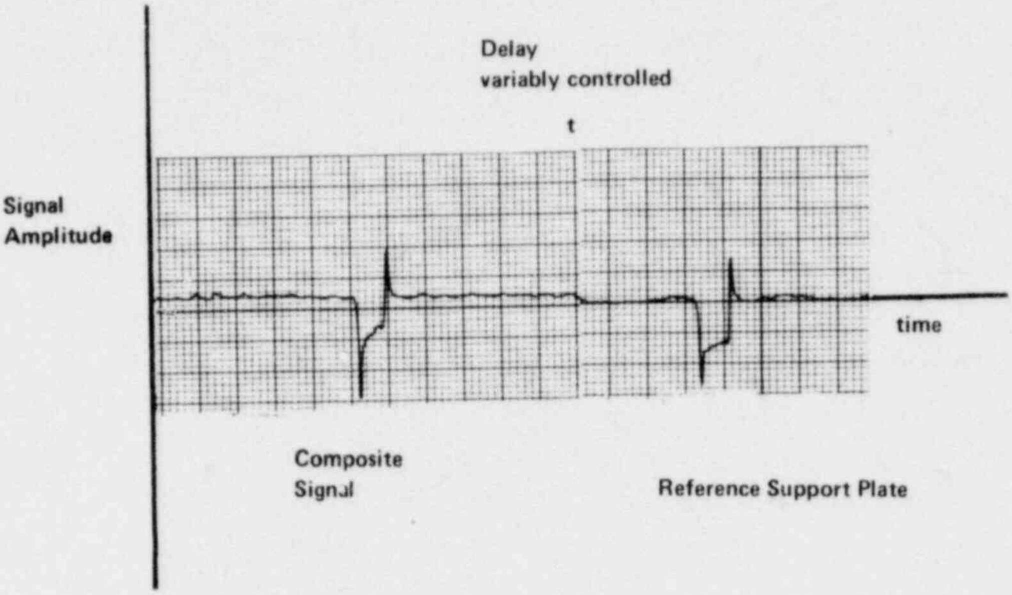
The first graphic display, Figure 8a, is used during the alignment of the composite signal and the reference support plate signal. Displayed are the quadrature or y-t signals for each case. The y-t for the support signal is fixed while the horizontal position of the y-t component of the composite signal is variably controlled by the operator with a voltage to the ADC. Also shown on the display are a vertical bar and two words, MAG and END. If a light pen touches the word MAG, the y-t for both signals are magnified, with the part beyond the vertical bar being displayed. This magnification may be repeated as many times as necessary (the magnification is by two each time) to allow accurate alignment of the two pictures. Touching the word END returns the graphic display to the original display and prints out the number of units the second picture was shifted in order to align the two y-t displays.

The second graphic display, Figure 8b, is the normal mode, and contains, side by side, three areas for x-y plots of eddy current data. The three areas are called Picture 1, 2, and 3, starting at the left. In the normal mode of operation, Picture 1 contains the reference support plate signal, while Picture 2 contains the composite support and defect signal. Picture 3 will contain the eddy current signal remaining after the computer subtracts the support plate in Picture 1 from the composite signal in 2. For convenience, though, any data set, captured by BNL1, may be read from the disk and displayed in any of the three pictures.

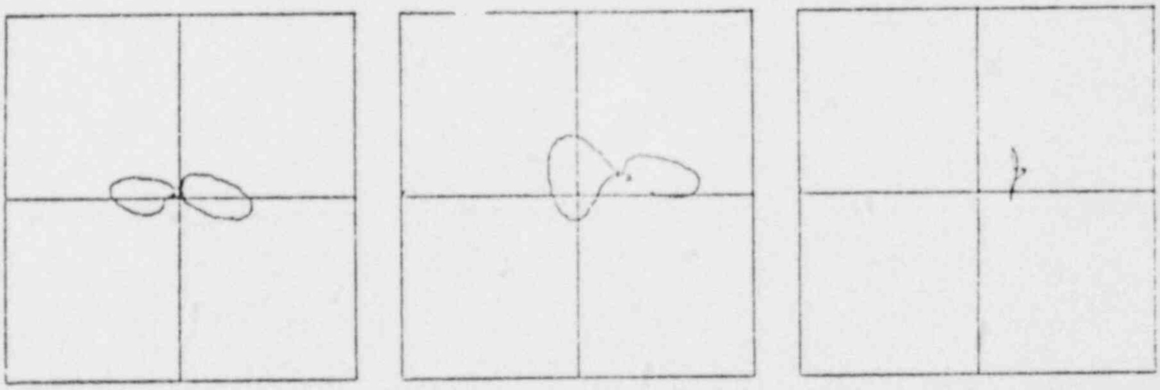
The third graphic display (not shown), is simply an enlargement of any one of the three pictures in the previous display.

The various commands accepted by this program and their function are detailed below:

GETD: Get data. Retrieves data stored under the DAT instruction from BNL1. Composite and support plate signals prompt the operator for the proper data file number and the proper location (Picture 1, 2, or 3).



(a) Signal shifting


Tube support
A[illegible]-B
Digitized 19-Oct-78
1000 pairs. DAT #13

Support + defect
A4-C, F
Digitized 19-Oct-78
1000 pairs. DAT #22

PIC 2 minus PIC:

(b) Signal vector display

Figure 8. Graphics display used for signal subtraction

EXP: Provides a constant-factor expansion of any of the three pictures. In general, both Pictures 1 and 2 should have the same expansion factor.

GETS: GET standard. Retrieve any data stored under the STD instruction from BNL1. Otherwise, the same as GETD.

ALIN: Change the display so that the y-t from Pictures 1 and 2 are shown. Allows the operator to align the two by changing the voltage input to the A/D converter. The portion of the picture beyond the vertical bar is expanded when the word MAG is touched with a light pen. When the work END is touched, the display returns to normal and the necessary time shift between Pictures 1 and 2 is displayed.

SHFT: Shifts the x-t and y-t data in Picture 2 by the amount typed in. The shift distance may be either positive or negative, and may contain a fractional part. Fractional shifts are done by a parabolic interpolation. A shift of one unit (1.0) corresponds to a time shift of 0.25 ms.

SUB: Subtracts the y-t and x-t of Picture 1 from the y-t and x-t of Picture 2. The result is displayed in Picture 3.

MAG: Provides a magnified view of the x-y display of Pictures 1, 2, or 3, as chosen by the operator. Magnification is ended by entering a carriage return. A plot on the x-y plotter of the magnified picture can be obtained at this time.

CLIP: Clips out the leading and trailing edges of any picture (1, 2, 3) to eliminate noise that may confuse a picture. The leading edge is determined by the voltage input to ADC channel 0. The trailing edge is determined by the voltage input to ADC 1. Especially effective on Picture 3.

HCPY: Provide a hardcopy, via an x-y plotter of Pictures 1, 2, 3. Useful for making a permanent record.

Because the scope of BNL3 is much larger than that of BNL1, its use is somewhat more complex, with more operator interaction and judgement called into play. It is recommended that it be used only by personnel intimately familiar with eddy current characterization of defects in steam generator tubes.

To recall data stored on disk, the operator types GETD. He is prompted for the data set number (the number under which it was stored in BNL1) and the picture number. If the operator wishes merely to view the data, he may place it in Picture 1, 2, or 3. However, if he wishes to perform a subtraction he must display standard support signals in Picture 1, and composite signals in Picture 2. Once a data set has been displayed, the operator may, at his option, expand the scale of any picture by typing EXP. The expansion is the same in both the x and y directions and lasts only until a new data set is displayed in the same picture. In general, both Pictures 1 and 2 should have the same expansion.

Once the proper data sets have been selected and displayed in Pictures 1 and 2, the operator types ALIN to view the y-t for both pictures. Because probe wobble is set to the horizontal in most applications, the y-t is used for alignment, rather than the x-t. The y-t from Picture 1 is fixed on the display terminal, while the start position of the y-t from Picture 2 until the two are aligned in time. If the operator desires an enlargement, he moves the vertical bar on the graphics terminal by controlling the input voltage to ADC channel 1. If the light pen touches the word MAG on the screen, the portion of the y-t to the right of the bar is displayed at twice the horizontal scale. Touching the word END with the light pen causes the screen to revert to the normal mode, and the amount the second picture should be shifted to align with the first picture is printed on the terminal. However, the shift is not performed until he operator types SHFT, along with the proper distance.

Picture 1 may then be subtracted from Picture 2 by typing SUB. The result is displayed in Picture 3. The operator then has several options which may enhance the interpretation. First, he may obtain a paper plot on the x-y plotter of any of the three pictures by typing HCPY. He may also blow up any of the three pictures by typing MAG, and he may also obtain a x-y plot of the blown-up picture. Finally, he may clip out leading and trailing edges of any of the three pictures to eliminate noise which may hide small defect signals. This is done by typing CLIP and using the ADC channels 0 and 1 to control the leading edge and trailing edge. This command is especially useful with Picture 3.

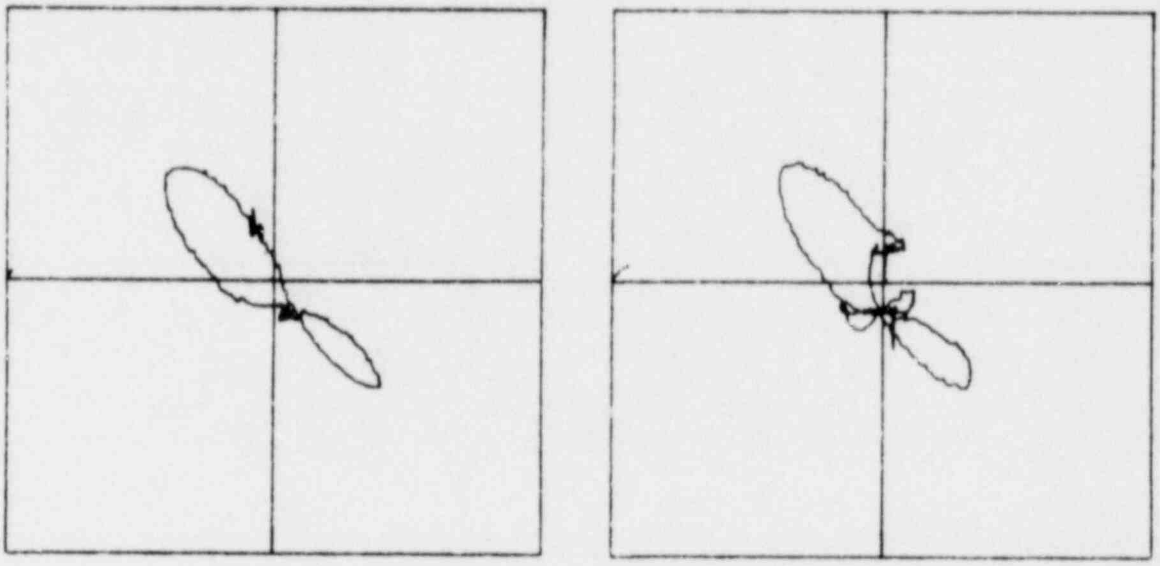
At this point, the operator has completed the steps necessary to perform one subtraction. If more are desired, he merely displays the new composite and or standard support signals with GETD and begins again.

RESULTS

Subtraction of Support Plate Signals

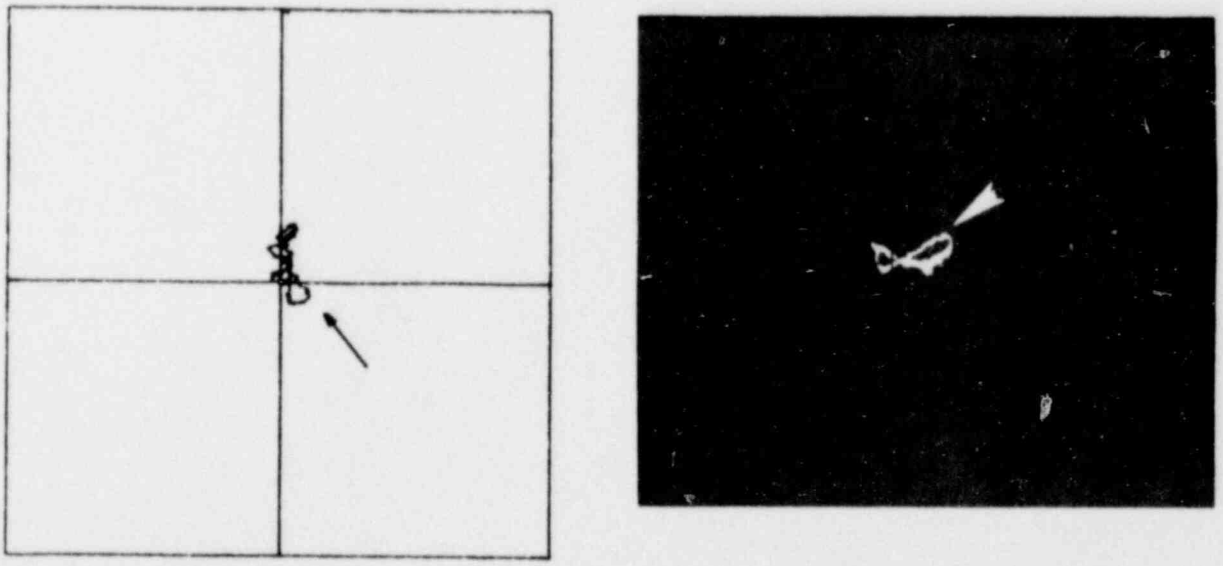
The application of the computer programs discussed previously for the digitization of eddy current data and the subtraction of a reference support plate signal from a distorted support plate signal are now considered. Also considered are similar results using the ML-2 signal analyzer. Examples are given of the computer reconstruction of the reference support plate signal used for subtraction, the distorted support plate signal (support plate signal plus defect signal) and their difference. For comparison, the conventional analog eddy current Lissajous pattern for the defect of interest scanned free of the support plate is also shown. The difference between the results of the digital subtraction technique and the conventional analog signal pattern as reflected through an ASME Section XI calibration curve can be taken as a measure of error associated with the subtraction process. Of equal importance is the computer subtraction estimated depth compared with the true defect depth. This error is more important from the viewpoint of establishing safety margins for plugging criteria, but contains error attributable to the eddy current technique itself as well as error introduced by variables associated with the subtraction process.

Figure 9 illustrates reference and distorted support plate (DSP) signals, their subtraction and the analog eddy current pattern for a simple pit. As is evident, the results of the subtraction process are similar to the analog trace. The equivalency of the computer subtraction process and the ML-2 signal analyzer is shown in Figure 10. Figure 10a shows the reference, distorted support plate and resultant subtraction. Notice that the resultant signal exhibits a residual signal. This can be removed by appropriate control of the vector analyzer intensity control on which the outputs of the signal analyzer are displayed. This same feature was implemented as the CLIP subroutine described previously in the BNL2 program. An



Tube support
A58-TSP B
Digitized 13-Nov-78
1000 pairs, DAT #4

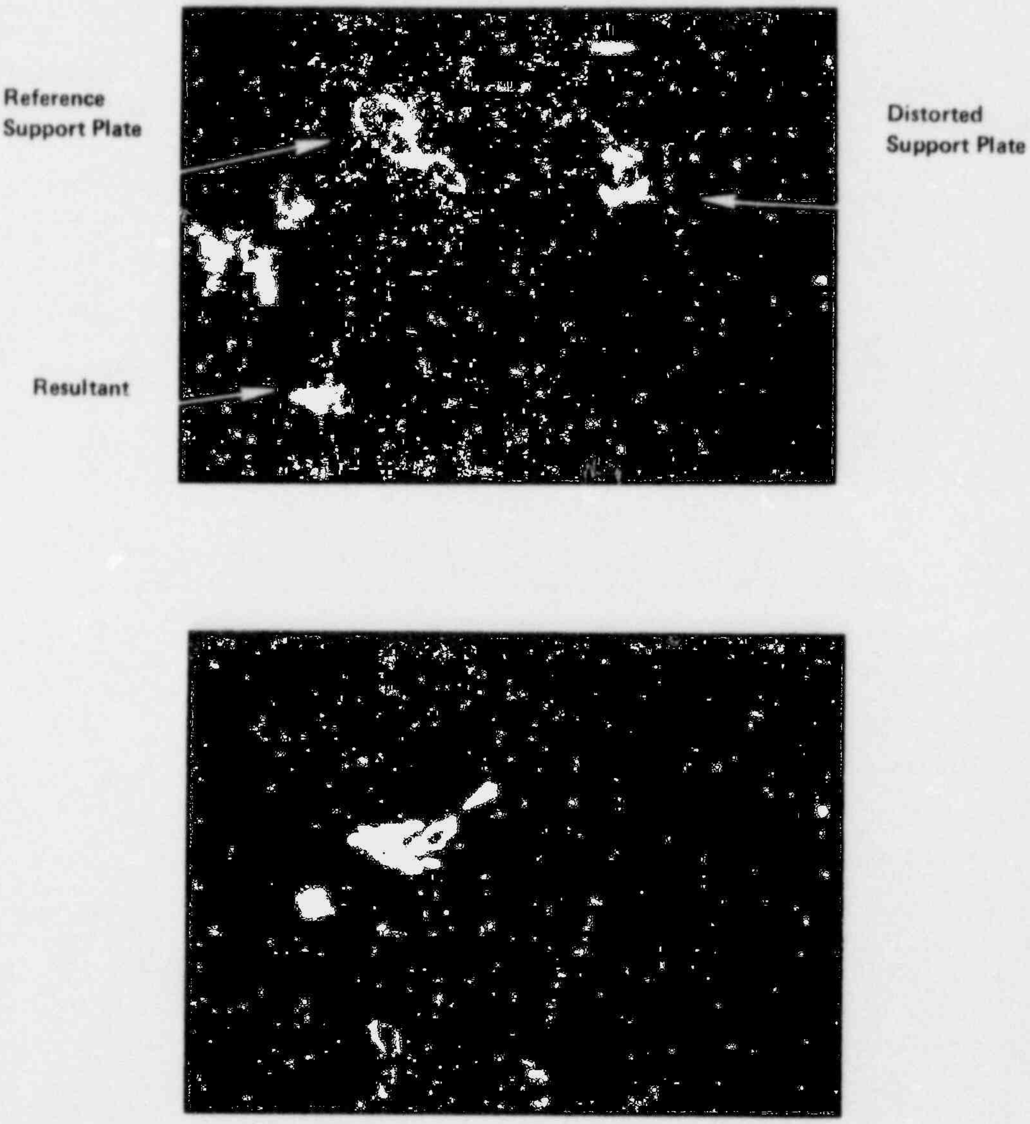
Support + defect
A58
Digitized 13-Nov-78
1000 pairs DAT #6



Resultant

Analog signal scanned free
of support plate

Figure 9. Specimen B. 54% pit centered in support plate



(b) Resultant signal expanded

Figure 10. Specimen B. 54% deep pit centered in support plate ML-2 signal analyzer

expanded view of the resultant signal is shown in Figure 10b. Notice the similarity with the resultant signal in Figure 9.

