BNWL-765

3-

5-28-68

MULTICHANNEL EDDY CURRENT
TUBING TESTER

H. L. Libby
C. R. Wandling

MAY 28, 1968

AEC RESEARCH &
DEVELOPMENT REPORT

ROUTE TO	P. R. NO.	LOCATION	FILED ROUTE DATE
<i>Sandwich Metals</i>	<i>60017</i>	<i>Per Wash</i>	
<i>for T. D. Mayhew</i>			
<i>P. J. Davis</i>	<i>32866</i>	<i>326</i>	

BATTELLE

NORTHWEST

BATTELLE MEMORIAL INSTITUTE

PACIFIC NORTHWEST LABORATORY

BATTELLE BOULEVARD, P. O. BOX 999, RICHLAND, WASHINGTON 99352

BNWL-765

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

PACIFIC NORTHWEST LABORATORY

RICHLAND, WASHINGTON

operated by

BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

PRINTED BY/ FOR THE U. S. ATOMIC ENERGY COMMISSION

3 3679 00061 3275

uc-37

MULTICHANNEL EDDY CURRENT TUBING TESTER

by

H. L. Libby and C. R. Wandling

May 28, 1968

FIRST UNRESTRICTED
DISTRIBUTION MADE

JUL 3 '68

PACIFIC NORTHWEST LABORATORIES
A Division of
Battelle Memorial Institute
P.O. Box 999
Richland, Washington 99352

LIST OF FIGURES

	<u>Page</u>
1(a) Multichannel Tester Set Up For Operation. Test Probe in Tube at Center	5
1(b) Transceiver Section Panel	6
1(c) Computer (Analyzer) Section Panel	7
2 Multichannel Eddy Current Tubing Tester Block Diagram	9
3 Analyzer Section, Functional Diagram	11
4 Eddy Current Test Signals, Phase Discrimination, Single Frequency Test	14
5 Eddy Current Test Signals, Two Frequency System	16
6 Flow Diagram Showing Successive Elimination of Parameters, Three Parameter Case	20
7 Test Specimen	24
8 Test Results for Tube Showing Comparison of Single Frequency and Two Frequency Modes of Operation	26
9 Transceiver Section - Schematic Diagram	27
10 Analyzer (Computer) Section - Schematic Diagram	28

ABSTRACT

MULTICHANNEL EDDY CURRENT TUBING TESTER

by

H. L. Libby and C. R. Wandling

A two channel, two frequency, eddy current, tubing nondestructive test device is described in which the undesirable effect of test probe wobble signals is reduced on both channels. A novel analyzer circuit or signal transformation section is used for the successive elimination of parameters. The tester is flexible in operation and can be operated using either of its two test frequencies, 100 kHz and 300 kHz singly, or both simultaneously. When operated in its single frequency modes, two test parameters, for example probe wobble, and the presence of defects giving signals having components in quadrature with probe wobble signals may be separated.

When operated in its two frequency mode the effects of one test parameter can be minimized and the effects of two other test parameters may be read out. Instrument test results for the two frequency mode of operation are shown in which probe wobble signals are minimized on both of the two output channels and signals due to defects opening on the inner wall of the tubular test specimen appear on one channel, and signals due to defects opening on the outer wall of the specimen appear on the other channel.

MULTICHANNEL EDDY CURRENT TUBING TESTER

by

H. L. Libby and C. R. Wandling

Introduction

This report describes a two channel, two frequency eddy current tubing tester in which the undesirable effect of test probe wobble signals is reduced in both channels by application of multiparameter test principles.

A two channel, single frequency eddy current tubing tester system⁽¹⁾ previously developed at Hanford provided two output data displays: (1) an oscilloscope display giving signal patterns for various tubing conditions, and (2) a two channel strip chart record giving a permanent record of the instrument output. The oscilloscope was found to be useful in relating test signals to specific tubing test conditions, and the chart record made it possible to reconstruct some significant features of the signal patterns at a later time without resorting to photographing the oscilloscope patterns at the time of the test.

