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IN-SERVICE EXAMINATION OF IHX TUBING WITH EDDY CURRENT NDT EQUIPMENT

HANFORD ENGINEERING DEVELOPMENT LABORATORY P.O. Box 1970 Richland, WA 99352
Operated by Westinghouse Hanford Company
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by

R. L. Brown

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ABSTRACT

Single and multiple frequency eddy current (ET) nondestructive testing (NDT) techniques and equipment were investigated for in-service inspection of sodium-contaminated intermediate heat exchanger (IHX) tubing. A four frequency technique, demonstrated in the laboratory, was relatively insensitive to signals caused by probe motion, tube support plates, and residual sodium on the outer surface of the tubes. No method was found to avoid the signals from residual sodium on the inside surfaces of the tube.

CONTENTS

INTRODUCTION

The Fast Flux Test Facility (FFTF) will include three intermediate heat exchangers (IHX) to transfer heat from the primary (radioactive) sodium loop to the secondary (non-radioactive) sodium loop. Each IHX contains 1540 tubes made of 304 stainless steel. These tubes are approximately 20 feet long by .875 inch outside diameter and approximately 0.049 inch wall thickness. They are mounted vertically within the IHX shell and include a complex (half moon) bend region approximately 5 feet long near the bottom.

During FY-1973, it was determined that in-service eddy current (ET) examination of IHX tubing might become necessary to provide: (1) a scheduled periodic method to monitor tube quality, and/or (2) reconnaissance examinations to locate leaking tubes for plugging, in response to independent evidence that excessive leakage had developed. Due to the uncertainties inherent in sodium removal and tube recertification procedures, it was considered desirable to be able to conduct in-service ET examinations after draining the sodium, but without cleaning the tubes. Although eddy current examination of clean IHX tubing can be accomplished with single frequency techniques and equipment, similar to those presently in use for water/water heat exchanger tubing, a study(1) conducted at HEDL during FY-1973 showed these single frequency techniques to be inadequate for in-service examination of sodium-contaminated IHX tubing.

During FY-1974, multi-frequency techniques and equipment were investigated by Hanford Engineering Development Laboratory (HEDL) Non-Destructive Testing (NDT)-Engineering in search of a successful method for in-service examination of sodium-contaminated IHX tubing. A four-frequency method that was relatively insensitive to signals caused by probe motion, tube support plates, and residual sodium on the outer surface of the tubes was demonstrated, but no method was found to avoid large signals from residual sodium on the inside surfaces of the tubes.

The purposes of this report are to: (1) record the results of the investigation into single and multi-frequency techniques; (2) to discuss the design criteria for necessary equipment such as probes, remote tube probing equipment, and physical standards; and (3) to summarize conclusions reached on in-service ET examination of IHX tubing.

SUMMARY

Single and multiple frequency eddy current (ET) techniques were evaluated for applicability to in-service inspection of IHX tubing. It was concluded that a conventional single frequency test (operated at approximately 100 kHz) can be effective on clean IHX tubing.* Use of the conventional test on sodium-contaminated tubing is not recommended because signals from sodium deposits can seriously interfere with the detection of significant discontinuities. If the sodium can be thoroughly removed from the inner surface of the tubes, and detection of outer surface discontinuities is not necessary, a single frequency test (operated at approximately 1 MHz) can be used to detect inner surface discontinuities. If discontinuities must be detected under the tube support plates or on the outer surfaces of tubes which have sodium on the outer surface, then a four-frequency test is recommended. A four-frequency test was demonstrated in which signals from probe motion, tube support plates, and sodium deposits on the tube outer surfaces were discriminated against, thereby simplifying the signal interpretation problem. No successful test technique was found for tubing with sodium deposits on the inner surfaces.

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* This investigation was completed prior to the recent eddy current testing of IHX tube bundles at a vendor's plant. The sample IHX tubing used in the investigation reported in this document was marked "PATCO SMLS-TP304 HEAT NO. C5112 A 213 AVE" and exhibited no significant magnetic indications or "ghosts". The probe used in straight tube sections was 0.750 ± 0.002 inch in diameter and passed easily through the four tube-to-tube sheet weld samples on hand. A short probe 0.720 ± 0.002 inch in diameter was used in two tubes with 12 inch radius bends to simulate the sharpest bends in the IHX. Any reduction in probe diameter should be expected to reduce sensitivity to discontinuities, and to increase probe motion signals. Any local variations in the permeability or conductivity of the tubing material should be expected to introduce extraneous signals.