Figure 11 illustrates computer subtraction results for a pit located at the edge of the broached support plate. The resultant signal is of very small amplitude and if the trace is analyzed dynamically, the phase angle illustrated results. As can be seen, the resultant phase angle is similar to the original analog eddy current angle. The pit in Figure 9 was centered within the support plate whereas the pit shown in Figure 11 was at the support plate edge. This can be seen by examining the strip chart recordings shown in Figure 12.

Figures 13 through 15 illustrate more complex signals which arise when simulated multiple scalloping defects are placed in proximity to a broached support plate edge. From the DSP signal, one can see the undistorted entrance loop and the distorted exit loop structure caused by the support plate edge. Similarity of the computer reconstructed patterns to the analog signal is apparent.

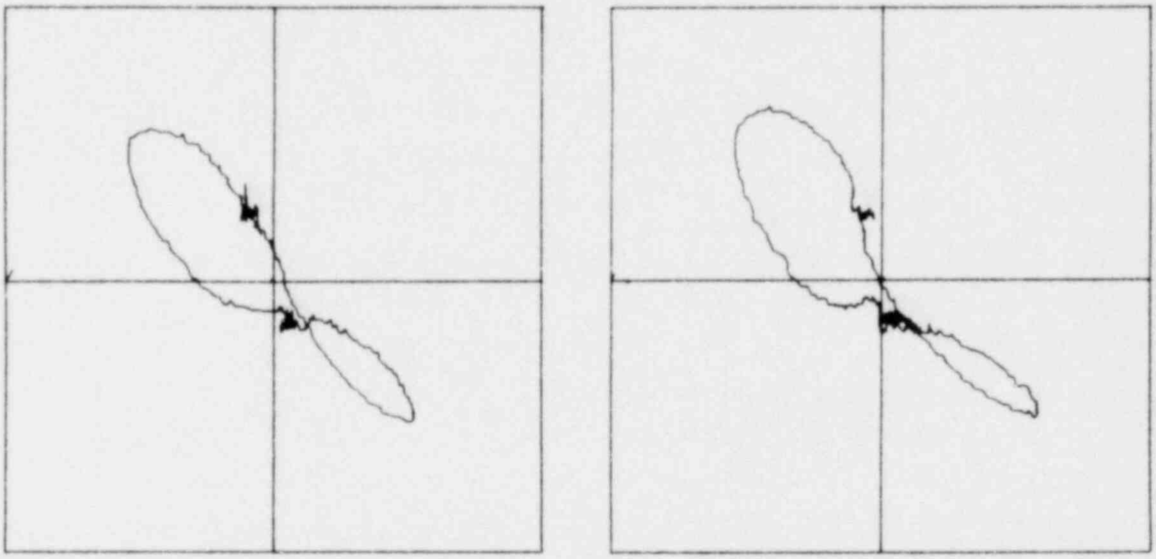
Examples of extraneous signal subtraction as applied to models of high-cycle fatigue cracks are illustrated in Figures 16 through 18. The defects were placed approximately 1/8 inch from the support plate edge. There is fairly good correlation between the analog signal patterns and the subtracted result. Figure 17 is a good illustration of how the subtraction process is implemented using either the computer subtraction method or ML-2 signal analyzer. Notice that the DSP signal entrance loop is not distorted as compared to the reference support plate signal entrance loop. In using the subtraction technique, the delay or time shift between the reference support plate and the DSP is varied such that in the subtracted result, the undistorted portion of the support plate signal is a minimum. Notice that in Figure 17, the support plate residual in the subtracted result is minimal.

Figures 19 through 22 show results for the simulated candleflame defect. This defect was also located at the broached support plate edge as can be seen by the distortion of the support plate exit loop.

The defect types considered up to this point have always occurred at the edge of the support plate. Hence, for alignment of the reference subtracted support plate signal, the undistorted support plate entrance or exit loop has been available. For fretting-type defects, distortion of both support plate loops can be expected. Experiments in subtracting support plate signals from composite fretting/support plate signals were accomplished using the Zetec ML-2 signal analyzer. Results are illustrated in Figure 23. Shown are the support plate

Tube Support
A58-TSP B
Digitized 13-Nov-78
1000 pairs, Dat # 4

Support + Defect
A60
Digitized 13-Nov-78
1000 pairs, Dat # 7



Resultant

Analog signal scanned
free of support plate

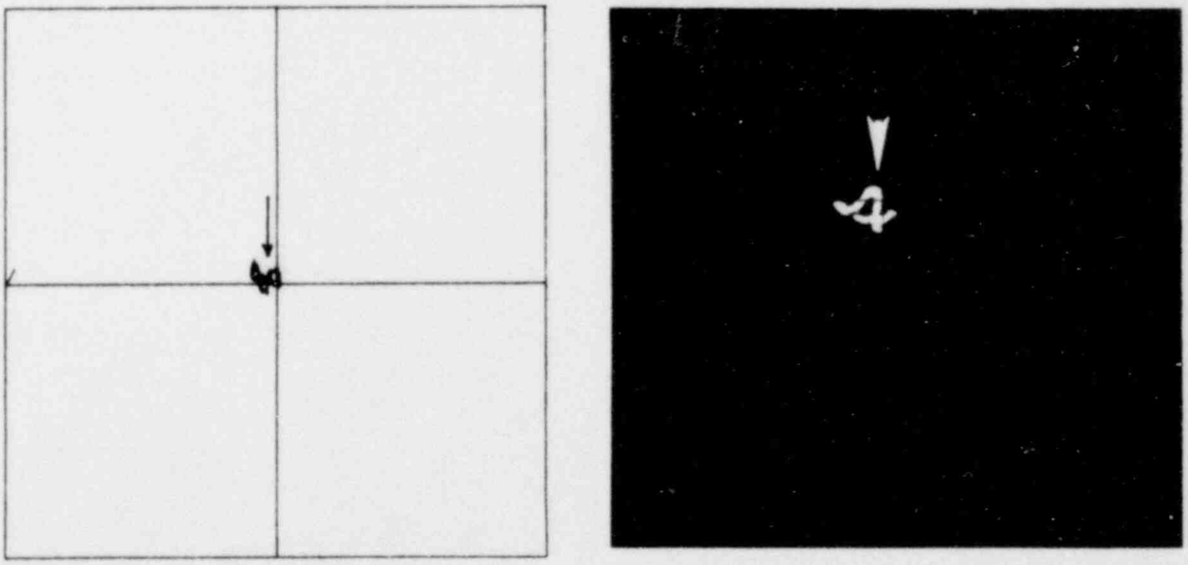
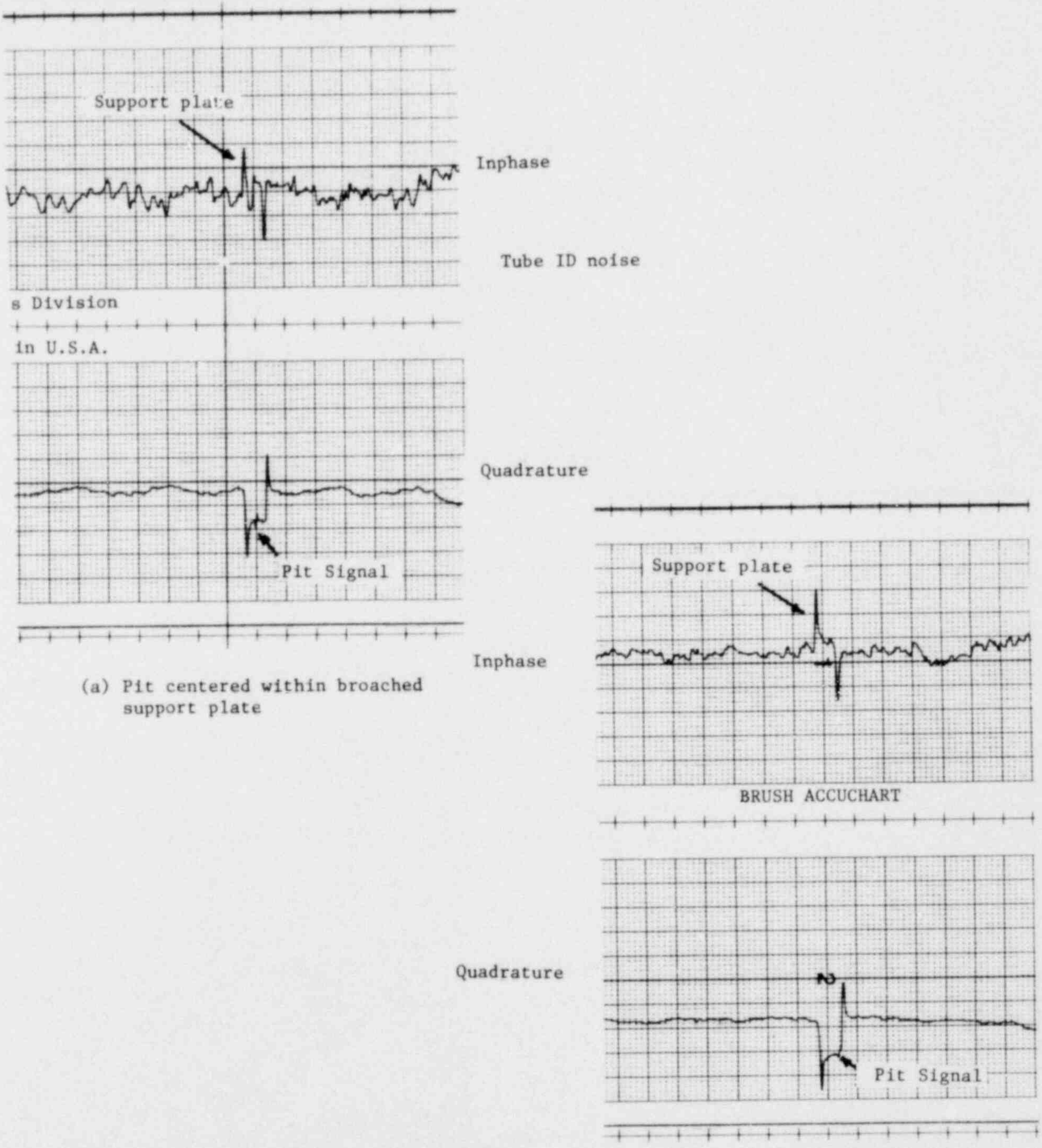


Figure 11. Specimen A. 66% deep pit at support plate edge



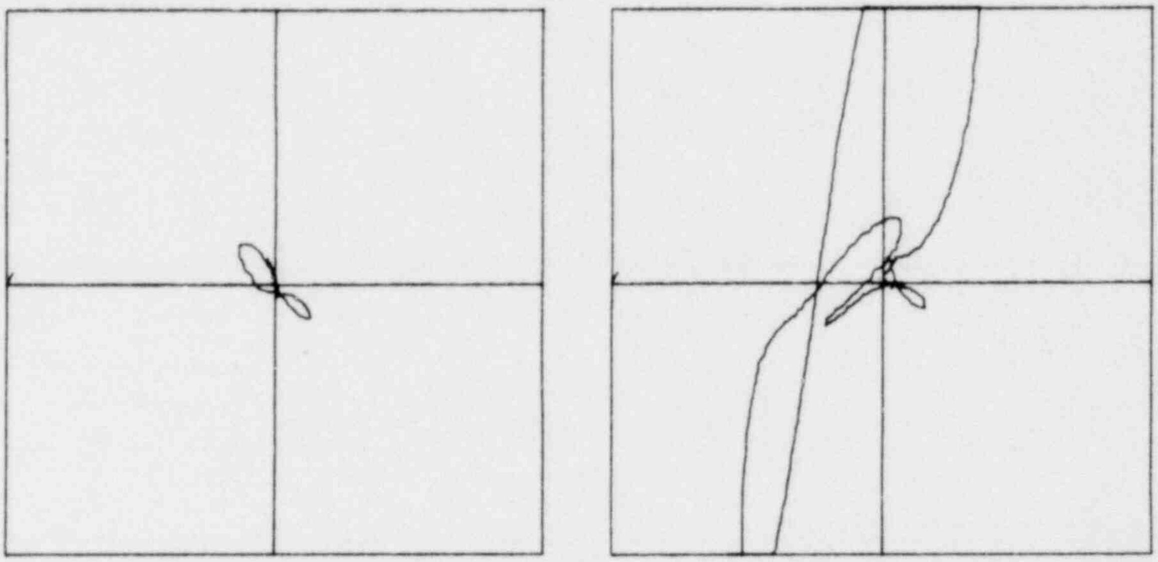
(a) Pit centered within broached support plate

(b) Pit located at plate edge

Figure 12. Strip chart recordings of small pit signals in proximity to broached support plates

Tube support
A58-TSP B
Digitized 13-Nov-78
1000 pairs DAT #4

Support + defect
A61
Digitized 13-Nov-78
1000 pairs DAT #8



Resultant

Analog signal scanned free
of support plate

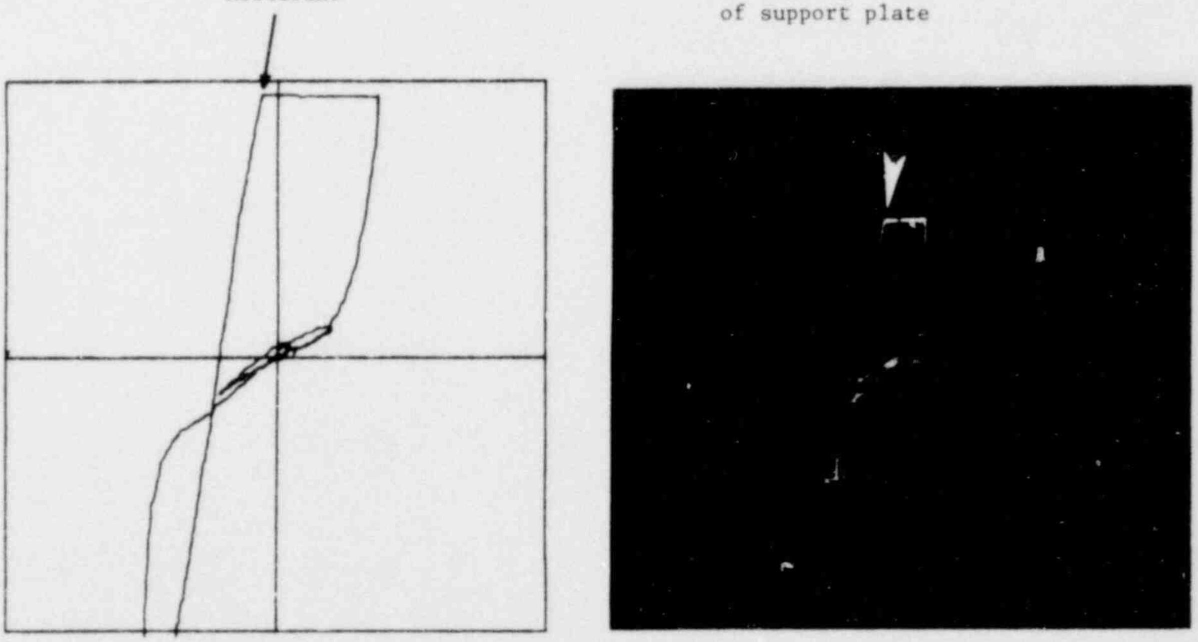
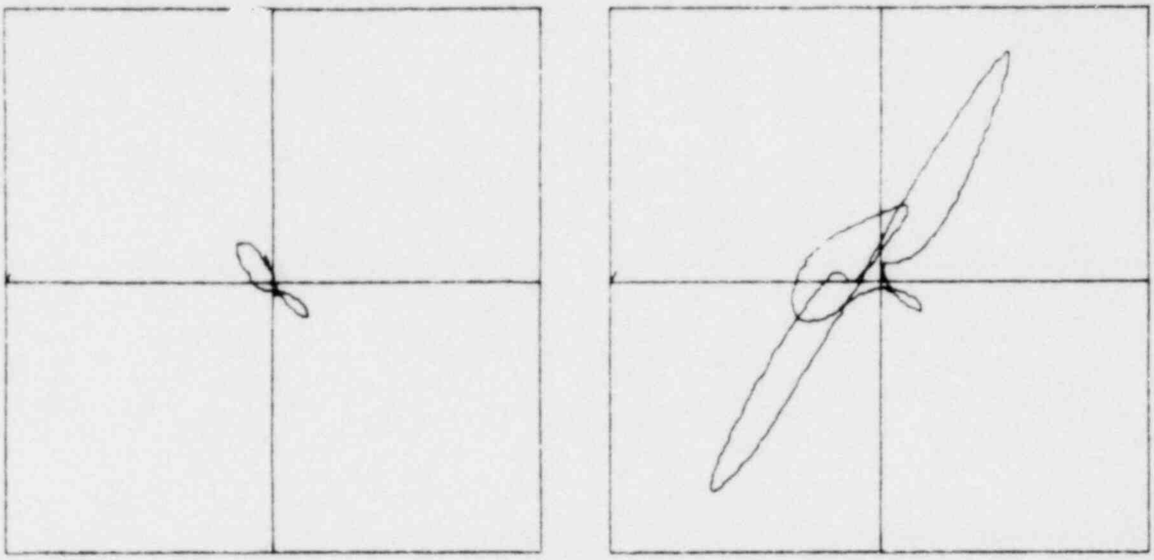