The undesirable effect of probe wobble was reduced in one channel by means of a phase discrimination technique, but as is typical in a single frequency system, the effect of probe wobble appeared in the other channel and when present could interfere with signal interpretation.

-2-

In the multichannel eddy current tester the additional information required for reducing the undesired probe wobble signals in each channel simultaneously is obtained by using two test frequencies and applying multiparameter test principles.^(2,3)

Summary and Conclusions

A two channel, two frequency, eddy current tubing nondestructive test device has been developed in which the undesirable effect of test probe wobble signals is reduced on both channels. The signal display and two channel chart record features of a previously developed eddy current tubing tester have been retained as aids in defect signal interpretation, and multiparameter techniques are used to reduce the effects of probe wobble signals on both output channels. A novel analyzer circuit or signal transformation section is used for the successive elimination of parameters. This first model was designed for use in examination of stainless steel tubing and uses two test frequencies 100 kHz and 300 kHz, simultaneously. The new tester is flexible in operation and can also be operated using either of the two test frequencies separately. When operated in its two frequency mode, it has the capability of minimizing the effects of one test parameter in its output and to read out the effects of two other parameters separately. Performance of the tester in minimizing the effects of two parameters is under study but a discussion of this mode of operation is beyond the scope of this report.

The signal display feature of the new tester, when operated in the two frequency mode, is less effective for estimating depth of defects opening onto the tubing surface adjacent to the test coil assembly than it is when operated in its signal frequency modes. Ambiguity of pattern angle as a function of surface defect depth and defect size requires further study.

Although this report is centered around the use of the device as a tubing tester using an inside test coil assembly it can also be used with a variety of other eddy current test coil designs including encircling and probe types.

Discussion

A two channel, single frequency eddy current tubing test system⁽¹⁾ with signal pattern display and two channel strip chart record features has previously proved useful in examination of stainless steel tubing under conditions where the enhanced signal interpretation aids were needed. However, in operation useful signal components on the second channel were sometimes masked by signals due to wobble between the probe and tubing. The multichannel tester described in this report was developed to retain features of the tester with signal pattern display and to reduce the undesired effect of probe-to-tubing wobble on the output signals. This was done by applying the multiparameter eddy current test principles. The new tester is the first eddy current tester made for field use using the multiparameter or multidimensional concepts.

Description of Instrument

The multichannel tester set up for operation is shown in Figure 1(a). The tester consists of four parts: (1) a transmitter-receiver (transceiver) section mounted in a carrying case, (2) a test probe and connecting cable, (3) a computer (analyzer) section mounted in a second carrying case which has a compartment for stowing cables and probes, and (4) signal display accessories which include an X-Y oscilloscope and two channel strip chart recorder.

The function of the transceiver section is to drive the test coils at the two test frequencies simultaneously and to determine the values of the coefficients of the Fourier series expansion of the test coil output signal.

The transceiver section, shown separately in Figure 1(b), has dual controls, one set for the 100 kHz channel and a second set for the 300 kHz channel. The main controls of this section and their locations are the bridge balance controls at the upper left, the amplifier gain switches at the upper right, and the detector DC balance controls at right center.

The function of the test coil assembly is to couple the transceiver section to the test specimen so that variations in its electrical characteristics can be monitored. The function of the analyzer section shown in Figure 1(c), is to transform the test coil output signal (represented at the analyzer input by the Fourier coefficients) into a new signal in which the effects of probe wobble are reduced, and in which the components of the signal due to defects opening onto the inner wall of the test specimen appear on one channel output, and the components of the signal due to defects opening onto the outer surface appear on a second channel. This is accomplished by constructing linear combinations of the Fourier coefficients. The principles of this technique are described under Principles of Operation.