DISCUSSION

The selection of eddy current NDT equipment and techniques for in-service examination of IHX tubing should be guided by design criteria such as those in Table I. Although these criteria may change as more boundary conditions become known, these criteria provide a basis for decisions on the acceptability of various techniques and provide a reference for future improvements.

Experimental investigations were conducted to determine the applicability of single and multi-frequency eddy current tests for the in-service inspection of IHX tubing. The following sections contain a discussion of methods, data, and results obtained.

Single Frequency Tests

Single frequency eddy current NDT equipment is commercially available, and is widely used for discontinuity detection in water/water heat exchanger tubing. This type of equipment induces eddy currents in the tube by inductive coupling between the probe and the tube. The eddy current density is greatest at the surface, closest to the probe and drops exponentially with depth. The depth at which the eddy current density has dropped to 1/e, or 37% of the current density at the surface, is referred to as the Standard Depth of Penetration. The Standard Depth of Penetration is given by:

$$\delta = 1.98 \sqrt{\rho / f\mu}$$

where δ = Standard Depth of Penetration in inches

ρ = electrical resistivity in $\mu\Omega$cm (72 for 304 SS)

f = operating frequency in Hz

μ = magnetic permeability (unity for 304 SS)

For 304 stainless steel, $\delta = 1.98 \sqrt{72/f} = 16.8/\sqrt{f}$.

The operating frequency for a single frequency eddy current test of IHX tubing can therefore be calculated from $f = 282/\delta^2$. This relationship is shown in Figure 1.

An experimental arrangement of single frequency ET equipment, typical of that used to obtain data on IHX tubing examination, is shown in Figure 2.

TABLE I

GENERAL DESIGN CRITERIA FOR IN-SERVICE ET EXAMINATION OF IHX TUBING

1. The primary objective of this examination is to detect crack type discontinuities in installed IHX tubing.

2. The secondary objective is to detect abrupt wall thickness changes such as might be caused by corrosion or tube/support plate interface wear.

3. The measurement of absolute wall thickness is not considered an essential objective.

4. It should be possible to conduct the test vertically (such as in an installed IHX with the head removed) or horizontally (such as in a tube bundle, lying on its side, in a repair shop).

5. The equipment should be capable of determining the longitudinal location of detected discontinuities with an accuracy of ± 1 inch or less.

6. The test should be capable of determining whether the discontinuity originates on the inner or outer surface of the tubing, and provide an estimate of its depth.

7. The capability to detect discontinuities under tube support plates is desired, if possible.

8. The detection of significant discontinuities should not be degraded excessively by interferring signals from irrelevant conditions such as probe motion, tube support plates, sodium deposits, etc.

9. Although it is not necessary to interpret test data taken in either tube sheet, it is desirable to extract any discontinuity information possible from the internal bore welds.