Figure 13. Specimen E. Multiple scallop 54% deep at support plate

Tube support
A58-TSP B
Digitized 13-Nov-78
1000 pairs DAT #4

Support + defect
A63
Digitized 13-Nov-78
1000 pairs DAT #10



Resultant

Analog signal scanned
free of support plate

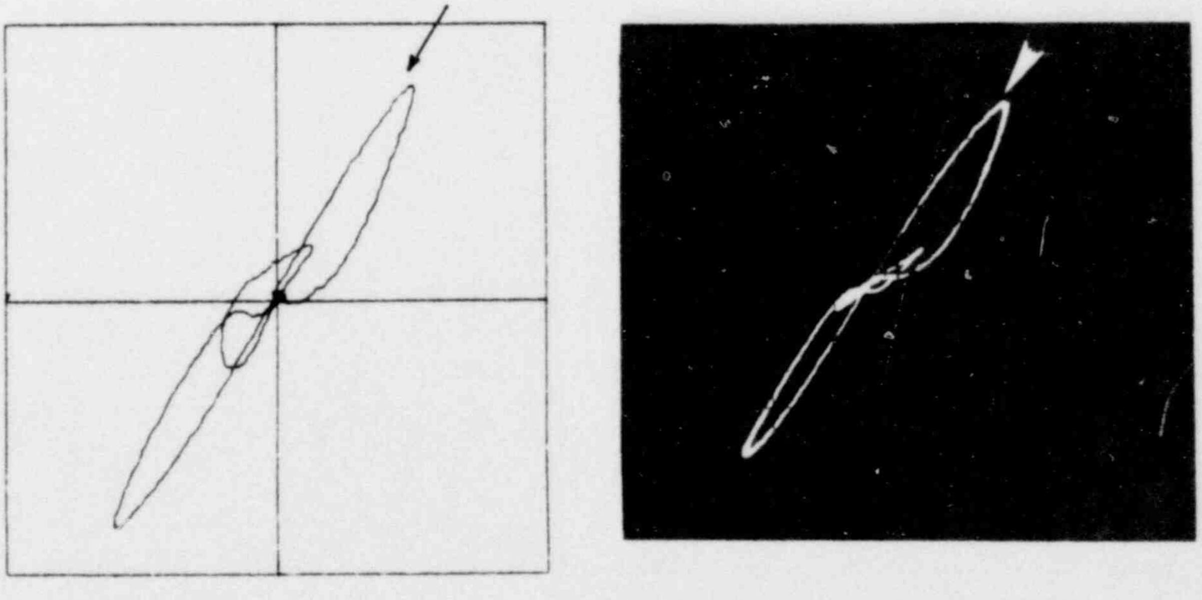
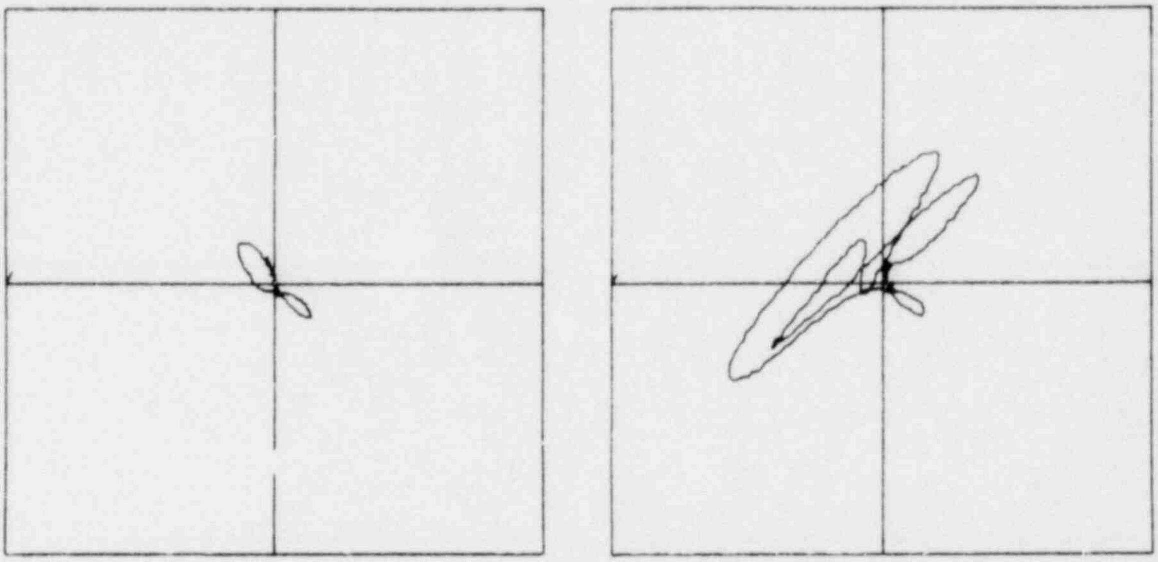


Figure 14. Specimen F. Multiple scallop 52% deep at support plate edge

Tube support
A58-TSP B
Digitized 13-Nov-78
1000 pairs DAT #4

Support + defect
A62
Digitized 13-Nov-78
1000 pairs DAT #9



Resultant

Analog signal scanned free of support plate

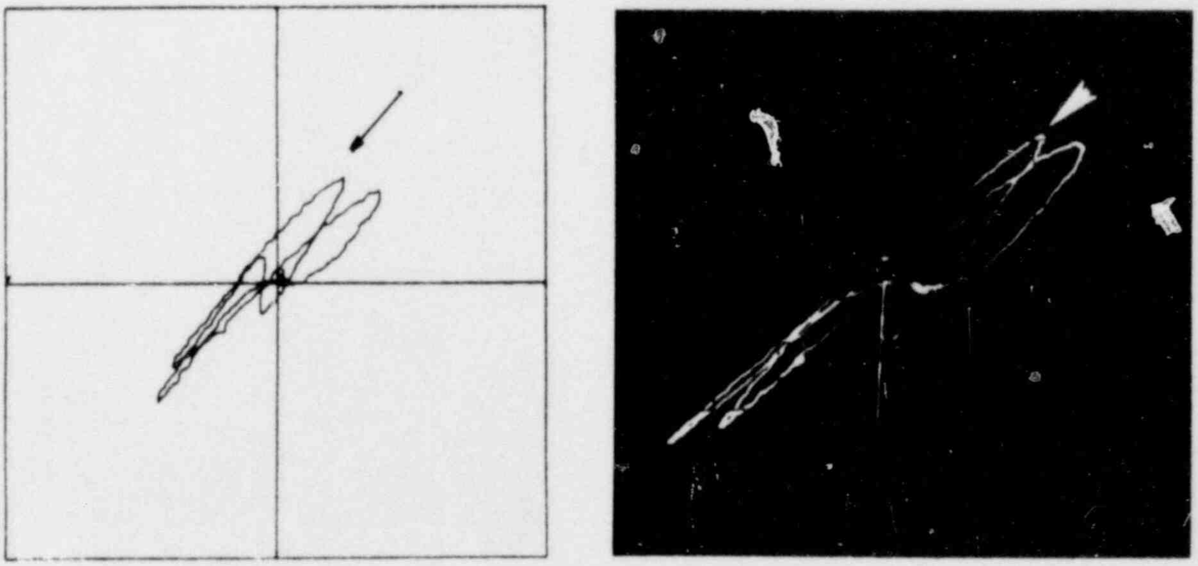
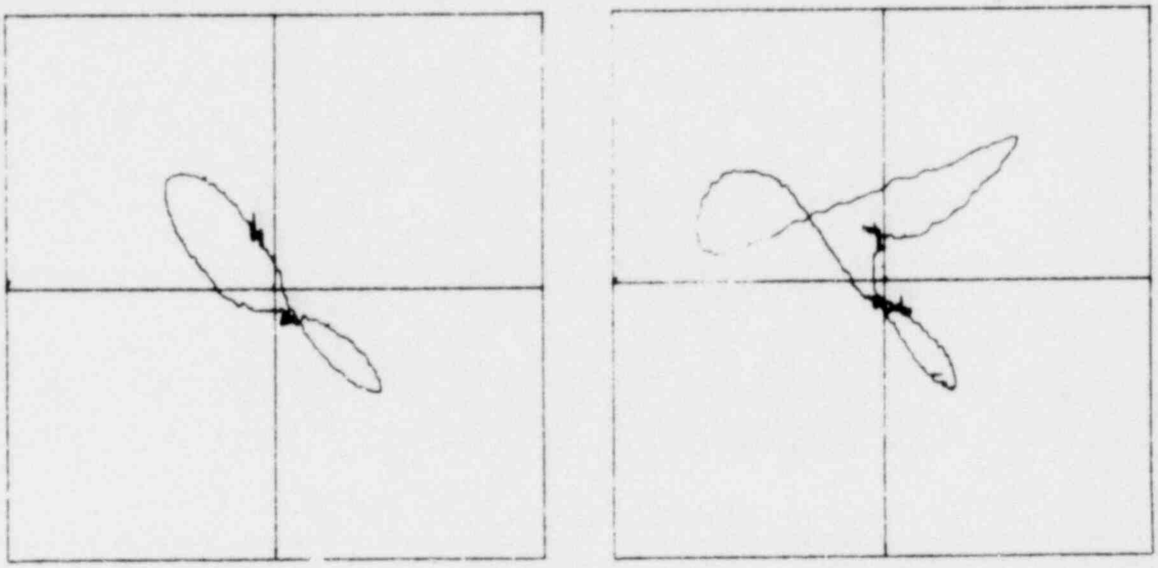


Figure 15. Specimen G. Multiple scallop 41% deep at support plate edge

Tube support
A58-TSP B
Digitized 13-Nov-78
1000 pairs DAT #4

Support + defect
A68
Digitized 13-Nov-78
1000 pairs DAT #15



Resultant

Analog signal scanned free of support plate

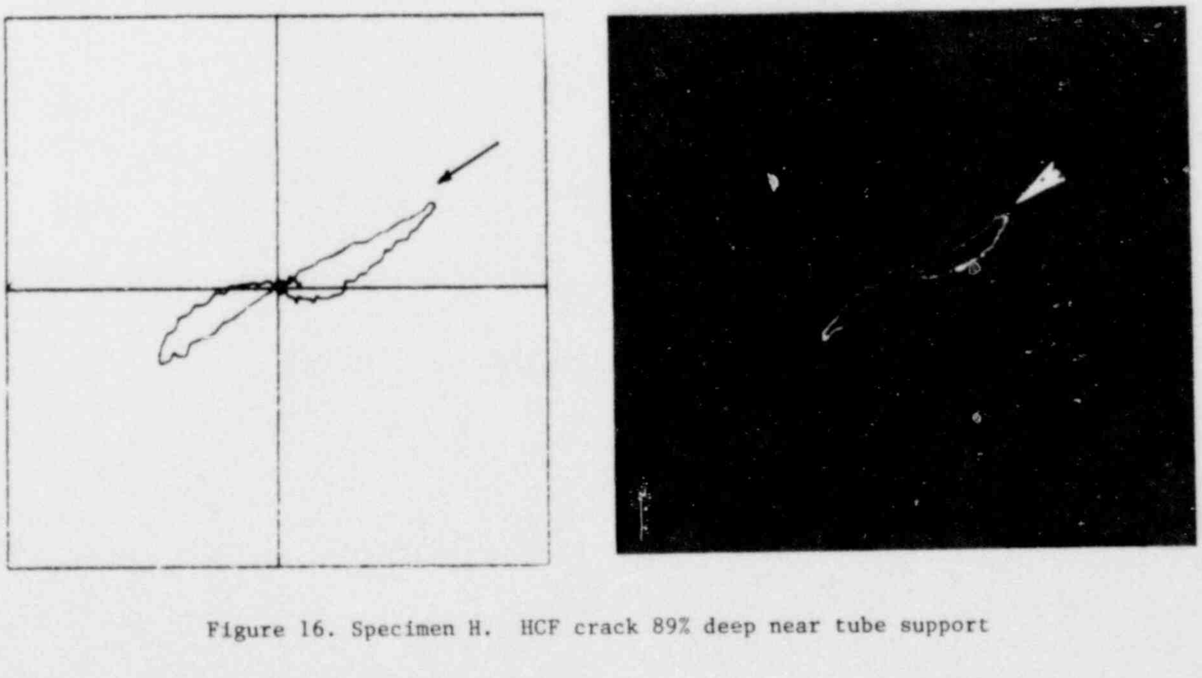
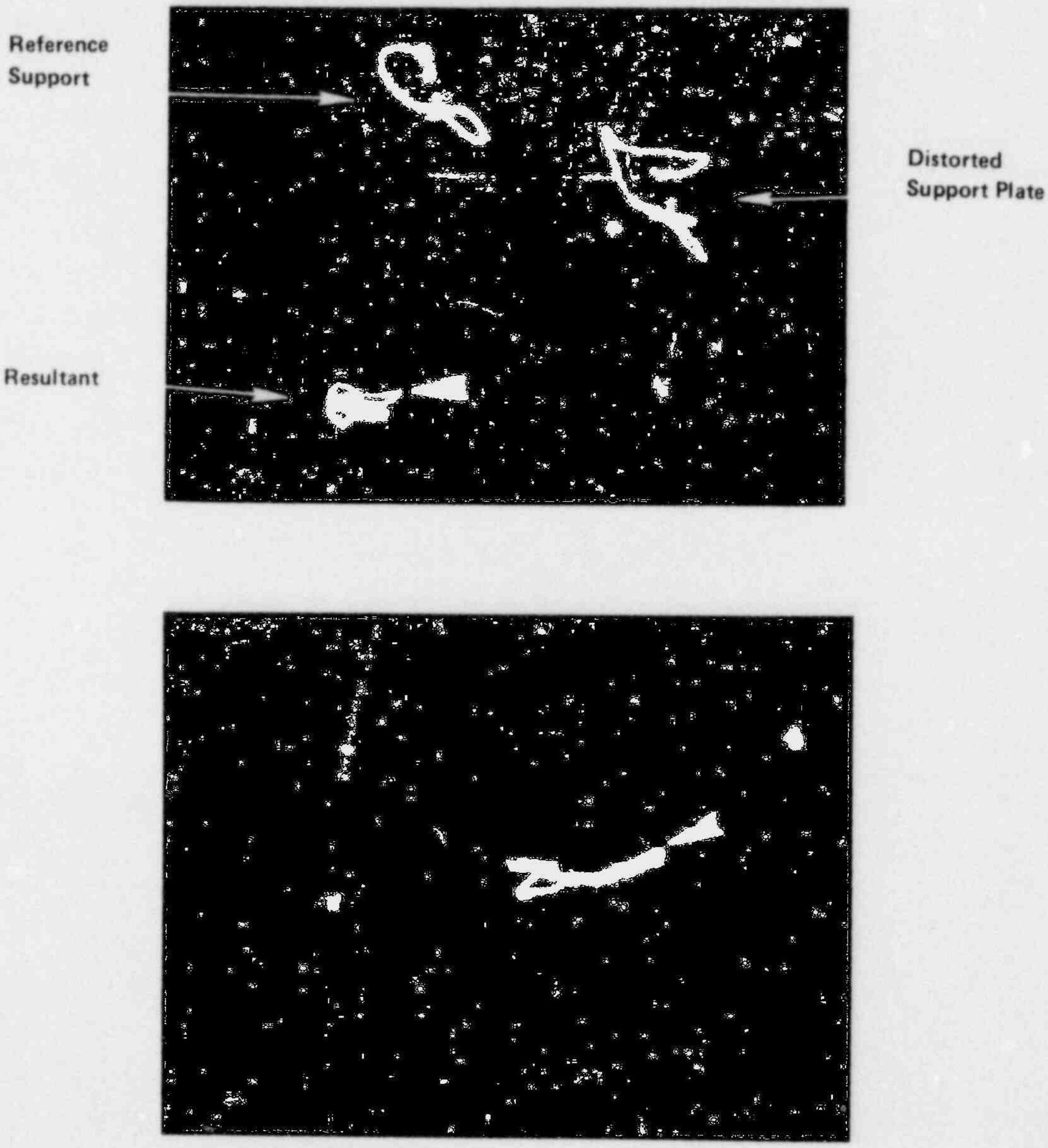