FIGURE 1(a). Multichannel Tester Set up for Operation. Test Probe in Tube at Center

FIGURE 1(a). Multichannel Tester Set up for Operation. Test Probe in Tube at Center

FIGURE 1(b). Transceiver Section Panel

FIGURE 1(c). Computer (Analyzer) Section Panel

The controls of the analyzer section are grouped in four columns. The summing potentiometer controls are in the first three columns having 6, 4, and 4 controls in the respective columns. The two controls in the last column are the output channel gain controls. Two multipoint switches are provided to connect various points in the circuit to monitor output connectors for use in calibration and auxiliary display. Three additional switches, labeled AC-DC are provided so that either the main outputs of the instrument or the monitor outputs may have the DC component blocked. This permits an approximate differentiation of the output signals which is desirable for some applications.

The transceiver and analyzer sections have their own 110v ac power supply and each is equipped with an ON-OFF switch.

Circuit Description

The circuit arrangement can be explained best by referring to the block diagram shown in Figure 2. The test coil assembly is driven simultaneously at two frequencies, 100 kHz and 300 kHz, obtained through the part of the circuit containing the 100 kHz oscillator A, the tripler B, the two automatic gain control circuits C and D, the summing circuit E, and the bridge driver amplifier F. The bridge circuit has three branches: (1) the test coil assembly G, and connecting cable H, (2) the 100 kHz balance circuit I and (3) the 300 kHz balance circuit J. The outputs of the two balance circuits are fed to their respective amplifiers K and L and phase detectors M and N. The 100 kHz phase detector reference signal is obtained from the 100 kHz oscillator A, and the 300 kHz reference signal is obtained from the tripler B.

FIGURE 2. Multichannel Eddy Current Tubing Tester Block Diagram

-10-

The outputs c_1 , c_2 , c_3 , and c_4 of the phase detectors constitute the main output of the transceiver section, and are fed to the analyzer or computer section 0.

A functional diagram of the analyzer section 0 is shown in Figure 3. Here the outputs c_1 , c_2 , c_3 , and c_4 of the phase detectors are inputs to the analyzer although the detector outputs are not necessarily always connected to the correspondingly labeled input terminals of the analyzer section. The summing circuits are arranged in Figure 3 in three columns corresponding to the positions of the summing potentiometer controls on the panel. Each summing potentiometer R is driven by two operational amplifiers, not shown in Figure 3, so that both positive and negative signals are available as desired for the summing operation. The effects of four selected parameters, p_1 , p_2 , p_3 , and p_4 to be separated are generally available in the signals c_1 , c_2 , c_3 , and c_4 as indicated by the p_1 , p_2 , p_3 , and p_4 designation on these signal leads in the diagram. Since this instrument reads out two parameters, for example p_3 and p_4 , the effects of the parameters p_1 and p_2 are eliminated or minimized. The effects of p_1 , probe wobble for example, are minimized by sequential adjustment of the potentiometers in the first column, so that signals d_1 , d_2 , and d_3 , in sequence, show a minimum variation when p_1 is varied. The effects of the second parameter, p_2 , is then minimized by adjustment of potentiometers in the second column so that a minimum effect of varying parameter 2 can be observed in signals e_1 and e_2 . The last two parameters are similarly separated by adjustment of potentiometers in the third column to successively eliminate or minimize the effects of p_4 in signal f_1 and p_3 in signal f_2 , thus, separating the effects of parameters p_3 and p_4 . The two potentiometers in the fourth column are gain controls in the two output channels, f_1 and f_2 .

FIGURE 3. Analyzer Section, Functional Diagram

The two monitor switches, not shown, are used to connect the various summed signals, for example d_1 , d_2 , d_3 , e_1 , e_2 , f_1 , or f_2 to a monitor for observation during adjustments. Additional details of the circuits are shown in the schematic diagram of the transceiver section, Figure 9, page 27, and the analyzer (computer) section, Figure 10, page 28.