10. Commercially available equipment should be utilized to the maximum possible extent.

11. Reproducible results should be obtainable with different qualified operators using a written test procedure.

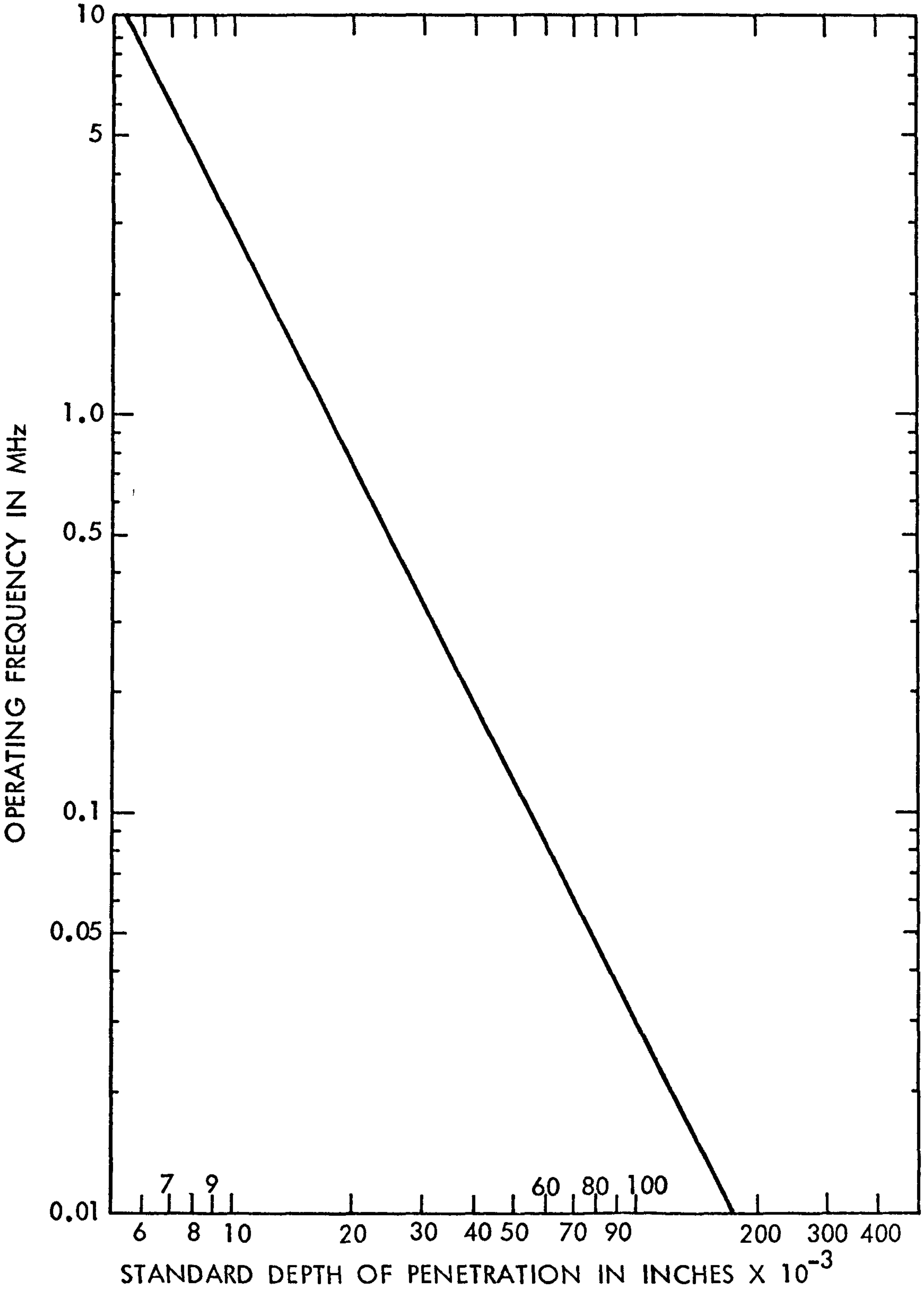

FIGURE 1 Eddy Current Penetration in 304 Stainless Steel.