Figure 16. Specimen H. HCF crack 89% deep near tube support

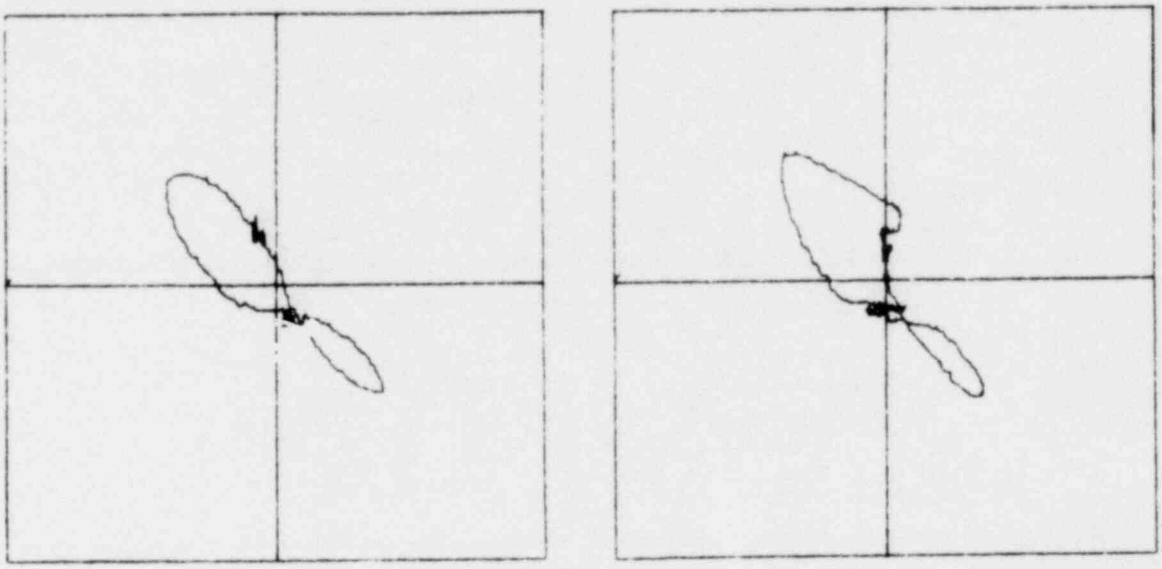


Analog signal scanned free of support plate

Figure 17. Specimen I. HCF crack 32% deep near support plate

Tube support
A58-TSP B
Digitized 13-Nov-78
1000 pairs DAT #4

Support + defect
A76
Digitized 13-Nov-78
1000 pairs DAT #23



Resultant

Analog signal scanned free of support plate

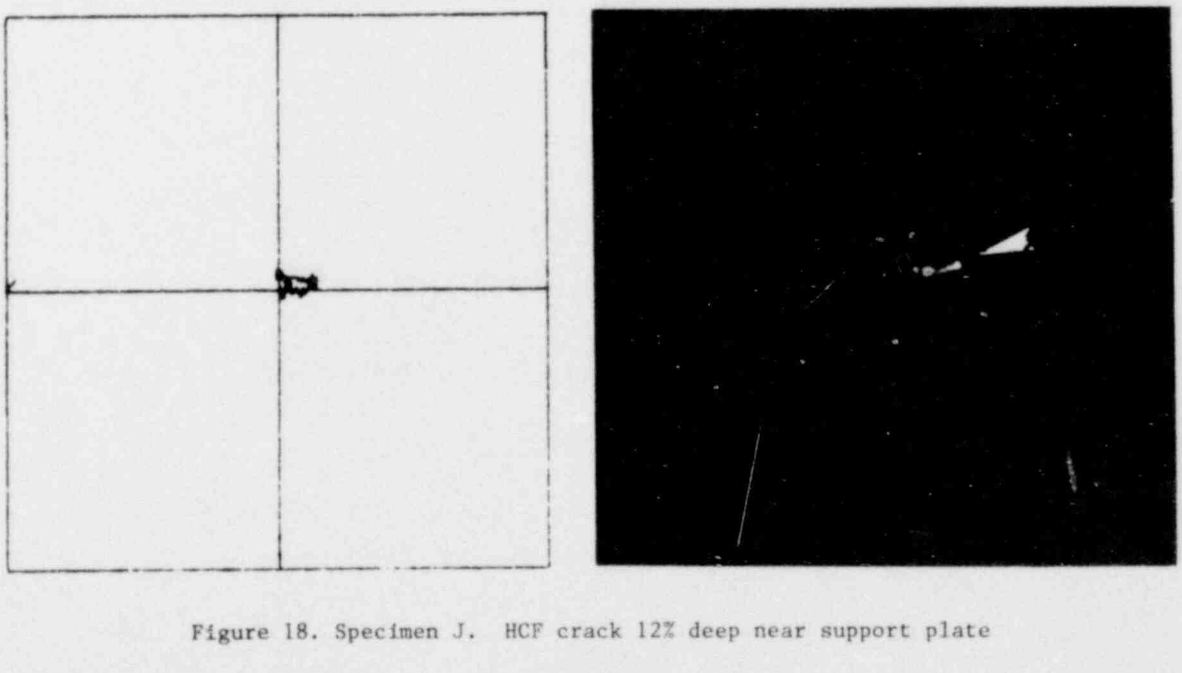
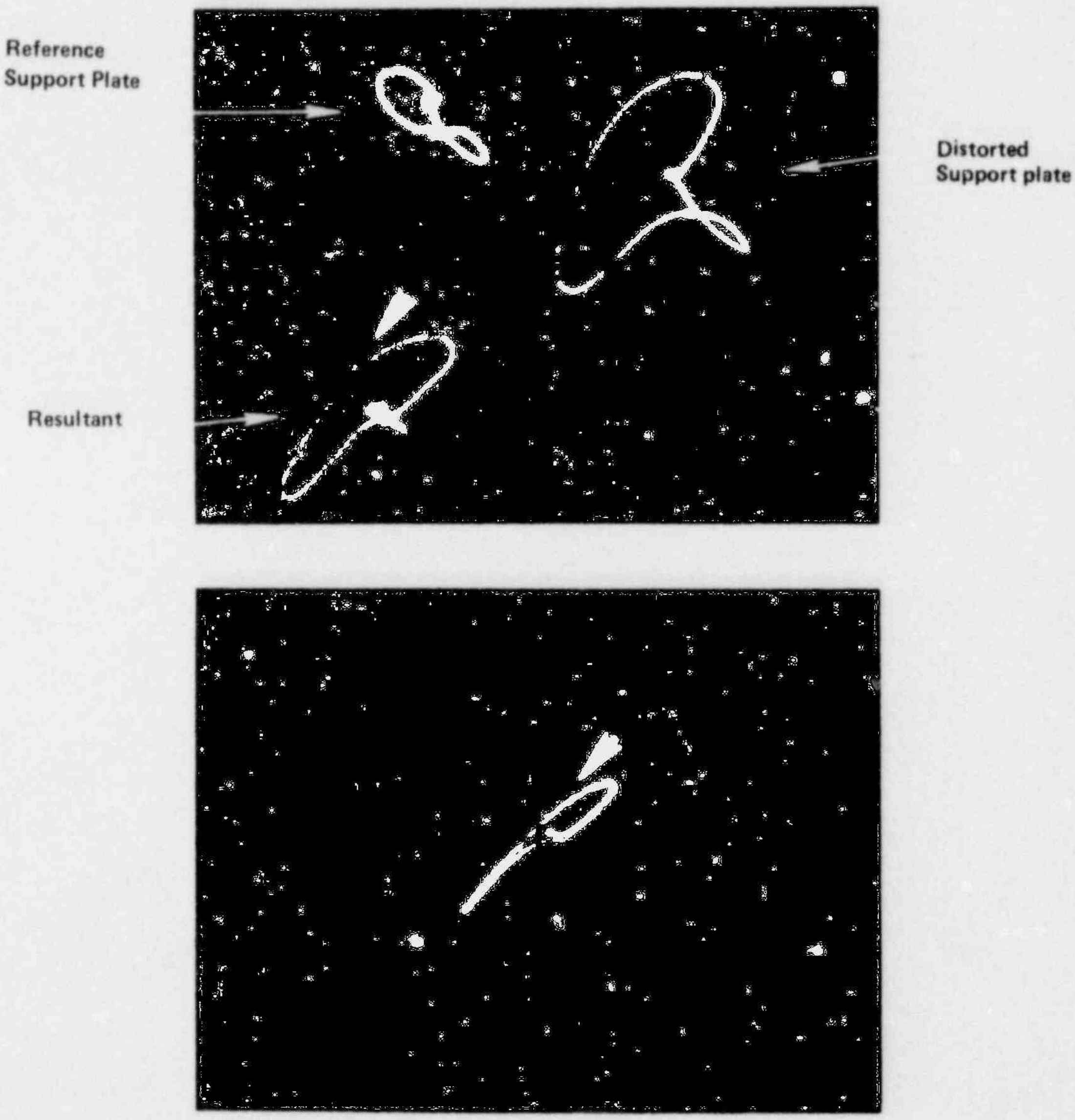


Figure 18. Specimen J. HCF crack 12% deep near support plate



Analog signal scanned free of support plate

Figure 19. Specimen M. 44% deep candleflame at support plate edge

Figure 20. Specimen L. 55% deep candleflame at support plate edge

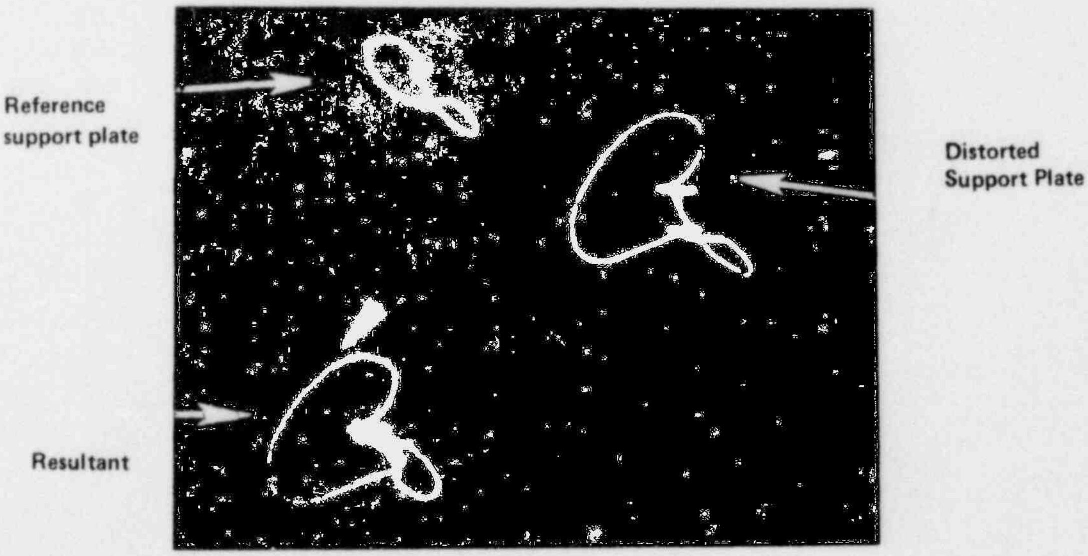
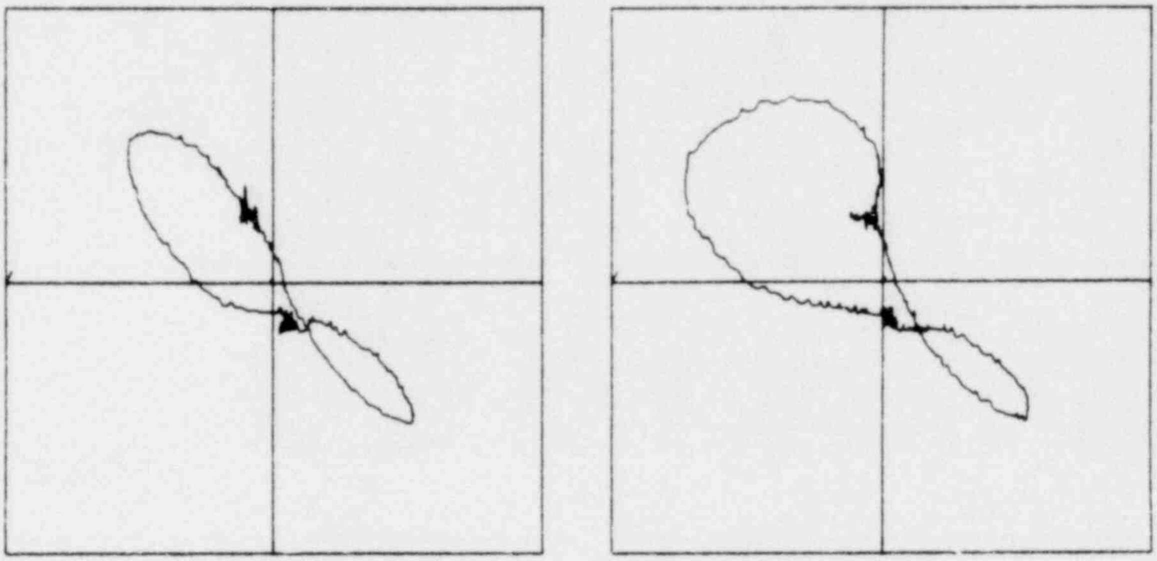


Figure 21. Specimen N. 41% deep candleflame at support plate edge

Tube support
A58-TSP B
Digitized 13-Nov-78
1000 pairs DAT #4

Support + defect
A65
Digitized 13-Nov-78
1000 pairs DAT #11



Resultant

Analog signal scanned
free of support plate

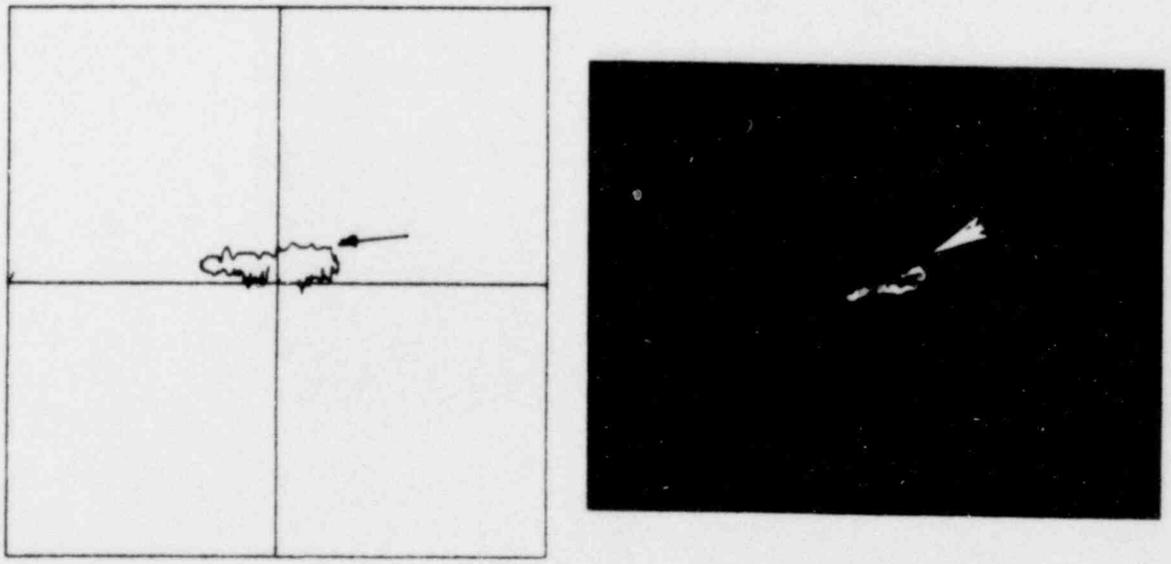
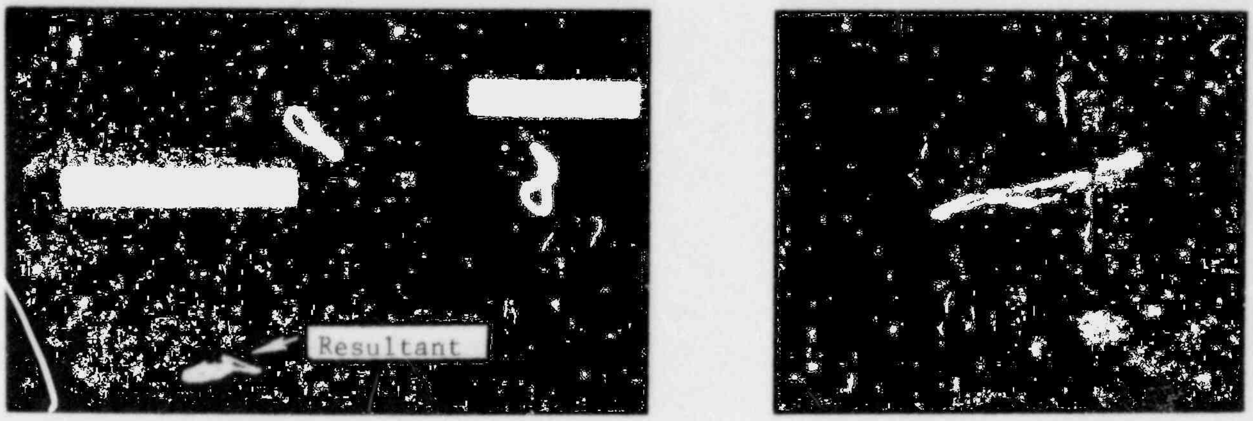
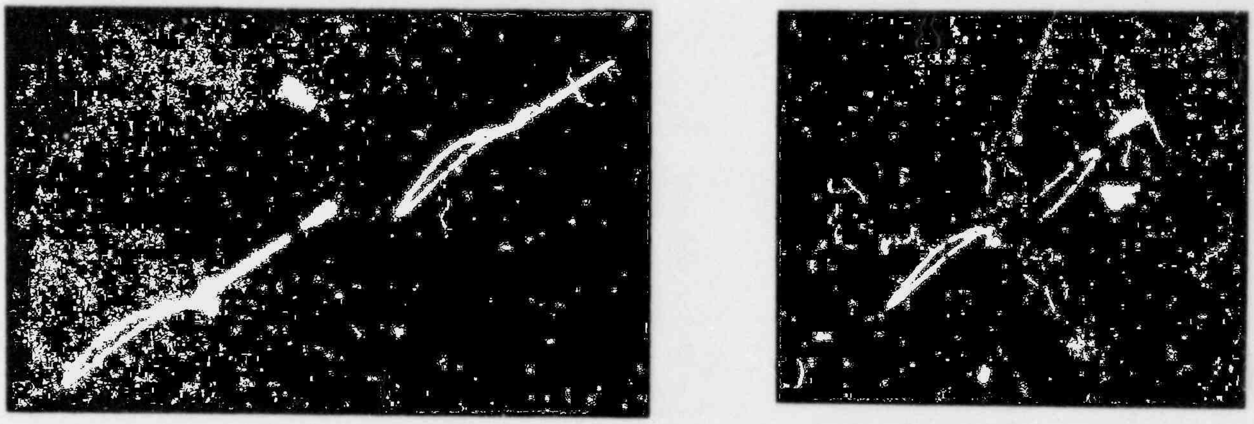


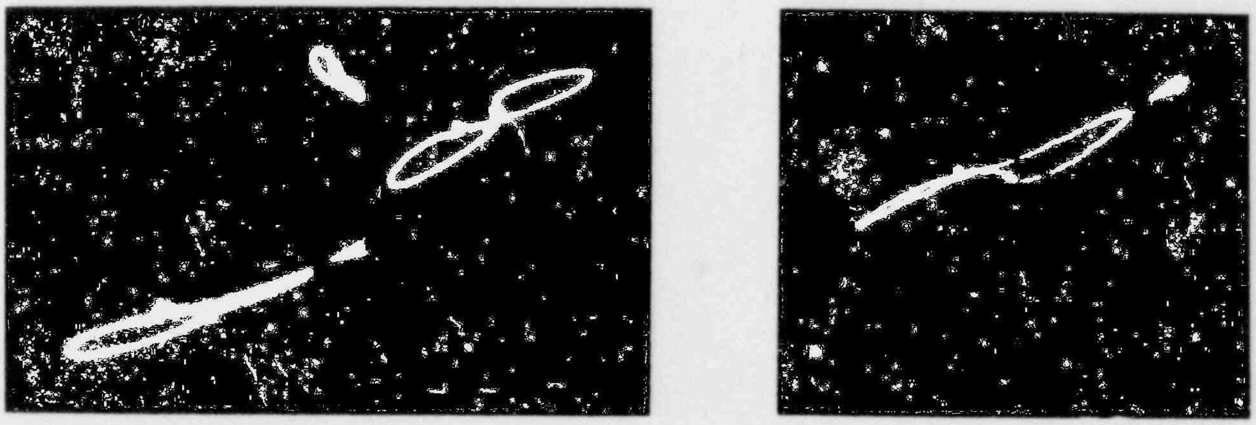
Figure 22. Specimen O. Candleflame 16% deep near support plate



Specimen R - 5% deep



Specimen Q - 19% deep



Specimen P - 34% deep
Reference support, distorted support
and resultant (clockwise)

Analog signal scanned free
of support plate

Figure 23. Fretting at broached support plate.
ML-2 signal analyzer

reference signal, the distorted support plate signal and the result of the subtraction process. The fretting signals scanned free of the extraneous support plate are also illustrated for comparison.

Estimates of the accuracy of digital subtraction techniques can be derived by reading the appropriate phase angle from the reconstructed signal and comparing with the analog signal phase angle from the defect free of the tube support plate. Depth estimates for both the analog and digitally constructed patterns can be done using a calibration standard that relates phase angle to flaw depth. The difference between the analog and digital depth estimates is a true estimate of the subtraction technique error.

It is important to realize that the difference between the subtraction depth estimate and the actual defect depth can contain a systematic error introduced by the choice of standard used to establish the original phase angle versus depth transfer function. As an example, if large and small volume flat-bottomed holes are used to establish an eddy current phase angle versus depth curve, the extreme curves shown in Figure 24 will result. The ASME Section XI standard represents a compromise in flat-bottomed hole volume such that in general a dashed line curve which represents an average between the two curves in Figure 24 results. If the dashed line calibration curve is used to estimate defect depth independent of signal amplitude or defect volume, then as can be seen a conservative or overestimation of defect depth results for large volume defects. For small volume defects an underestimation of the defect depth results.

Figure 25 shows scatter plots for the subtraction method estimated defect depth. Two types of error are illustrated, i.e., the correlation between the actual defect depth and the subtraction estimate, and the correlation between the analog eddy current estimated depth and the subtraction estimate. The average absolute error curve for both error types is 14 and 6 percent, respectively.