Principles of Operation

The principle of operation of the multichannel tester may be explained on the basis of either signal space concepts or those of algebra. The multiparameter test principles which are used in the present tester were developed using both signal space and algebraic concepts. Signal space concepts are the more general of the two, including as they do the principles of algebra, and have been found to be useful in the development of the multidimensional tests. However, explanations based on elementary algebra are just as valid, although less picturesque, and will be used in this discussion. Perhaps the most straightforward approach to the explanation of the new tester is to compare its principles with those of the single frequency phase discrimination type eddy current testers, placing less emphasis for the time being on the generality of the underlying principles.

Conventional single frequency eddy current tests usually make use of test signals having only one or two dimensions. The reasons for this is that a single frequency signal, under steady conditions, can be described by two numbers, an amplitude and phase angle, or by the amplitudes of two signals of the same frequency having different specified phase angles. The higher dimensionality of a modulated ac carrier with its sidebands of many different frequencies can also be used in the display of the signal patterns as it is in the present instrument.

A single frequency eddy current test will now be described in which the effect of one test specimen parameter on the output signal is minimized by use of the phase discrimination technique. A common way to accomplish this is to use the component of the test signal which is in quadrature with respect to the signal caused by the unwanted parameter. Thus, this component can be read independently of the other component to a first order approximation. For example, the test coil output signals at a test radian frequency ω_1 might be as shown in Figure 4 where 0 is the null or no-defect signal, 0-PW₁ is the signal due to probe wobble or probe lift-off, 0-S₂ is a signal due to a defect near the surface adjacent to the test coil, and 0-S₃ is a signal due to a defect located at a greater depth below the surface.

The individual signals shown are those due to conditions present individually. Small signal conditions are assumed so that when defect conditions occur simultaneously, that is they are present within the effective zone of the test probe at the same time, the signals add linearly. In the eddy current test the signals do not vary linearly with defect size and depth, and this approximation causes errors which increase rapidly as defect signals increase in size. Signals shown in this section have been chosen for explanatory purposes and resemble real signals only to the extent necessary for explaining the principles of operation.

FIGURE 4. Eddy Current Test Signals, Phase Discrimination, Single Frequency Test

-15-

The signals may be applied to a phase detector in which the reference (switching) signal is of the proper phase so that the phase detector outputs are proportional to the components of the signals which are in phase quadrature with respect to undesired signal $O-PW_1$. For example, the components of the desired signals in phase quadrature with respect to signal $O-PW_1$ in Figure 4 are $O-P_2$ and $O-P_3$. The projection of the undesired signal $O-PW_1$ on the "phase detector axis" is zero, thus, the undesired signal is discriminated against. A second phase detector is often used to read out components of the signals which are in phase with the undesired signal. Of course, in this case, the undesired signal is also read in this output whenever it is present.

In contrast to the single frequency system, the multichannel tester applies two excitation (test) frequencies to the test coil assembly simultaneously instead of one, and uses four phase detectors instead of one or two. Signals for the same test conditions considered in Figure 4 are shown in Figure 5 for the two frequency system. The lower frequency ω_1 is assumed to be the same as that in Figure 4, thus Figure 5(a) is similar to Figure 4. However, due to skin effect, the defect signals at a higher frequency are assumed to lag in phase angle compared to the signals for the same defects at a lower frequency.

FIGURE 5. Eddy Current Test Signals, Two Frequency System

-17-

Equations relating the parameter values and the phase detector outputs can now be written. Referring to Figures 4 and 5 it can be seen that the output of each phase detector is approximately proportional to the sum of the projections of the various signals present upon the corresponding phase detector axis. The proportionality factor which gives the relationship between parameter value and corresponding phase detector output signals is given the symbol a_{ij} . The resulting set of equations for a three parameter system gives each of the phase detector outputs c_1 , c_2 , c_3 , as a summation of contributions due to the three parameters. For example, assuming that unit changes in parameters PW_{11} , S_{21} , and S_{31} give signal projections -6, -5, and -1 respectively upon the c_1 axis as shown in Figure 5(a), an equation relating the parameters and phase detector output c_1 can be written: $-6PW_{11} - 5S_{21} - S_{31} = C_1$.