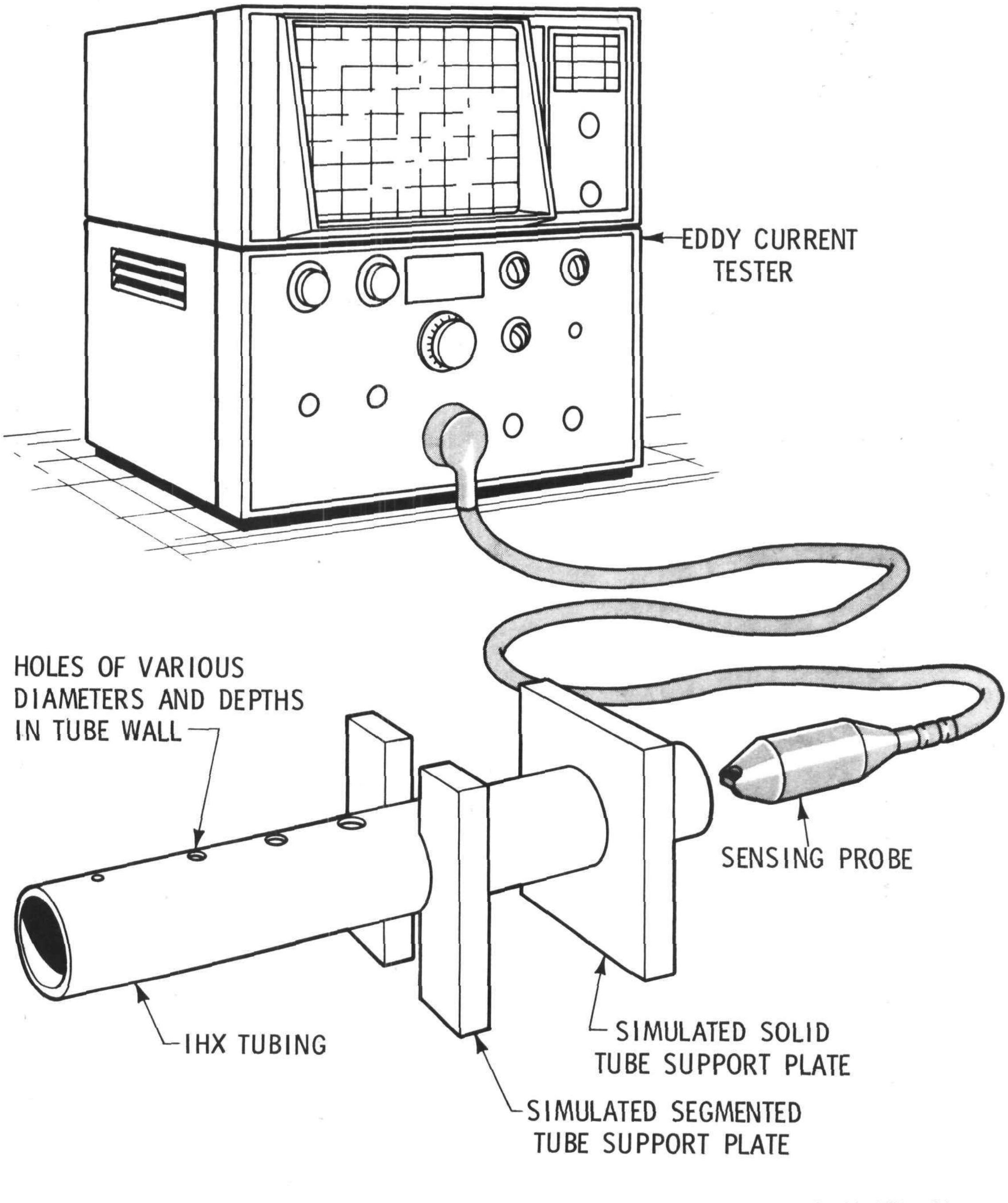

FIGURE 2. Experimental Arrangement to Obtain Data on the Single Frequency ET of IHX Tubing.

Tester output waveforms obtained at 100 kHz from several known artificial discontinuities in IHX tubing are shown in Figures 3 through 18.

Figure 3 shows the figure-eight shaped waveforms that are obtained from two holes through the tube wall. Note that the signal from a 1/16 inch diameter hole, which has four times the volume of a 1/32 inch diameter hole, produces a figure-eight shaped signal approximately four times larger than that from a 1/32 inch diameter hole. Figure 4 shows signals from a 1/16 inch diameter hole through the wall and flat bottomed 1/16 inch diameter holes (0.010, 0.020, and 0.030 inches deep) on the inside of the tube. Figure 5 shows signals obtained from similar holes on the outside of the tube. By comparing Figures 4 and 5, it can be seen that the depth of hole shaped discontinuities can be estimated by measuring the amplitude and angle between the axis of the figure-eight pattern and the horizontal axis. The uncertainty introduced by probe motion is shown in Figure 6.