One of the more interesting results from Figure 25 is specimen H which was a simulated high-cycle fatigue crack. The crack was made to correspond to Figure 2b in which a near through wall crack exists with some propagation of the crack around the circumference of the tube. The eddy current data gave a signal which suggests a crack nominally 30 percent through the wall. The difficulty is the averaging effect of the circumferential eddy current flow. Present ID bobbin-coil designs are designed for the detection of predominantly axially oriented discontinuities. The true characterization of circumferentially oriented defects could be

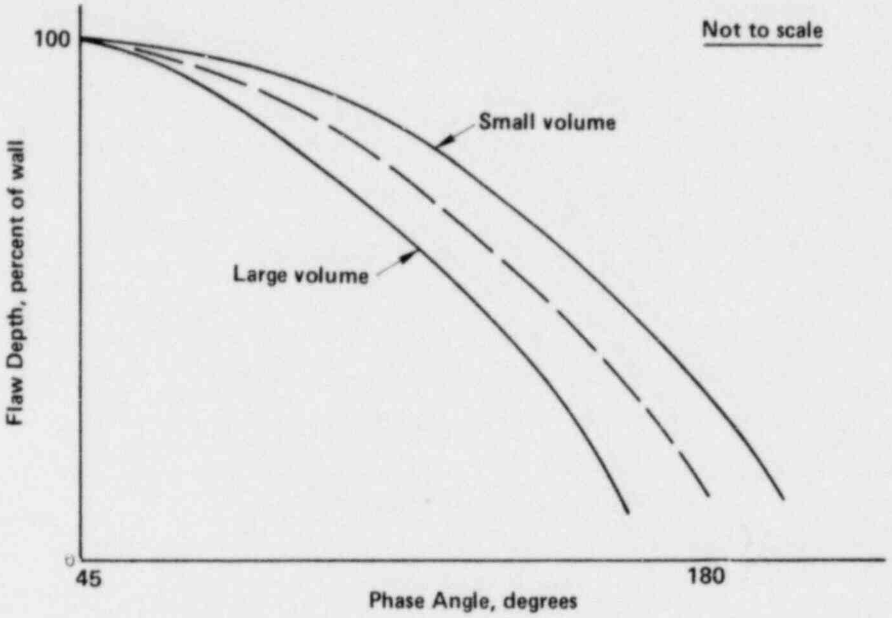


Figure 24. General effect of flaw volume on eddy current phase angle

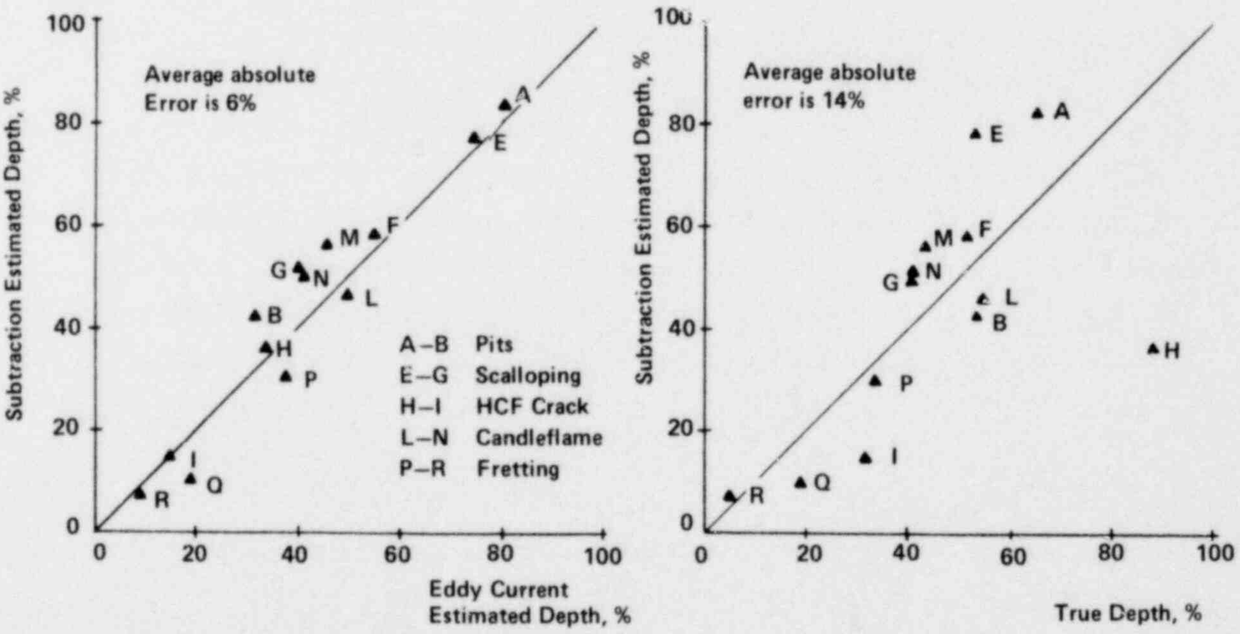


Figure 25. Correlation of subtraction estimated depth
with eddy current and true depth

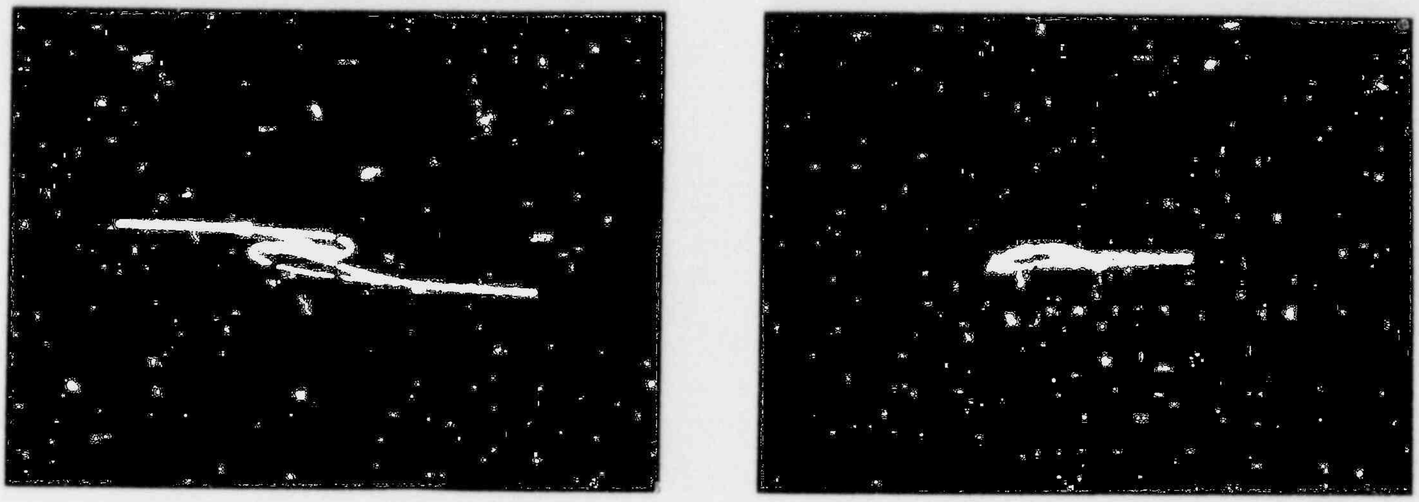
achieved by other coil designs, i.e., rotating pancake coil or a tangential differential coil in which the eddy current flow is directed along the tube axis.

Multifrequency Aspects of Steam Generator Tubing Inspection

The choice of eddy current coil excitation frequency is an important parameter with regards to the characterization of signals which can occur during the inservice inspection of steam generators. For certain defect types and inspection frequencies, the resultant eddy current signature is non-unique and the unambiguous recognition of what is occurring on the secondary or primary side of the tube is not possible. The use of more than one frequency to characterize a signal type represents a powerful tube inspection tool in attempting to identify causative factors giving rise to the signal. The term multifrequency eddy current is used in the sense of exciting the test coil either sequentially or simultaneously at more than one frequency.

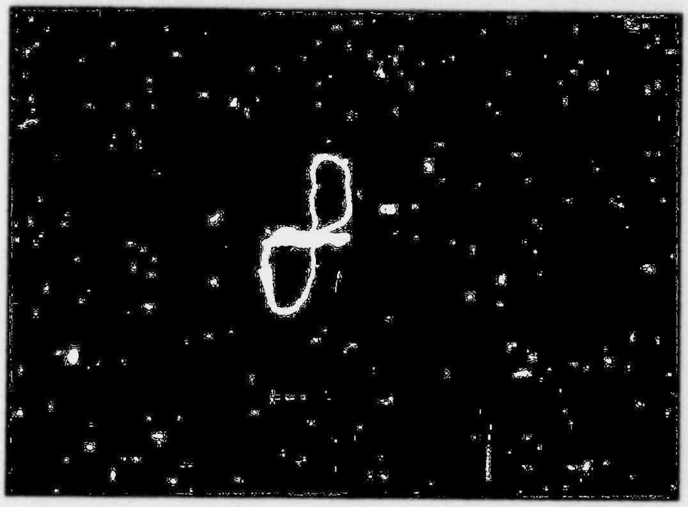
Tube dings can give rise to eddy current signals which can be confused with shallow secondary side corrosion or thinning. Figure 26 shows the signal from a tube ding and shallow secondary side attack at 675 KHz. Both signals are similar in that they both start to the left (negative x-direction). If the shallow secondary side attack is examined at a lower frequency, the signal pattern rotates in the counterclockwise direction. The ding signal does not rotate if probe wobble is used as the reference axis. For the example considered on Figure 26, it is also apparent that the use of lower inspection frequencies (400 KHz for 0.037-inch wall tube or 200 KHz for 0.050-inch-wall tube) would lead to the more reliable detection of shallow thinning attack, where probe wobble is an extraneous variable, since again the signal is rotated off the wobble prone horizontal channel.

Another interesting feature of the ding is its occurrence in conjunction with secondary side attack. Figure 27a shows the signal which results from a small ding with a 100 percent through-wall hole. The frequency used was 675 KHz. Notice that the ding signal is rotated in the counterclockwise direction (compare with Figure 26) but it mimics the response of an approximate 20 percent secondary side defect. The ambiguity is resolved by lowering the inspection frequency. Figure 27b shows the eddy current response at 200 KHz for the same ding/through-hole combination. Notice the signal is rotated in the counterclockwise direction.



(a) Tube ding signal - 675 KHz

(b) Shallow OD signal - 675 KHz

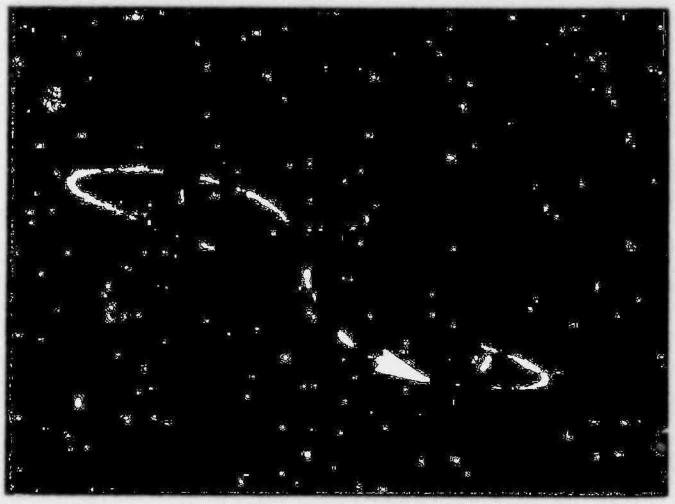


(c) Shallow OD signal - 400 KHz

Figure 26. Tube ding/shallow OD discrimination

(a) 675 KHz

(b) 200 KHz



(c) 55 KHz

Figure 27. Tube ding characterization at different frequencies

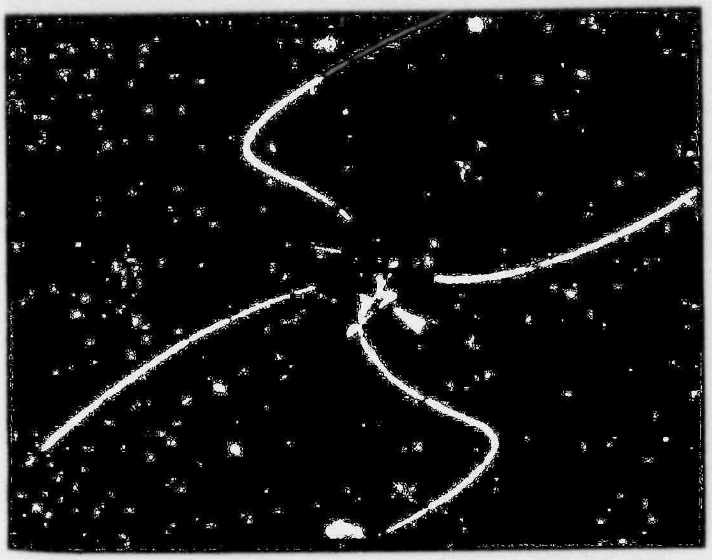
At a still lower frequency, i.e., 55 KHz, the ding is essentially transparent allowing for the through-wall hole to become dominant.

One OTSG generator has a broached hole tube support plate which was fabricated from carbon steel plate containing laminations. During the inservice inspection of the steam generator, distorted support plate signals or defect-like signals were observed within the support plate. Figure 28 shows the eddy current patterns which result from a laminated support plate at three frequencies. Notice the defect-like signal which occurs within the central region of the support plate entrance and exit lobes. As the inspection frequency is changed, notice that the entire signal pattern rotates. A true secondary side defect would exhibit a different rotation rate as the frequency is changed.

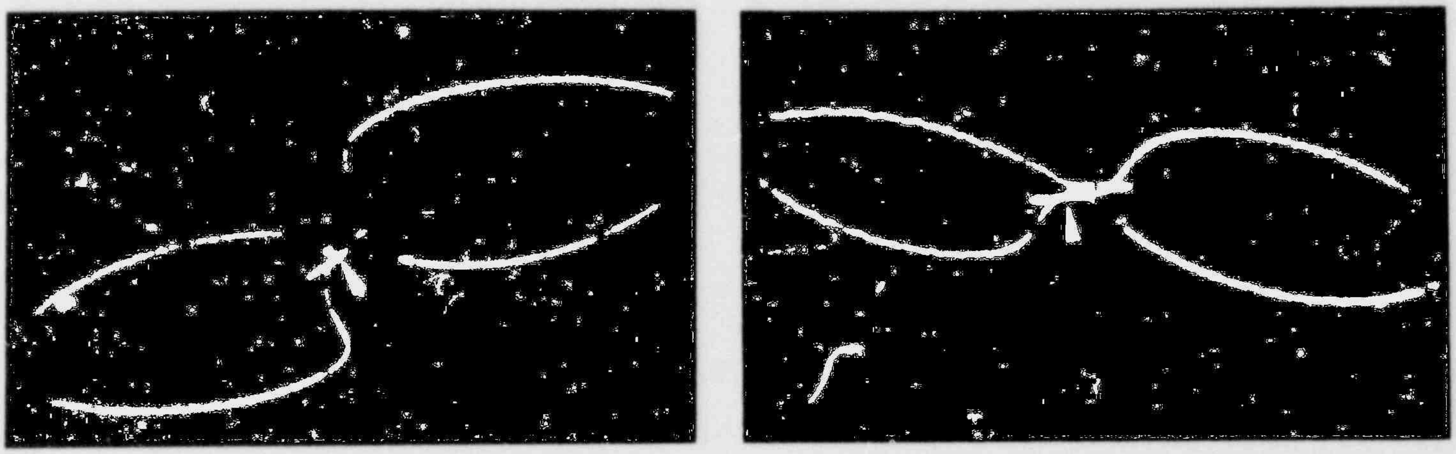
The detection of small pitting, while not of a safety concern, is of interest to the utility from a plant availability standpoint. Experiments in detecting small pits were conducted by scanning a series of pits at different frequencies. The initial test setups for each frequency were normalized by setting probe wobble on the horizontal axis and adjusting the EM-3300 sensitivity setting so that the response from a 100 percent through wall hole (ASME STD) was the same. Figure 29a shows the strip chart recordings of the inphase and quadrature components from a small through-wall pit. Notice that the vertical channel amplitude is largest at 400 KHz. Normally, the vertical channel is monitored for the detection of defects at 400 KHz. The eddy current Lissajous pattern rotates in the counterclockwise direction, which basically projects more of the signal onto the vertical channel. Hence, the signal rotation aspects, where defect components are rotated off the horizontal or wobble prone axis, would lead to enhanced detectability at a lower frequency.

For the pit size extremes considered in this test program (see Table 2), only specimens A and B were detectable. The smaller pitting examples, i.e., specimens C and D could not be detected. These results were independent of frequency over a range from 100-675 KHz.

The existence of tube ID noise, which is the result of manufacturing processes, introduces another factor which must be considered when optimum inspection frequencies are being explored. Figure 29b shows the strip chart recordings of a small pit 0.022 inch in diameter approximately 60 percent through



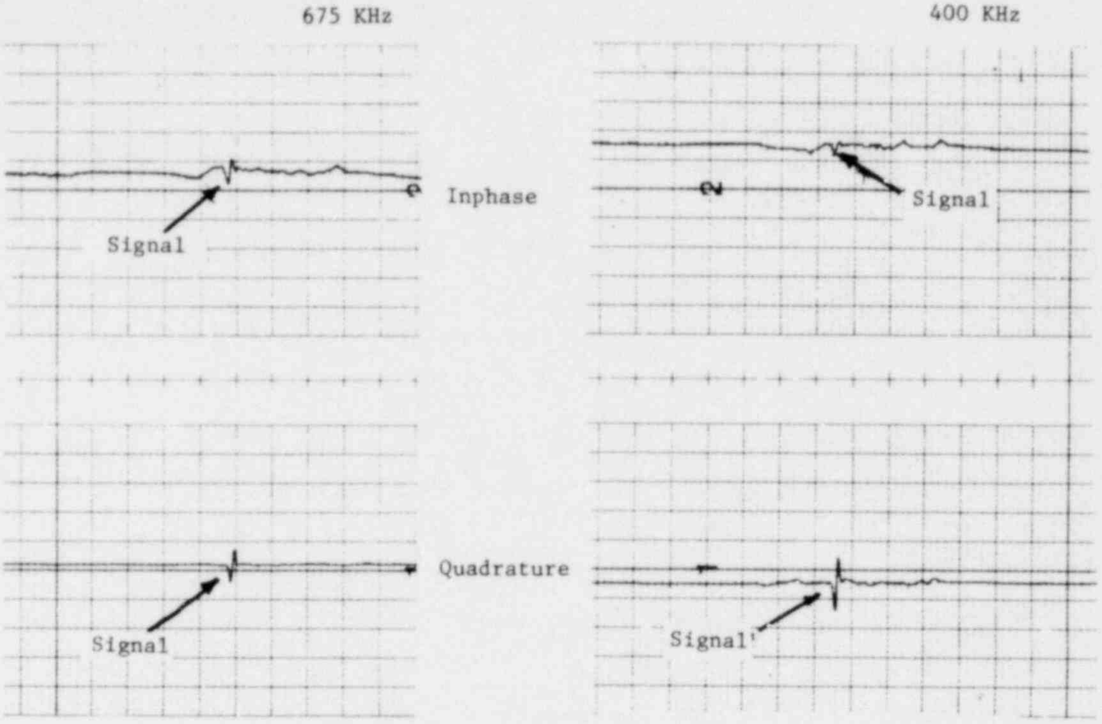
(a) Laminated broached support plate
signal showing psuedo defect - 100 KHz



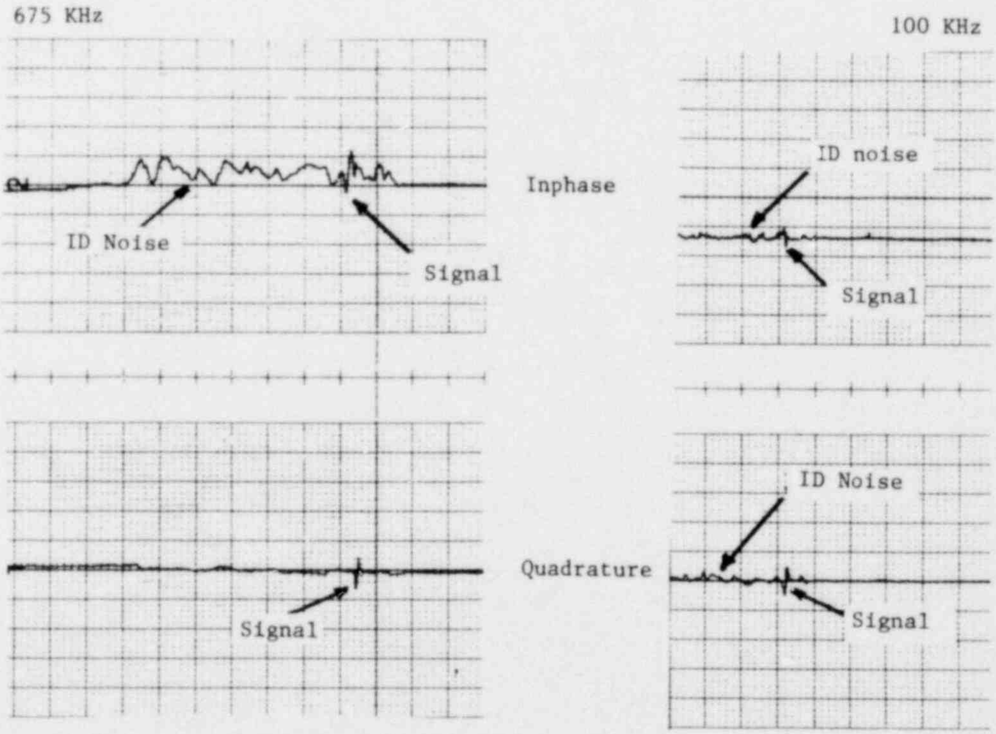
(b) Same signal pattern at 200 KHz

(c) Same signal pattern at 400 KHz

Figure 28. Distorted broached support plate signals
at different frequencies



(a) Signal rotational effects



(b) ID noise effects

Figure 29. Small flaw detectability considerations

the tube wall. Recordings for two frequencies are illustrated. For each frequency, probe wobble was set on the horizontal and the sensitivity adjusted to obtain the same response from the ASME STD 100 percent through wall hole.