Letting PW_{11} , S_{21} , and S_{31} be represented generally by p_1 , p_2 , and p_3 , respectively, and using the symbol a_{ij} to represent the proportionality factors (for example, $a_{11} = -6$, $a_{12} = -5$ and $a_{13} = -1$, etc.) a general set of equations may be written as follows:

$$a_{11}p_1 + a_{12}p_2 + a_{13}p_3 = c_1 \quad (1)$$

$$a_{21}p_1 + a_{22}p_2 + a_{23}p_3 = c_2 \quad (2)$$

$$a_{31}p_1 + a_{32}p_2 + a_{33}p_3 = c_3 \quad (3)$$

Small signal conditions have been assumed so that the theory of linear equations may be applied.

-18-

The relationships between phase angles of the different signals is that expected for two small defects of about the same size at some depth below the surface adjacent to the test coil, and may vary from this substantially for other test situations. Thus, signals S_{12} and S_{22} lag signals S_{11} and S_{12} , respectively.

The phase detectors produce signals which are proportional to the quadrature components of the signals at each of the two test frequencies. In principle, the test is not limited to only two frequencies, but the two frequency test is used as an example for simplicity and because the instrument described in this report uses two frequencies.

For convenience, and without loss of generality, the outputs of the phase detectors are assumed to be equal to the horizontal and vertical components of the signal vectors (phasors). Thus, the phase detectors give a total of four outputs which are equal to the sums of the signal projections on the c_1 , c_2 , c_3 , and c_4 axes, respectively, and which will be identified as c_1 , c_2 , c_3 , and c_4 . It is assumed that the signals shown were obtained by varying each of the corresponding parameters p_1 (probe wobble), p_2 (near surface defect) and p_3 (defect at greater depth) one parameter unit.

In this example, only three parameters are assumed to vary, although the two frequency system, using four phase detectors, is capable of separating a total of four parameters. The separation of parameters becomes more difficult as the difference between signal phase angles becomes less and as the defect signals become nonlinear as caused by large defects.

-19-

An important function of the tester is, given the phase detector outputs represented by the set of Equations (1), (2), and (3), to separate or read independently the effects of variations of parameters 2 and 3, thus, eliminating or reducing the effect of parameter 1. This is accomplished by constructing linear combinations of the three equations in a manner that results in the successive elimination or separation of parameters. Since each of the equations represents an equality the outputs of the phase detectors can be represented by either side of the equation. For illustrating the successive elimination and separation of parameters, it is most suitable to choose the left sides of Equations (1), (2), and (3) to represent the inputs to the parameter separating or computer section. For this particular example, the coefficients of a_{ij} of these equations are assigned the values of the components of the signals along the c_1 , c_2 , and c_3 coordinate axes in Figure 5, giving the following equations:

$$-6p_1 - 5p_2 - 1p_3 = c_1 \quad (4)$$

$$2p_1 + 4p_2 + 4p_3 = c_2 \quad (5)$$

$$-6p_1 - 4p_2 + 3p_3 = c_3 \quad (6)$$

These equations represent the inputs to the computer section as shown in the flow diagram in Figure 6. The inputs are represented by the appropriate coefficients of the p_1 , p_2 , and p_3 parameters or variables. The flow diagram shows how the desired linear combinations of the input equations are obtained for eliminating parameters. The signals on lines 1 and 2 are summed at point a, after changing the amplitude of the

FIGURE 6. Flow Diagram Showing Successive Elimination of Parameters, Three Parameter Case