Figure 7 shows that longitudinal notches (0.005 inch wide, 0.125 inch long, and 0.010, 0.020, and 0.030 inches deep) produce signals similar to those from the holes in Figures 4 and 5. It is noted that circumferential notches of the same dimensions produce significantly smaller signals, as shown in Figure 8. Signals obtained from 3/4 inch thick simulated solid and segmented tube support plates are shown in Figures 9 and 10. The gain in these two figures was reduced by a factor of approximately 18, because the signals from support plates are much larger than the signals from 1/16 inch diameter holes. Each IHX will contain three 3/4 inch solid support plates, four 3/4 inch segmented support plates, and one 2-3/4 inch segmented support plate. Signals from these eight support plates should appear in the data from each tube.

Figures 11 and 12 show signals obtained from sodium deposits on the outer and inner surfaces of IHX tubing. These data were obtained during a previous sodium pot experiment. Figures 13 and 14 show signals obtained from deposits of solder on the outer and inner surfaces of the tube. Although Figures 11 through 14 were not made at exactly the same gain, note the similarity in the shape of the signals obtained from sodium and solder. It was found that well wetted solder provided a practical substitute for sodium in laboratory bench tests. Therefore, solder was used throughout this study for convenience.

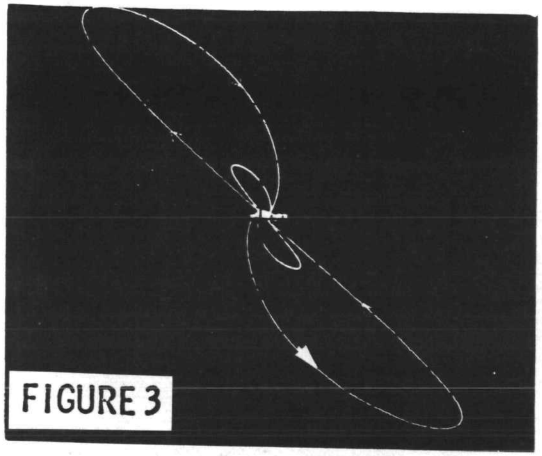

FIGURE 3

1/32" & 1/16" Dia. Holes Through Wall

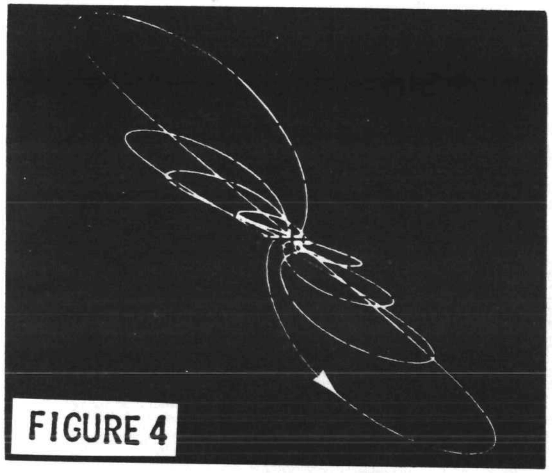

FIGURE 4

1/16" ID Holes (0.010, 0.020 & 0.030" Deep & Through)

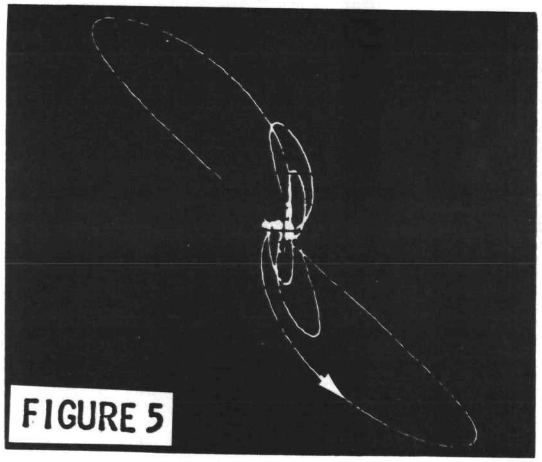

FIGURE 5

1/16" OD Holes (0.010, 0.020 & 0.030" Deep & Through)