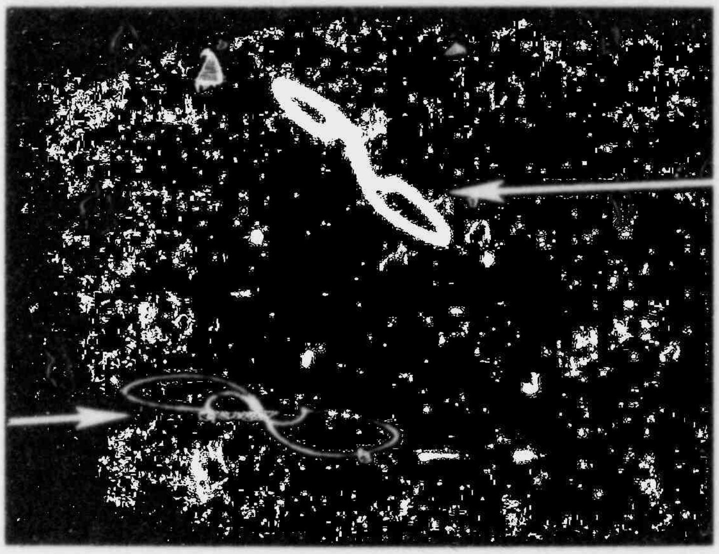
As Figure 29b illustrates, the phase angle differences between wobble and ID noise increase as probe excitation frequency is decreased. With wobble initially set on the horizontal channel, the phase angle difference between ID noise and wobble at 675 KHz is essentially zero, hence the tube ID noise shows up only on the horizontal channel. As frequency is decreased, the ID noise rotates off the wobble axis and is projected onto the vertical axis. This explains why the vertical channel becomes more noisy as frequency is lowered. In general, a higher defect signal-to-noise ratio for both channels is obtained at a lower inspection frequency for the situation in which ID noise is predominant.

Secondary side tube deposits can sometimes give rise to pseudo defect signals. Again, by examining the suspect signal at different frequencies, information to the legitimacy of a true tube defect can be acquired. Figure 30a shows eddy current signal patterns which result when magnetite is wrapped around a tube. Notice that as the frequency is lowered, the signal pattern rotates in the counterclockwise direction in a manner not characteristic of a true tube defect. Figure 30b illustrates distorted tube sheet entry signals caused by wrapping increasing amounts of magnetite around the tube. As the mass of magnetite is increased, the tube sheet entry signal becomes more flattened and elongated.

DISCUSSION

Digital subtraction techniques in which an extraneous test variable, i.e., tube support signal, is subtracted from a distorted plate signal is an effective means for characterizing small volume defects located in proximity to support plates. The success of the method would be dependent on the matching of the reference signal to an undistorted portion of the distorted plate signal.

Various conditions within the OTSG steam generator can give rise to the need for different support plate reference signals. Those that have been identified to date would include tube ID noise and cold work. Cold work is introduced into a tube as the result of mechanical wear or fretting of the tube as it



(a) **Psuedo signals** resulting from magnetite wrapped around tube

(b) Normal and distorted tube sheet signals

Figure 30. Eddy current response to magnetic tube deposits

vibrates against the broached support plate. ID noise is the result of surface abnormalities introduced during tube manufacturing processes which can superimpose a noise-like signal on the support plate signal. The ID noise signature of a particular tube tends to be somewhat unique. Using ID noise data obtained from other tubes would result in the imperfect cancellation of the desired support plate signal.

The use of subtraction methods is a cost-effective method of characterizing distorted support plate signals in a situation where the total number of signals to be analyzed is relatively small. The advantage of the technique is that it can be accomplished using conventional inservice inspection instrumentation. As the number of distorted plate signals increase, and with the presence of tube ID noise or dings, multiparameter eddy current methods would probably be more cost effective, i.e., minimizing outage time. A second advantage of the multiparameter method is that eddy current data can be taken at different frequencies allowing one to resolve certain signal ambiguities as they arise by simple frequency discrimination. All of the necessary data can be gathered in one probing of the tube again offering advantages over present inspection methods where a tube may be probed two or three times, i.e., 200 KHz, 400 KHz, and 600 KHz.

CONCLUSIONS

- A computer subtraction method has been implemented and applied to eddy current data derived from simulated once-through steam generator tubing defects. Based on experimental studies, the average absolute error between the true defect depth and that provided by the subtraction method is 14 percent.
- The subtraction method coupled with existing ISI coil design, is not foolproof and depending on the defect type, i.e., high-cycle fatigue crack, or in some cases, distorted tube sheet entry signals, the use of alternate coil types such as a rotating pancake coil, can provide better information as to tube condition.

- A steam generator can be a complex signal environment and the use of more than one coil excitation frequency, i.e., multifrequency, can provide additional information in identifying causative factors affecting tube condition.

ACKNOWLEDGEMENTS

The use of the Zetec ML-2 Signal Analyzer was through the courtesy of Mr. Albert Curtiss III from the Rochester Gas and Electric Materials Engineering Laboratory.

REFERENCES

1. Tube Damage - Once Through Steam Generators. Sarver and Rigdon, Babcock and Wilcox, Alliance Research Center. Corrosion Advisory Committee Meeting, Electric Power Research Institute, February 7, 1978. (Used by permission)

2. Computer Analysis of Eddy Current Signals. Whaley and Wehrmeister, Babcock and Wilcox, Lynchburg Research Center. Second International Conference on Nondestructive Evaluation in the Nuclear Industry, February, 1978, Salt Lake City, Utah.

APPENDIX A

COMPUTER PROGRAMS

SUMMARY

Program Title	Program Descriptor	Page
BNL 1	Program to digitize and store steam generator tube data	A-1
BNL 3	Program to subtract tube support data patterns from steam generator tube data	A-6
Subroutine ASKPIC	This routine prompts the operator for a picture number. A response other than 1, 2, or 3 is invalid.	A-13
BNL 3 D	Program to generate a display buffer to be used by Program BNL 3	A-14
Subroutine ATTIN	This subroutine attaches a file for input by checking the file name directory for the file name and default sequence number. Either the default will be used or the operator will be prompted for one.	A-16
Subroutine ATTOUT	This subroutine attaches a file for output by checking the file name directory for the file name and the next available sequence number; then, either the default number will be used or the operator will be prompted for one.	A-18
Subroutine DIROPN	This subroutine attaches the file name directly, looks up the requested entry, and reports the current and next sequence numbers.	A-20
Subroutine DIRCLO	This subroutine updates and closes the file name directory.	A-21
Subroutine COMAND	A four-character command is input from the keyboard and a search is made for a match. If no match is found, all commands are listed out and the routine waits for another input.	A-22

Program Title	Program Descriptor	Page
Subroutine TITLE	This subroutine lists the 40-character title contained in array ITITLE, asks the operator if he wants to change it, and returns with either the old title or a new title as entered by the operator.	A-23
Function NROUND	This function performs integer rounding of a real number, rounding up for a positive, and down for a negative.	A-24
Subroutine DATCHK	This routine checks for a current date; if no current date exists, execution is halted.	A-25
Subroutine DRAW	Plots the x-y data on the display terminal	A-26
Function KEYBRD	This function is used to put the keyboard into a special mode and then checks to see if a (CR) has been pressed.	A-27

```
FORTRAN IV      V01C-03A   TUE 28-NOV-78 20:02:22

0001            PROGRAM BNL1
        C..
        C..     PROGRAM TO DIGITIZE AND STORE
        C..     STEAM GENERATOR TUBE DATA
        C..
        C..     PROGRAMMED SEPT 1978.
        C..     CHIP WILSON
        C..     BATTELLE COLUMBUS LABORATORIES.
        C..
        C..     SPONSORED BY:
        C..     BROOKHAVEN NATIONAL LABORATORY
        C..
0002            REAL*8 XMEAN,YMEAN
0003            DIMENSION VERB(12),IDISP(3500),IXY(4000),ITITL1(10),ITITL2(10),
              $     IDATE(5),WINDOW(2),XCROSS(2),YCROSS(2),ITITL3(10),SIZE(2)
        C..
0004            DATA ITITL1/'  ', 'NO', ' T', 'IT', 'LE', 5*'  '/
0005            DATA ITITL2/'  ', 'NO', ' T', 'IT', 'LE', 5*'  '/
0006            DATA VERB/'DIGI', 'WIND', 'ZM  ', 'HCPY', 'SAVE', 'SIZE',
              $          'TITL', 'STO ', 'DAT ', 3*'EXIT'/
0007            DATA WINDOW, XCROSS, YCROSS/6*0.0/, SIZE/500., 0./
0008            DATA ITWIND/1/, XWIND, YWIND/2*0.0/, NTYPE/0/
0009            DATA IXY/4000*0/, IDATE/5*"20040/
0010            DATA NUM, NUM2, NPAIR/1000, 2*2000/
0011            FACT = FLOAT(NPAIR)/1000.
0012            CALL STVCTR
0013            CALL DATCHK
        C..
        C..     INITIALIZE GRAPHICS AND DRAW BOXES.
        C..
0014            CALL INIT(IDISP, 3500)
0015            CALL SCROL(4, 95)
0016            CALL APNT(10., 125.)
0017            CALL VECT(1000., 0.)
0018            CALL VECT(0., 400.)
0019            CALL VECT(-1000., 0.)
0020            CALL VECT(0., -400.)
0021            CALL VECT(0., 200., 0, -5)
0022            CALL VECT(1000., 0.)
0023            CALL VECT(0., -100., 0, -3)
0024            CALL VECT(-1000., 0.)
0025            CALL VECT(0., 200., 0, -3)
0026            CALL VECT(1000., 0.)
        C..
0027            CALL APNT(50., 550., 0, 5)
0028            CALL VECT(200., 0.)
0029            CALL VECT(0., 200.)
0030            CALL VECT(-200., 0.)
0031            CALL VECT(0., -200.)
0032            CALL VECT(0., 100., 0, -3)
0033            CALL VECT(200., 0.)
0034            CALL VECT(-100., 100., 0, -3)
0035            CALL VECT(0., -200.)
        C..
```

```
       C..   WINDOW SUBPICTURE
       C..
0036         CALL SUBP(100)
0037         CALL APNT(10., 125.)
0038         CALL FIGR(WINDOW, 2, 0, -6)
0039         CALL VECT(0., 400.)
0040         CALL FIGR(SIZE, 2, 0, -6)
0041         CALL VECT(0., -400.)
0042         CALL APNT(0., 225.)
0043         CALL FIGR(YCROSS, 2, 0, -6)
0044         CALL SUBP(101)
0045         CALL VECT(20., 0.)
0046         CALL VECT(-10., -10., 0, -6)
0047         CALL VECT(0., 20.)
0048         CALL ESUB
0049         CALL APNT(0., 425.)
0050         CALL FIGR(XCROSS, 2, 0, -6)
0051         CALL SUBP(102,101)
0052         CALL ESUB
0053         CALL OFF(100)
       C..
       C..   PUT READOUT DATA ON SCREEN
       C..
0054         CALL APNT(300., 700., 0, -5)
0055         CALL TEXT('T=')
0056         CALL NMBR(110, ITWIND, 'I6')
0057         CALL APNT(300., 675., 0, -5)
0058         CALL TEXT('X=')
0059         CALL NMBR(111, XWIND, 'F6.3')
0060         CALL APNT(300., 650., 0, -5)
0061         CALL TEXT('Y=')
0062         CALL NMBR(112, YWIND, 'F6.3')
       C..
       C..   DUMMY SUBPICTURES FOR DATA CURVES
       C..
0063         DO 10 J=90,92
0064         CALL SUBP(J)
0065      10 CALL ESUB
       C..
       C..   WAIT FOR A NEW COMAND
       C..
0066      90 CALL COMAND(VERB, 12, MATCH)
0067         GO TO (100, 200, 300, 400, 500, 600, 700, 800, 900,
           $  1000, 1100, 1200), MATCH
       C..
       C..  'DIGI', DIGITIZE ADC CHANNELS 2 (HOR) & 3 (VERT)
       C..
       C..   SET UP AND ACQUIRE DATA.
0068     100 J = KEYBRD(0)
0069         CALL STRTS(1, 250, IXY, NFAIR, 2, 2, 0)
0070     105 IF(KEYBRD(1) .EQ. 0) GO TO 105
0072         CALL TERM
       C..
       C..   CONVERT DATA FORMAT
```

```
            DO 110 J=1, 2*NPAIR
        110 IXY(J) = (IXY(J) - 2048) * 10
      C..
      C..   ERASE OLD SUBPICTURES.
        115 DO 120 J=90,92
        120 CALL ERAS(J)
            CALL CMPRS
            CALL SUBP(90)
            CALL ESUB
      C..
      C..   PLOT X VS. T
        125 IYOLD = 0
            CALL SUBP(91)
            CALL APNT(9., 425., 0, 5)
            DO 130 J=1,1000
            ISUB = IFIX(FLOAT(J) * FACT) * 2 - 1
            IY = NROUND(FLOAT(IXY(ISUB)) * 4.882813E-3)
            CALL VECT(1., FLOAT(IY - IYOLD))
        130 IYOLD = IY
            CALL ESUB
      C..
      C..   PLOT Y VS. T
            IYOLD = 0
            CALL SUBP(92)
            CALL APNT(9., 225., 0, 5)
            DO 140 J=1,1000
            ISUB = IFIX(FLOAT(J) * FACT) * 2
            IY = NROUND(FLOAT(IXY(ISUB)) * 4.882813E-3)
            CALL VECT(1., FLOAT(IY - IYOLD))
        140 IYOLD = IY
            CALL ESUB
            GO TO 90
      C..
      C..  'WIND', DISPLAY A 200 POINT WINDOW, AND PLOT X VS. Y DATA
      C..
        200 CALL ON(100)
      C..   PUT KEYBOARD IN SPECIAL MODE
            J = KEYBRD(0)
            TYPE 205
        205 FORMAT('$ ENTER <CR> TO DISPLAY X-Y DATA.')
            K = FLOAT(NUM) / FACT
        210 CALL STRTS(3, 10, L, 1, 1, 0, 1)
            CALL TERM
            ITWIND = MIN0(1 + L / 4, 1000 - K)
            MID = ITWIND + K / 2 - 1
            MID1 = FLOAT(MID) * FACT
            XWIND = FLOAT(IXY(MID1 * 2 - 1)) * 4.882813E-5
            YWIND = FLOAT(IXY(MID1 * 2)) * 4.882813E-5
            CALL NMBR(110, MID1, 'I6')
            CALL NMBR(111, XWIND, 'F6.3')
            CALL NMBR(112, YWIND, 'F6.3')
            CALL APUT(WINDOW(1),FLOAT(ITWIND))
            CALL APUT(XCROSS(1), FLOAT(MID))
            CALL APUT(XCROSS(2), XWIND * 100.)
```