-21-

signal on Line 1 by the multiplying factor ($\frac{1}{3}$) which is set in by manually adjusting a potentiometer. This operation gives a signal on Line 4 which would be zero for unit value of p_1 , $+\frac{7}{3}$ for unit value of p_2 and $\frac{11}{3}$ for unit value of p_3 . The effect of parameter 1 on the signal on Line 5 is similarly reduced to zero by changing the amplitude of the signal on Line 1 by the multiplying factor (-1). This gives a signal on Line 5 which is zero for a unit value of p_1 , 1 for unit value of p_2 , and 4 for unit value of p_3 . The effect of changes in value of p_1 has now been eliminated from the signals on Lines 4 and 5. Similarly, the effect of p_2 on the signal on Line 7 is eliminated by changing the amplitude of the signal on Line 4 by a multiplying factor equal to ($-\frac{3}{7}$) and adding the resultant to the signal on Line 5. This results in only p_3 having any effect on the signal on Line 7 as the coefficients related to both p_1 and p_2 have been reduced to zero.

The effect of p_3 on the signal on Line 6 is similarly eliminated by modifying the amplitude of the signal on Line 5 by a multiplying factor equal to ($-\frac{11}{12}$) and adding the resultant to the signal on Line 4. The resulting signals on Line 6 and 7 are respectively:

$$Op_1 + \frac{17}{12} p_2 + Op_3$$

$$Op_1 + Op_2 + \frac{17}{7} p_3$$

Thus, Line 6 is the p_2 output channel and Line 7 is the p_3 output channel.

-22-

Circuits within the tester corresponding to the flow diagram in Figure 6 are shown in the schematic diagram of the computer section shown in Figure 10. This schematic diagram is more complicated due to the need for providing signal sign reversal and the four parameter separating capability. As an aid in following this diagram, it can be observed that points a, b, c, and d in Figure 6 correspond to the summing points of amplifiers 15, 17, 19, and 20, respectively. The multiplying factors $(\frac{1}{3})$, (-1) , $(-\frac{3}{7})$ and $(-\frac{11}{12})$ of Figure 6 are controlled by potentiometers R7, R8, R13, and R12, respectively. The input lines of Figure 6, Lines 1, 2, and 3 correspond to test points TP 5, 6, and 7 of Figure 10. In operating the tester with three input signals as in the example of Figure 6 the input signals are connected to input terminals c_2 , c_3 , and c_4 of Figure 10 and R4, R5, and R6 are set at maximum. This feeds the three input signals to test points TP 5, 6, and 7.

The phase detector output signals, c_1 , c_2 , and c_3 are fed to signal flow lines 1, 2, and 3 in Figure 6. Signals on Lines 1 and 2 are summed at point a after changing the amplitude of the signal on Line 1 by the multiplying factor $-\frac{a_{21}}{a_{11}}$. Points b, c, and d are other similar summing points, each associated with the other multiplying factors $-\frac{a_{31}}{a_{11}}$,

$$-\frac{a_{23} a_{11} - a_{13} a_{21}}{a_{33} a_{11} - a_{13} a_{31}} \quad \text{and} \quad -\frac{a_{32} a_{11} - a_{12} a_{31}}{a_{22} a_{11} - a_{12} a_{21}}$$

-23-

These multiplying factors are selected so that the signal on Lines 4 and 5 have components due only to p_2 and p_3 so that the signal on Line 6 has components due only to p_2 and similarly the signal on Line 7 has components due only to p_3 . Thus, parameter 1, p_1 , has been eliminated from the output Lines 6 and 7 and parameters 2 and 3 have been effectively separated as can be seen by examining the pertinent signal equations on the respective lines.

Test Results

Comparative results were obtained operating the multichannel tubing tester in its two single frequency modes and its single two frequency mode using the test specimen whose cross section sketch is shown in Figure 7. This is type 304 stainless steel tubing having 0.050 inch wall and 1/2 inch inside diameter. Irregularities of interest in this specimen, from right to left (in the direction of movement of the test coil assembly) are a 1/8 inch long notch, approximately 0.015 inches deep by .003 inches wide opening on the inner surface, a kink or dent in the tubing, a suspected region of intergranular corrosion on the inner wall of the tubing, and a 1/8 inch long notch approximately .023 inches deep by .003 inches wide opening onto the outer surface of the tubing. The results of runs made using this specimen and an inside test coil assembly having two differentially connected test coils are shown in Figure 8. For the single frequency runs, 100 kHz, Figure 8(a), and 300 kHz, Figure 8(b), the instrument was adjusted to minimize probe wobble signal on channel 1, the lower trace of each chart record. The test coil assembly was pulled

Technical drawing of a specimen with the following dimensions and features:

- Overall length: 14"
- Distance from left end to feature A: 12-1/2"
- Distance between features B and C: 7"
- Distance from feature C to right end: 4"
- Distance from right end to feature D: 1-1/2"
- Feature A: NOTCH
- Feature B: CORROSION
- Feature C: DENT
- Feature D: NOTCH
- Thickness of the specimen: 0.05"
- Distance from bottom surface to feature D: 1/2"

NOTES ON TUBE DEFECTS:

- FIGURE 7. Test Specimen

-25-

nearly through the specimen tube, resulting in signal indications due to the tubing irregularities. The test coil assembly, then near the end of the tubing, was caused to wobble severely, resulting in the large signals near the left end of the upper trace of the chart records shown in Figures 8(a) and 8(b). In these two single frequency runs, the division of the defect signals between the two channels is very much predetermined by the phase relationship between these defect signals and the probe wobble signals, and in the conventional eddy current test is not under control by the operator.

In contrast, performance of the new instrument operated in its two frequency mode is shown in Figure 8(c). Here the instrument has been adjusted so that the effect of probe wobble has been minimized on both output channels, and so that the signal due to the inside notch appears mainly on channel 1 and the signal due to the outside notch appears mainly on channel 2. The probe wobble signal has been greatly reduced on channel 2 making signals on that channel more useable than in the case of the single frequency test. Some loss of signal-to-noise ratio has occurred on channel 1.

(a) SINGLE FREQUENCY MODE - 100 KHz

(b) SINGLE FREQUENCY MODE - 300 KHz

(c) TWO FREQUENCY MODE - 100 KHz AND 300 KHz

Showing Separation of Inside and Outside Defects and the Reduction of Probe Wobble Signals on Both Output Channels

FIGURE 8. Test Results for Tube in Figure 7 Showing Comparison of Single Frequency and Two Frequency Modes of Operation

FIGURE 9. Transceiver Section - Schematic Diagram

FIGURE 10. Analyzer (Computer) Section - Schematic Diagram

Acknowledgement

The contributions of M. J. Churchill who did the basic circuit design of the transciever circuits is acknowledged.

References

1. H. L. Libby and C. R. Wandling, "Eddy Current Nondestructive Testing Service Using an Oscilloscope to Identify and Locate Irregularities in a Test Piece", U.S. Patent No. 3,302,105, January 31, 1967
2. H. L. Libby, "Eddy Current Nondestructive Testing Service for Measuring Multiple Parameter Variables of a Metal Sample", U.S. Patent No. 3,229,198, January 11, 1966
3. H. L. Libby and K. W. Atwood, "Broadband Electromagnetic Testing Methods, Part 3, Parameter Extraction", HW-79553, November 1963

DISTRIBUTION LISTNo. of CopiesAEC, RL

1 C. L. Robinson
1 Technical Library

AEC, Chicago Patent Group

1 G. H. Lee
1 R. K. Sharp

AEC, Division of Technical Information
Exchange

278 For UC-37 Distribution

Battelle-Northwest

5 Technical Information
2 Technical Publications
1 R. L. Brown
2 G. J. Dau
1 C. J. Denton
1 D. R. Green
1 L. T. Lamb
30 H. L. Libby
1 V. I. Neeley
1 H. N. Pedersen
1 C. B. Shaw
2 J. C. Spanner
5 C. R. Wandling
1 D. C. Worlton
1 Legal (File)