POOR ORIGINAL

```
      CALL APUT(YCROSS(1), FLOAT(MID))
      CALL APUT(YCROSS(2), YWIND * 100.)
C..
C..   CHECK FOR <CR>
      IF(KEYBRD(1).EQ.0) GO TO 210
C..
C..   PLOT X-Y DATA
  200 CALL ERAS(90)
      CALL CMPRS
      CALL SUBP(90)
      CALL APNT(150., 650., 0, -5)
      JJ = IFIX(FLOAT(ITWIND) * FACT) * 2 - 1
      CALL DRAW(IXY(JJ), NUM, 100.)
      CALL ESUB
      CALL OFF(100)
      GO TO 9
C..
C..  'ZM  ', ELIMINATE ANY OFFSET IN THE X & Y DATA
C..
  300 JJ = IFIX(FLOAT(ITWIND) * FACT) * 2 - 1
      XMEAN = 0.D0
      YMEAN = 0.D0
  305 DO 310 J= JJ,JJ+NUM2,2
      XMEAN = XMEAN + DBLE(FLOAT(IXY(J)))
  310 YMEAN = YMEAN + DBLE(FLOAT(IXY(J+1)))
      IXM = XMEAN / FLOAT(NUM)
      IYM = YMEAN / FLOAT(NUM)
      DO 320 J=1,2*NPAIR,2
      IXY(J) = IXY(J) - IXM
  320 IXY(J+1) = IXY(J+1) - IYM
      GO TO 115
C..
C..   NOT IMPLEMENTED YET
C..
  400 CONTINUE
      GO TO 90
C..
C..  'SAVE', STORE THE DIGITIZED DATA IN A DISK DATA FILE
C..
  500 J = NTYPE
      IF (J .LE. 0 .OR. J .GT. 2) GO TO 90
C..
      CALL ATTOUT(2,J,0,IDUM)
C..
      CALL DATE(IDATE)
      ENCODE(20, 550, ITITL3) IDATE
  550 FORMAT('DIGITIZED ', 5A2)
      WRITE (2) ITITL1, ITITL2, ITITL3, NUM
      JJ = IFIX(FLOAT(ITWIND) * FACT) * 2 - 1
      WRITE (2) (IXY(J), J = JJ, JJ+NUM2)
      CALL CLOSE(2)
      GO TO 90
C..
C..  'SIZE', LIST OUT DISPLAY BUFFER SIZE
```

```
      C..
0156    600 CALL DPTR(J)
0157        TYPE 605,J
0158    605 FORMAT(' DISPLAY BUFFER SIZE = ', I6)
0159        GO TO 90
      C..
      C..  'TITL', ENTER DATA SET TITLE INFORMATION
      C..
0160    700 CALL TITLE(ITITL1)
0161        CALL TITLE(ITITL2)
0162        GO TO 90
      C..
      C......    'STD ', CHANGE MODE TO STORE ZETEC STANDARD DATA
      C..
0163    800 NTYPE = 1
0164        NUM = 600
0165        GO TO 910
      C..
      C......    'DAT ', CHANGE MODE TO STORE TUBE SUPPORT DATA
      C..
0166    900 NTYPE = 2
0167        NUM = 1200
0168    910 NUM2 = 2 * NUM
0169        CALL APUT(SIZE(1), FLOAT(NUM)/FACT)
0170        GO TO 90
0171   1000 CONTINUE
0172   1100 CONTINUE
      C..
      C..  'EXIT', TERMINATE THE DISPLAY AND EXIT
      C..
0173   1200 CALL FREE
0174        CALL SCROL(32, 744)
0175        CALL EXIT
0176        END
```

```
FORTRAN IV      V01C-03A

          PROGRAM BNL3
    C..
    C..   PROGRAM TO SUBTRACT TUBE SUPPORT DATA
    C..   PATTERNS FROM STEAM GENERATOR TUBE DATA
    C..
    C..   PROGRAMMED SEPT  1978.
    C..   CHIP WILSON  &  DONALD HAYFORD
    C..   BATTELLE COLUMBUS LABORATORIES
    C..
    C..   SPONSORED BY BROOKHAVEN NATIONAL LABORATORY
    C..
          DIMENSION IDAT(2000,3), IDISP(4750), VERB(15), LABELS(11, 4, 4),
         $     SCLFCT(4),XRNG(2), XBEG(2), IADC(2), ICLIPB(3), ICLIPR(3),
         $     ALIN(4)
          DATA NUM/1000/, NUM2/2000/, ICLIPB,ICLIPR/3*1, 3*400/
          DATA VERB/'GETS', 'GETD', 'GGETF', 'SCL ', 'SUB ', 'SIZE',
         $             'MAG ', 'SHFT', 'HCPY', 'EXP ', 'ALIN', 'CLIP',
         $            3 * 'EXIT'/
          DATA LABELS/176 * "20040/, IDAT/6000 * 0/
          DATA SCLFCT/1., 0., 0., 1./, KFLAG/0/
          DATA STD, DAT/'STD', 'DAT'/, IBEG, IRNG/1, 51/
          CALL STVCTR
    C..
    C..   SET UP DISPLAY TERMINAL
          CALL INIT(IDISP,4750)
          CALL SCROL(13,288)
    C..
    C..   READ IN DISPLAY BUFFER.
          CALL RSTR('BNL3D')
    C..
    C..   WAIT FOR A NEW COMMAND.
       90 CALL COMAND(VERB,15,MATCH)
          GO TO (100, 200, 300, 400, 500, 600, 700, 800, 900,
         $          1000, 1100, 1200, 1300, 1400, 1500) , MATCH
    C..
    C.....    'GETS' , INPUT A .STD DATA FILE.
    C.....    'GETD' , INPUT A .DAT DATA FILE.
    C..
      100 DTYPE = STD
          NENTRY = 1
          GO TO 205
      200 DTYPE = DAT
          NENTRY = 2
      205 CALL ASKPIC( IPIC)
          CALL ATTIN(2, NENTRY, 0, IFILE)
          READ (2) ((LABELS(JJ, J, IPIC), JJ=1,10), J=1,3), NUM
          NUM2 = NUM * 2
          READ (2) (IDAT(J, IPIC), J=1,NUM2)
          CALL CLOSE(2)
    C..
          ENCODE(20, 220, LABELS(1, 4, IPIC)) NUM,DTYPE,IFILE
      220 FORMAT(I4, ' PAIRS,', A3, ' F', I4)
    C..
    C..   DISPLAY DATA ON SCREEN.
```

```
  212 CALL ERAS(10 * IPIC)
      CALL CMPRS
      CALL SUBP(10 * IPIC)
      CALL APNT(FLOAT(IPIC*340 - 170), 510.)
      CALL SUBP(40+IPIC, 44)
      CALL DRAW(IDAT(1, IPIC), NUM, 150.)
      CALL ROOT(-120., 234., 2, -5)
C..
C..   PUT LABELS ABOVE DATA PLOTS.
      DO 250 J=1,4
      LABELS(11, J, IPIC) = 0
      CALL TEXT(LABELS(1, J, IPIC) )
  250 CALL ROOT(-240., -24., 0, -5)
      CALL ROOT(120., -138., 2, -5)
      CALL SUBP(65+IPIC, 60+IPIC)
      CALL ESUB
C..
C..   INITIALIZE CLIP LIMITS.
      ICLIPB(IPIC) = 1
      ICLIPR(IPIC) = NUM - 1
      CALL NMBR(50+IPIC, 1, 'I6')
      CALL NMBR(53+IPIC, NUM-1, 'I6')
      GO TO 90
C..
C.....     'GGETF' , READ IN A SCALING FACTORS FILE.
C..
  300 CALL ATTIN(2, 3, 0, IDUM)
      READ (2) ((LABELS(JJ, J, 4), JJ=1,10), J=1,3), SCLFCT(J)
      CALL CLOSE(2)
      TYPE 330, ((LABELS(JJ, J, 4), JJ=1,10), J=1,3), SCLFCT(J)
  330 FORMAT(3(1X, 10A2/), 1X, 4F8.4)
      GO TO 90
C..
C.....     'SCL' , USE SCALING FACTORS READ IN BY 'GGETF'.
C..
  400 CALL ASKPIC(IPIC)
      DO 440 J=1,NUM2-1,2
      ITEMP = NROUND(SCLFCT(1) * FLOAT(IDAT(J, IPIC)) +
     $                SCLFCT(2) * FLOAT(IDAT(J+1, IPIC)))
      IDAT(J+1, IPIC) = NROUND(SCLFCT(3) * FLOAT(IDAT(J, IPIC)) +
     $                         SCLFCT(4) * FLOAT(IDAT(J+1, IPIC)))
  440 IDAT(J, IPIC) = ITEMP
C..
C..   PUT NEW DATA ON SCREEN
      GO TO 210
C..
C.....     'SUB ', SUBTRACT PICTURE 1 FROM PICTURE 2.
C..
  500 DO 520 J=1,NUM2
  520 IDAT(J, 3) = IDAT(J, 2) - IDAT(J, 1)
      IPIC = 3
C..
C..   TITLE NEW PICTURE.
      DO 550 J=1, 4
```

```
            DO 550 JJ=1, 10
        550 LABELS(JJ, J, 3) = "20040
            ENCODE(20, 555, LABELS(1, 2, 3))
        555 FORMAT('  PIC 2 MINUS PIC 1 ')
      C..
      C..   PUT NEW DATA ON SCREEN.
            GO TO 210
      C..
      C.....     'SIZE', LIST OUT DISPLAY BUFFER SIZE
      C.
        600 CALL DPTR(J)
            TYPE 605,J
        605 FORMAT(' DISPLAY BUFFER SIZE =', I6)
            GO TO 90
      C..
      C.....     'MAG ', MAGNIFY ONE PICTURE TO FILL THE SCREEN
      C..
        700 CALL ASKPIC(IPIC)
      C..
      C..   TURN OFF PRESENT DISPLAY AND MOVE THE SCROLLER.
            DO 710 J=10, 40, 10
        710 CALL OFF(J)
            CALL SCROL(2,40)
      C..
      C..   PUT DATA ON SCREEN
            CALL ERAS(100)
            CALL CMPRS
            CALL SUBP(100)
            CALL SUBP(151, 150)
            CALL DRAW(IDAT(ICLIPB(IPIC)*2-1, IPIC), ICLIPR(IPIC), 350.)
            CALL ESUB
      C..
      C..   WAIT FOR A <CR>
            PAUSE
      C..
      C..   RETURN TO THE REGULAR DISPLAY
            CALL DPTR(J)
            TYPE 605,J
            CALL OFF(100)
            DO 770 J=10, 40, 10
        770 CALL ON(J)
            CALL SCROL(13,288)
            TYPE 715
        715 FORMAT('$DO YOU WANT A HARD COPY (Y/N) ? ')
            ACCEPT 720, J
        720 FORMAT(A1)
            IF((J .AND. "177) .NE. "131) GO TO 90
            IPIC = 10
            GO TO 905
      C..
      C.....     'SHFT', TIME SHIFT TO ALIGN PICTURE 2 WITH PICTURE 1.
      C..
        800 TYPE 801
        801 FORMAT('$ENTER SHIFT DISTANCE: ')
```

```
0098          IPIC = 2
0099          READ(5, 802, ERR=800)DSHFT
0100      802 FORMAT(F10.0)
0101          ISHFT = NROUND(DSHFT)
0102          IF(IABS(ISHFT) .GT. NUM/2) GO TO 800
0104          P = DSHFT - FLOAT(ISHFT)
0105          IF(ABS(P) .LT. .001) GO TO 804
0107          P2 = P * P
0108          DO 803 I = 1,2
0109          TEMP1 = FLOAT(IDAT(I,2))
0110          DO 803 J=I+2,NUM2-2,2
0111          TEMP2 = FLOAT(IDAT(J,2))
0112          E = (FLOAT(IDAT(J+2,2)) - TEMP1) / 2.
0113          F = E - TEMP2 + TEMP1
0114          IDAT(J,2) = NROUND(TEMP2 + E * F + F * P2)
0115      803 TEMP1 = TEMP2
0116      804 I2 = 2 * ISHFT
0117          IF (I2) 830, 90, 810
      C..
      C..     SHFT TO THE RIGHT (ISHFT POS.)
0118      810 ITOP = NUM2 - I2
0119          IDAT(NUM2, 2) = IDAT(ITOP, 2)
0120          DO 820 J=1,ITOP-1
0121      820 IDAT(NUM2-J, 2) = IDAT(ITOP-J, 2)
      C..
      C..     FILL THE BEGINNING OF THE ARRAY WITH THE FIRST POINT
0122          DO 825 J=3,I2-1,2
0123          IDAT(J, 2) = IDAT(1, 2)
0124      825 IDAT(J+1, 2) = IDAT(2, 2)
0125          GO TO 210
      C..
      C..     SHIFT TO THE LEFT (ISHFT NEG.).
0126      830 DO 840 J=1,NUM2+I2
0127      840 IDAT(J, 2) = IDAT(J-I2, 2)
0128          I = NUM  - 1
      C..
      C..     FILL THE END OF THE ARRAY WITH THE LAST POINT
0129          DO 845 J=NUM2+I2+1,NUM2-3,2
0130          IDAT(J, 2) = IDAT(I, 2)
0131      845 IDAT(J+1, 2) = IDAT(NUM2, 2)
0132          GO TO 210
      C..
      C......     'HCPY', PLOT A HARD COPY ON THE X-Y PLOTTER.
      C..
0133      900 CALL ASKPIC(IPIC)
0134      905 IF(KFLAG .NE. 0)GO TO 950
0136          CALL INITXY(KFLAG, 2048, 1336)
0137      950 CALL HCPY(IDISP, 10*IPIC)
0138          GO TO 90
      C..
      C......     'EXP '
      C..
0139     1000 CALL ASKPIC(IPIC)
0140          TYPE 1001
```

```
0141     1001 FORMAT('$ENTER SCALE FACTOR:  ')
0142          ACCEPT 1002, F
0143     1002 FORMAT(F10.0)
0144          DO 1003 J=1,NUM2
0145          RIDAT = FLOAT(IDAT(J,IPIC)) * F
0146          IF(ABS(RIDAT) .GT. 2.E4) RIDAT = SIGN(2.E4, RIDAT)
0148     1003 IDAT(J,IPIC) = RIDAT
0149          GO TO 210
       C..
       C.....     'ALIN', ALIGN Y2 WITH Y1.
       C..
0150     1100 DO 1101 J=10,30,10
0151     1101 CALL OFF(J)
       C..
       C..    CREATE VERTICAL BAR AND READOUTS.
0152          CALL SUBP(110)
0153          CALL APNT(0., 360., 0, -6)
0154          ALIN(2) = 0.0
0155          ALIN(1) = 0.0
0156          CALL FIGR(ALIN, 2, 0, -6)
0157          CALL VECT(0., 420.)
0158          CALL APNT(0., 336., 0, -5)
0159          CALL NMBR(111, 0., 'I10')
0160          CALL NMBR(112, 0., 'F10.3')
0161          CALL RDOT(150., 0., 1, -6)
0162          CALL SUBP(113)
0163          CALL TEXT('MAG')
0164          CALL ESUB
0165          CALL RDOT(50., 0., 1, -6)
0166          CALL SUBP(114)
0167          CALL TEXT('END')
0168          CALL ESUB
0169          CALL APNT(0., 560., -1, -4)
0170          CALL VECT(1000., 0.)
0171          CALL ESUB
0172          IB1 = 1
0173          IR1 = NUM - 1
0174          IB2 = 1
0175          IR2 = NUM - 1
0176          DINC = 2.
0177          INCSUB = 2
0178          OLDSH = 0.
       C..
       C..    PLOT Y1 VS. TIME AND Y2 VS. TIME.
0179     1140 CALL ERAS(100)
0180          CALL CMPRS
0181          CALL SUBP(100)
0182          IYOLD = IDAT(2*IB1, 1) / 100
0183          CALL APNT(0., FLOAT(560 + IYOLD), 0, -5)
0184          DO 1150 J=2*IB1,(IB1+IR1)*2,INCSUB*2
0185          IY = IDAT(J, 1) / 100
0186          CALL VECT(DINC, FLOAT(IY - IYOLD))
0187     1150 IYOLD = IY
       C..
```

```
      IYOLD = IDAT(2*IB2, 2) / 100
      CALL APNT(0., 560. + FLOAT(IYOLD), 0, -4)
      ALIN(3) = 0.0
      ALIN(4) = 0.0
      CALL FIGR(ALIN(3), 2, 0, -5)
      DO 1160 J=2*IB2, (IB2+IR2)*2,INCSUB*2
      IY = IDAT(J, 2) / 100
      CALL VECT(DINC, FLOAT(IY - IYOLD))
 1160 IYOLD = IY
      CALL ESUB
 1170 CALL STRTS(3, 12, IADC, 1, 2, 0, 1)
      CALL TERM
      IVERT = MIN0(IADC(1)/8, 499, IR2 * IFIX(DINC))
      ISHFT = MAX0(-499, MIN0((IADC(2)-2048)/4, 499))
      CALL APUT(ALIN(1), FLOAT(IVERT))
      CALL APUT(ALIN(3), FLOAT(ISHFT))
C..
      SHFT = OLDSH + FLOAT(ISHFT * INCSUB)/DINC
      CALL NMBR(112, SHFT, 'F12.3')
      II = IB1 + NROUND(FLOAT(IVERT * INCSUB) / DINC)
      CALL NMBR(111, II, 'I10')
C..
      CALL LPEN(M, ITAG)
      IF(M .EQ. 0) GO TO 1170
      IF(ITAG .EQ. 113) GO TO 1180
      IF(ITAG .NE. 114) GO TO 1170
C..
C..   END ALIGN COMMAND
      CALL ERAS(110)
      CALL OFF(100)
      CALL CMPRS
      DO 1175 J=10,30,10
 1175 CALL ON(J)
      TYPE 1176, SHFT
 1176 FORMAT(' SHIFT VALUE: ', F10.4)
      GO TO 90
C..
C..   MAGNIFY DATA PAST VERTICAL BAR.
 1180 IR1 = IR1 / 2
      IB2 = MIN0(MAX0(1,IB2+NROUND(FLOAT((IVERT-ISHFT)*INCSUB)/DINC)),
     $     NUM-1)
      IR2 = MIN0(IR1, NUM-IB2)
      IB1 = II
      DINC = DINC / FLOAT(INCSUB) * 2.
      INCSUB = 1
      OLDSH = NROUND(SHFT)
      GO TO 1140
C..
C.....    'CLIP', CLIP LEADING AND TRAILING EDGES OF PICTURES.
C..
 1220 CALL ASKPIC(IPIC)
      J = KEYBRD(0)
      TYPE 1222
 1222 FORMAT('$ENTER <CR> TO CONTINUE')
```

```
0235     1221 IF(KEYBRD(1) .NE. 0) GO TO 92
0237          CALL STRTS(3, 10, IADC, 1, 2, 2, 1)
0238          CALL TERM
0239          IBEG = MIN0(IADC(1) / 4 + 1, NUM - 1)
0240          IEND = MIN0(IADC(2) / 4 + 1, NUM-IBEG) + IBEG
0241          CALL NMBR(50+IPIC, IBEG,'I6')
0242          CALL NMBR(53+IPIC, IEND-IBEG, 'I6')
0243          ICLIPB(IPIC) = IBEG
0244          ICLIFR(IPIC) = IEND - IBEG
      C..
0245          CALL GETTAG(IDISP, 10*IPIC, MADDR)
      C..
      C..     SEARCH FOR FIRST VECT OR LVECT MODE WORD.
0246          DO 1205 J=1,1000
0247          ITEMP = IPEEK(MADDR) .AND. "174000
0248          IF(ITEMP .EQ. "104000  .OR.  ITEMP .EQ. "110000) GO TO 1210
0250     1205 MADDR = MADDR + 2
      C..
0251     1210 ITEMP = IPEEK(MADDR)
0252          IF(ITEMP .GE. 0) GO TO 1240
0254          ITEMP = (ITEMP .AND. "74000) / "4000
0255          IF(ITEMP .LE. 0 .OR. ITEMP .GT. 2) GO TO 1221
0257          INC = ITEMP * 2
0258          GO TO 1270
      C..
0259     1240 IBEG = IBEG - 1
0260          IEND = IEND - 1
0261          IF(IBEG .LE. 0) GO TO 1260
0263     1250 J = IPOKE(MADDR, IPEEK(MADDR) .AND. "137777)
0264          GO TO 1270
0265     1260 IF(IEND .LE. 0) GO TO 1250
0267          J = IPOKE(MADDR, IPEEK(MADDR) .OR. "40000)
0268     1270 MADDR = MADDR + INC
0269          GO TO 1210
      C..
      C..     NOT PROGRAMMED YET
      C..
0270     1300 CONTINUE
0271     1400 CONTINUE
      C..
      C.....     'EXIT'
      C..
0272     1500 CALL SCROL(32, 744)
0273          IF(KFLAG .NE. 0) CALL ENDXY
0275          CALL FREE
0276          CALL EXIT
0277          END
```

```
FORTRAN IV      V01C-03A

0001          SUBROUTINE ASKPIC(N)
      C..
      C..     THIS ROUTINE PROMPTS THE OPERATOR FOR A PICTURE NUMBER.
      C..
      C..     A RESPONSE OTHER THAN 1, 2, OR 3 IS INVALID.
      C..
0002        5 TYPE 10
0003       10 FORMAT('$PICTURE #: ')
0004       20 READ(5, 30, ERR = 5) N
0005       30 FORMAT(I10)
0006          IF(N .LE. 0  .OR.  N .GT. 3) GO TO 5
0008          RETURN
0009          END
```

```
      PROGRAM BNL3D
C..
C..   PROGRAM TO GENERATE A DISPLAY BUFFER TO BE USED BY
C..   PROGRAM BNL3.
C..
C..   PROGRAMMED SEPT  1978.
C..   CHIP WILSON  &  DONALD HAYFORD
C..   BATTELLE COLUMBUS LABORATORIES
C..
C..   SPONSORED BY BROOKHAVEN NATIONAL LABORATORY
C..
      DIMENSION IDISP(500)
      CALL INIT(IDISP,500)
C..
      CALL SUBP(95)
      CALL ESUB
C..
      CALL SUBP(44)
      CALL BOX(150.)
      CALL ESUB
      CALL OFF(44)
C..
C..   GENERATE NULL SUBPICTURES FOR PLOTS 1, 2, & 3.
      DO 10 J=1,3
      CALL SUBP(J *10)
      CALL APNT(FLOAT(J*340 - 170), 510.)
      CALL SUBP(40+J, 44)
   10 CALL ESUB
C..
C..   CREATE CLIP READOUT SUBPICTURES.
      DO 20 J=1,3
      CALL SUBP(60+J)
      CALL ROOT(-84., -180., 0, -5)
      CALL NMBR(50+J, 1, 'I6')
      CALL NMBR(53+J, NUM)
      CALL ESUB
   20 CALL OFF(60+J)
C..
C..   GENERATE DASHED LINE ABOVE SCROLLER.
      CALL SUBP(40)
      CALL APNT(0., 321., 0, -5)
      CALL VECT(1023., 0., 0, 0, 0, 2)
      CALL ROOT(0., 0., 0, -5, 0, 1)
      CALL ESUB
C..
C..   CREATE A LARGE BOX.
      CALL SUBP(150)
      CALL APNT(500., 415.)
      CALL BOX(350.)
      CALL ESUB
      CALL OFF(150)
C..
C..   SAVE DISPLAY BUFFER ON DISK.
      CALL SAVE('BNL3D')
```

```
FORTRAN IV        V01C-03A   TUE 28-NOV-78 02:04:11

      C..
0033         CALL EXIT
0034         END
```

```
FORTRAN IV      V01C-03A   TUE 28-NOV-78 20:01:15

C..
C..   BNLSUB.FOR
C..
C..                        PROGRAMMED BY CHIP WILSON
C..                     BATTELLE COLUMBUS LABORATORIES
C..
      SUBROUTINE ATTIN(LUN, NENTRY, IFLAG, IOPEN)
C..
C..    THIS SUBROUTINE ATTACHES A FILE FOR INPUT BY
C..   CHECKING THE FILE NAME DIRECTORY FOR THE FILENAME
C..   AND DEFAULT SEQUENCE NUMBER. EITHER THE DEFAULT
C..   WILL BE USED OR THE OPERATOR WILL BE PROMPTED FOR
C..   ONE.
C..
C..   INPUT PARAMETERS:
C..
C..   LUN -- LOGICAL UNIT NUMBER TO BE USED FOR
C..          THE FILE TO BE ATTACHED.
C..
C..   NENTRY -- NUMBER FOR THE DIRECTORY ENTRY
C..          TO BE OPENED.
C..
C..   IFLAG -- =0  PROMPT OPERATOR FOR SEQUENCE NO.
C..            =-1  USE DEFAULT VALUE
C..            .GT. 0  USE IFLAG AS CURRENT FILE NUMBER
C..
C..   OUTPUT PARAMETERS
C..
C..   IOPEN -- SET EQUAL TO THE SEQUENCE NO.
C..             OF THE FILE OPENED.
C..
      LOGICAL*1 STRING(42)
      COMMON/FILNAM/ LUNUM, N, STRING, ICUR, INEXT, IAV
      LUNUM = LUN
      N = NENTRY
C..
C..   ATTACH THE FILE NAME DIRECTORY.
C..
      CALL DIROPN
      I = IFLAG
      IF(IFLAG) 100, 35, 50
C..
C..   USE CURRENT FILE SEQUENCE NUMBER?
C..
 35   TYPE 40, (STRING(I), I=12, 14), ICUR
 40   FORMAT('$OPEN ', 3A1, ' FILE #', I3, ' ? ')
      READ(5, 30, ERR=35) I
 30   FORMAT(I10)
      IF(I .LT. 0  .OR.  I .GT. 999) GO TO 35
      IF(I .EQ. 0) I = ICUR
 50   ICUR = I
      CALL DIRCLO
      GO TO 150
 120  CALL CLOSE(LUNUM)
```

```
      C..
      C..    OPEN THE FILE.
      C..
0021   150   IF(IFLAG .NE. 0) TYPE 62, (STRING(I),I=12,14), ICUR
0023    62   FORMAT(' ', 3A1, ' FILE #', I3, ' OPENED.')
0024         CALL ASSIGN(LUNUM, STRING, 14, 'OLD')
0025         IOPEN = ICUR
0026         RETURN
0027         END
```

```
0001          SUBROUTINE ATTOUT(LUN, NENTRY, IFLAG, INEW)
        C..
        C..    THIS SUBROUTINE ATTACHES A FILE FOR OUTPUT
        C..   BY CHECKING THE FILE NAME DIRECTORY FOR THE
        C..   FILENAME AND THE NEXT AVAILABLE SEQUENCE
        C..   NUMBER; THEN, EITHER THE DEFAULT NUMBER WILL
        C..   BE USED OR THE OPERATOR WILL BE PROMPTED FOR
        C..   ONE.
        C..
        C..   INPUT:
        C..
        C..   LUN -- LOGICAL UNIT NUMBER FOR THE FILE
        C..          TO BE ATTACHED.
        C..
        C..   NENTRY -- THE DIRECTORY TO BE OPENED.
        C..
        C..   IFLAG -- =0  PROMPT OPERATOR FOR SEQ. NO.
        C..            =-1  USE NEXT AVAILABLE SEQ. NO.
        C..  .GT. 0  USE IFLAG AS FILE SEQ. NO.
        C..   OUTPUT:
        C..
        C..   INEW -- EQUAL TO THE SEQUENCE NO. OF FILE OPENED.
        C..
0002          LOGICAL*1 STRING(42)
0003          COMMON/FILNAM/ LUNUM, N, STRING, ICUR, INEXT, IAV
0004          LUNUM = LUN
0005          N = NENTRY
        C..
        C..   ATTACH THE FILE NAME DIRECTORY.
        C..
0006          CALL DIROPN
0007          I = IFLAG
0008          IF(IFLAG) 100, 35, 50
        C..
        C..   USE NEXT SEQUENCE NUMBER?
        C..
0009     35   TYPE 40, (STRING(I), I=12, 14), INEXT
0010     40   FORMAT('$SAVE AS ', 3A1, ' FILE #', I3, ' ? ')
0011          READ(5, 30, ERR=35) I
0012     30   FORMAT(I10)
0013          IF(I .LT. 0  .OR.  I .GT. 999) GO TO 35
0015      50  ICUR = I
0016          IF((I .NE. 0) .AND. (I .NE. INEXT)) GO TO 150
        C..
        C..   USE NEXT AVAILABLE SEQUENCE NUMBER.
        C..
0018    100   ICUR = INEXT
0019          INEXT = INEXT + 1
0020    150   IF(IFLAG .NE. 0) TYPE 60, (STRING(I), I=12,14), ICUR
0022     60   FORMAT(' SAVE AS ', 3A1, ' FILE #', I3, '.')
0023          CALL DIRCLO
0024          CALL ASSIGN(LUN, STRING, 14, 'NEW')
0025          INEW = ICUR
0026          RETURN
```

```
FORTRAN IV      V01C-03A   TUE 28-NOV-78 22:21:17

0027         END
```

```
FORTRAN IV      V01C-03A   TUE 28-NOV-78 00:01:20

0001          SUBROUTINE DIROPN
      C..
      C..      THIS SUBROUTINE ATTACHES THE FILE NAME DIRECTORY,
      C..     LOOKS UP THE REQUESTED ENTRY, AND REPORTS THE
      C..     CURRENT AND NEXT SEQUENCE NUMBERS.
      C..
      C..     INPUT:
      C..
      C..     LUNUM -- LOGICAL UNIT NUMBER.
      C..
      C..     NENTRY -- DIRECTORY ENTRY TO BE OPENED.
      C..
      C..     OUTPUT:
      C..
      C..     STRING -- ARRAY CONTAINING THE FILE NAME.
      C..
      C..     ICUR -- CURRENT SEQUENCE NUMBER.
      C..
      C..     INEXT -- NEXT SEQUENCE NUMBER.
      C..
0002          LOGICAL*1 STRING(42), DUM1(3), DUM2(3)
      C..
0003          COMMON/FILNAM/ LUNUM, NENTRY, STRING, ICUR, INEXT, IAV
      C..
0004          EQUIVALENCE (DUM1(1), STRING(8)), (DUM2(1), STRING(16))
      C..
      C..
      C..     ATTACH THE FILE NAME DIRECTORY.
      C..
0005          CALL ASSIGN(LUNUM, 'BNLBNL.DIR', 10)
0006          DEFINE FILE LUNUM(4, 21, U, IAV)
0007          IAV = NENTRY + 1
      C..
      C..     READ IN THE REQUESTED ENTRY.
      C..
0008          READ(LUNUM'IAV) STRING
      C..
      C..     DETERMINE CURRENT AND NEXT AVAILABLE SEQ. NO.
      C..
0009          DECODE (3, 30, DUM1) ICUR
0010          DECODE (3, 30, DUM2) INEXT
0011     30   FORMAT(I3)
0012          RETURN
0013          END
```

```
0001            SUBROUTINE DIRCLO
          C..
          C..    THIS SUBROUTINE UPDATES AND CLOSES THE FILE
          C..   NAME DIRECTORY.
          C..
          C..   INPUT:
          C..
          C..   LUNUM -- LOGICAL UNIT NUMBER.
          C..
          C..   NENTRY -- DIRECTORY ENTRY TO BE UPDATED.
          C..
          C..   STRING -- ARRAY CONTAINING THE FILENAME.
          C..
          C..   ICUR -- CURRENT SEQUENCE NUMBER.
          C..
0002            LOGICAL*1 STRING(42), DUM1(3), DUM2(3), DUM3, DUM4
          C..
0003            COMMON/FILNAM/ LUNUM, NENTRY, STRING, ICUR, INEXT, IAV
          C..
0004            EQUIVALENCE (DUM1(1), STRING(8)), (DUM2(1), STRING(16))
          C..
          C..
          C..   ENCODE ICUR AND INEXT INTO STRING
          C..
          C..
0005            DUM3 = STRING(11)
0006            ENCODE (3, 30, DUM1) ICUR
0007            STRING(11) = DUM3
          C..
0008            DUM3 = STRING(19)
0009            ENCODE (3, 30, DUM2) INEXT
0010            STRING(19) = DUM3
          C..
0011       30   FORMAT(I3)
          C..
          C..   CONVERT BLANKS TO ZEROS.
          C..
0012            IF(STRING(8)  .EQ. "040) STRING(8)   = "060
0014            IF(STRING(9)  .EQ. "040) STRING(9)   = "060
0016            IF(STRING(16) .EQ. "040) STRING(16) = "060
0018            IF(STRING(17) .EQ. "040) STRING(17) = "060
0020            IAV = NENTRY + 1
          C..
          C..   UPDATE DIRECTORY ENTRY AND CLOSE IT.
          C..
0021            WRITE(LUNUM'IAV) STRING
0022            CALL CLOSE(LUNUM)
0023            RETURN
0024            END
```

```
FORTRAN IV        V01C-03A    TUE 28-NOV-78 22:01:24

0001          SUBROUTINE COMAND(ARRAY, ISIZE, MATCH)
        C..
        C..   PROGRAMMED BY CHIP WILSON.
        C..
        C..    A FOUR CHARACTER COMMAND IS INPUT FROM THE
        C..   KEYBOARD AND A SEARCH IS MADE FOR A MATCH.
        C..   IF NO MATCH IS FOUND, ALL COMMANDS ARE LISTED OUT
        C..   AND THE ROUTINE WAITS FOR ANOTHER INPUT.
        C..
        C..   INPUT -
        C..     ARRAY -- ARRAY OF COMMANDS TO BE CHECKED.
        C..     ISIZE -- NUMBER OF COMMANDS TO BE CHECKED.
        C..
        C..   OUTPUT -
        C..     MATCH -- ARRAY SUBSCRIPT WHERE MATCH OCCURED.
        C..
0002          DIMENSION ARRAY(1)
0003        3 TYPE 50
0004       50 FORMAT( /, '$COMMAND: ')
0005          READ(5, 110, ERR=3) REPLY
0006      110 FORMAT(A4)
0007          DO 10 MATCH=1, ISIZE
0008     10   IF(ARRAY(MATCH) .EQ. REPLY) RETURN
0010          TYPE 210, (ARRAY(I),I = 1, ISIZE)
0011      210 FORMAT ('+', A4, 10(', ', A4) )
0012          GO TO 3
0013          END
```

```
FORTRAN IV      V21C-03A   TUE 28-NOV-78 00:01:27

0001          SUBROUTINE TITLE( ITITLE)
        C..
        C..   PROGRAMMED BY CHIP WILSON.
        C..
        C..   THIS SUBROUTINE LISTS THE 40 CHARACTER TITLE CONTATNED IN
        C..   ARRAY ITITLE, ASKS THE OPERATOR IF HE WANTS TO CHANGE IT,
        C..   AND RETURNS WITH EITHER THE OLD TITLE OR A NEW TITLE AS
        C..   ENTERED BY THE OPERATOR.
        C..
0002          LOGICAL*1 ITITLE(20), ANS
        C..
0003          TYPE 200, ITITLE
0004     200  FORMAT(' PRESENT TITLE:  >', 20A1, '<', /, '$NEW TITLE (Y/N)? ')
0005          ACCEPT 210, ANS
0006     210  FORMAT( 20A1)
0007          IF( ANS .NE. "131) RETURN
0009          DO 300 J=1,20
0010     300  ITITLE(J) = "040
0011          TYPE 350
0012     350  FORMAT('$ENTER NEW TITLE: ')
0013          ACCEPT 210, ITITLE
0014          RETURN
0015          END
```

```
FORTRAN IV      V01C-03A   TUE 28-NOV-78 00:01:29

0001            FUNCTION NROUND(A)
        C..
        C..     THIS FUNCTION PERFORMS INTEGER ROUNDING OF A REAL
        C..     NUMBER, ROUNDING UP FOR POSITIVE , AND DOWN FOR NEGATIVE
        C..
0002            NROUND = IFIX(A + SIGN(0.5, A))
0003            RETURN
0004            END
```

```
FORTRAN IV      V01C-03A   TUE 28-NOV-78 00:01:21

0001            SUBROUTINE DATCHK
        C..
        C..     THIS ROUTINE CHECKS FOR A CURRENT DATE
        C..     IF NO CURRENT DATE EXISTS, EXECUTION IS HALTED
        C..
0002            LOGICAL*1 L(9)
0003            CALL DATE(L)
0004            IF(L(1) .NE. "262  .OR.  L(2) .NE. "060) RETURN
0006            TYPE 10
0007         10 FORMAT(' PLEASE ENTER DATE DD-MMM-YY')
0008            CALL EXIT
0009            END
```

```
FORTRAN IV      V01C-03A   TUE 28-NOV-78 00:21:33

             SUBROUTINE DRAW(IXY, NPAIR, FS)
       C..
       C..   PLOT THE X-Y DATA ON THE DISPLAY TERMINAL.
       C..
       C..   IXY   -  ARRAY CONTAINING PAIRS OF X-Y POINTS WITH
       C..              A FULL SCALE VALUE OF +/- 20480.
       C..   NPAIR -  NUMBER OF PAIRS OF X-Y POINTS.
       C..   FS    -  FULL SCALE SIZE OF PLOT IN SCREEN UNITS
       C..
       C..   THE CENTER OF THE PLOT IS TAKEN AS THE CURRENT SCREEN
       C..   POSITION.      THE DISPLAY BEAM IS LEFT IN THE CENTER
       C..   OF THE PLOT AT COMPLETION.
       C..
             DIMENSION IXY(1)
       C..
       C..   ASSIGNMENT STATEMENT FOR CONVERSION
             ICONV(I) = NROUND(FLOAT(I) * FACT)
       C..
             FACT = FS / 20480.
             IXOLD = ICONV(IXY(1))
             IYOLD = ICONV(IXY(2))
             CALL ROOT(FLOAT(IXOLD), FLOAT(IYOLD),0,-5)
             DO 100 J=3,2*NPAIR-1,2
             IX = ICONV(IXY(J))
             IY = ICONV(IXY(J+1))
             CALL VECT(FLOAT(IX - IXOLD), FLOAT(IY - IYOLD))
             IXOLD = IX
         100 IYOLD = IY
             CALL ROOT(FLOAT(-IX), FLOAT(-IY), 0, -5)
             RETURN
             END
```

```
FORTRAN IV      V01C-03A   TUE 28-NOV-78 20:21:35

0001            FUNCTION KEYBRD(MODE)
          C..
          C..   THIS FUNCTION IS USED TO PUT THE KEYBOARD INTO
          C..   A SPECIAL MODE AND THEN CHECK TO SEE IF A <CR>
          C..   HAS BEEN PRESSED
          C..
          C..   MODE = 0 -- SET KEYBOARD TO SPECIAL MODE
          C..   MODE = 1 -- CHECK FOR CARRIAGE RETURN. IF YES, CLEAR
          C..                SPECIAL MODE, AND RETURN WITH KEYBRD = 1.
          C..                IF NO, RETURN WITH KEYBRD = 0.
0002            GO TO (100, 200), MODE + 1
0003        100 J = IPOKE("44, IPEEK("44) + "100)
0004            RETURN
0005        200 KEYBRD = 0
0006            IF(ITTINR( ) .LT. 0) RETURN
0008            KEYBRD = 1
0009            J = IPOKE("44, IPEEK("44) - "100)
0010            RETURN
0011            END
```

DISTRIBUTION LIST

Battelle-Columbus Laboratories (50)

BNL Corrosion Science Group (50)

Nuclear Regulatory Commission (OSD) (50)