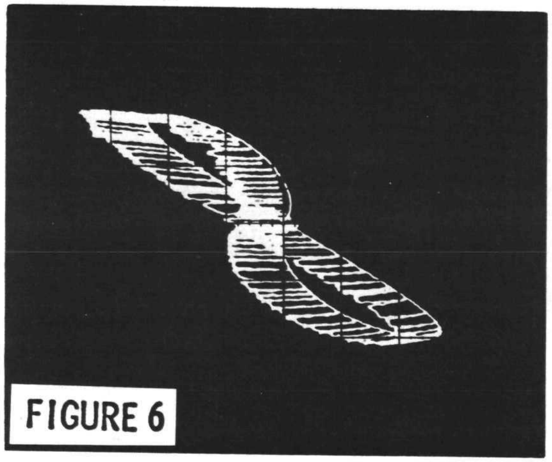

FIGURE 6

1/16" ID Hole (0.030" Deep) with Probe Motion

FIGURES 3-6 Waveforms of Signals from Single-Frequency ET Showing Holes on IHX Tubing.

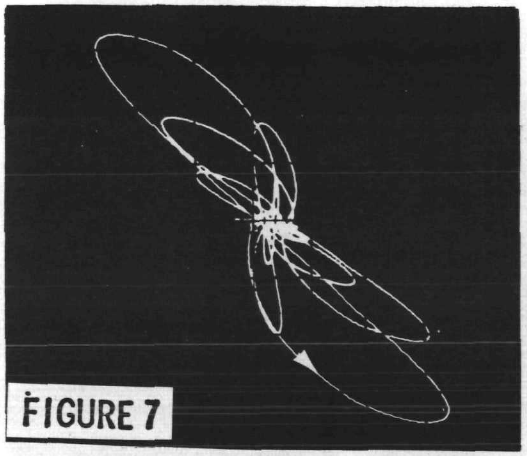

FIGURE 7

1/16" Hole Through & Longitudinal Notches on ID & OD

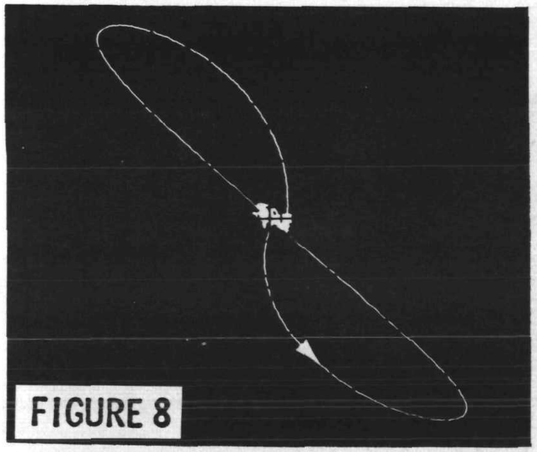

FIGURE 8

1/16" Hole Through and Circumferential Notches on ID & OD

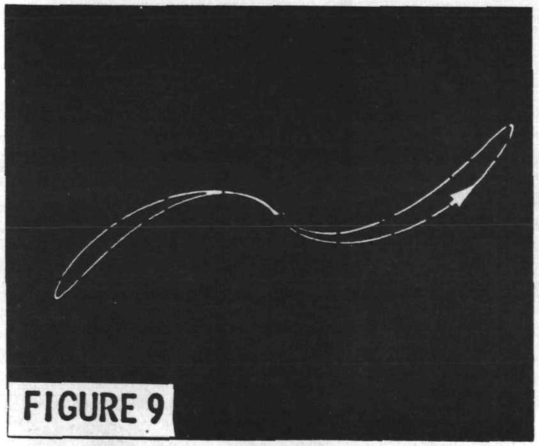

FIGURE 9

Solid Tube Support Plate

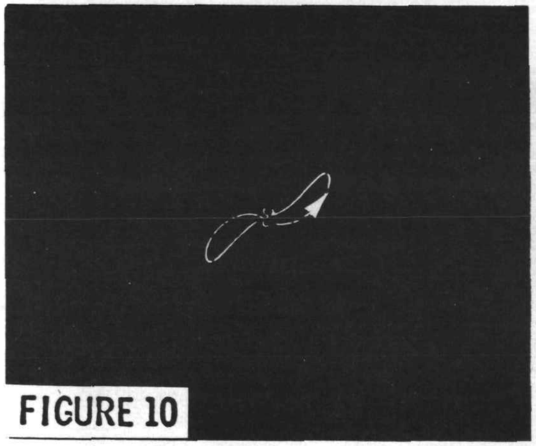

FIGURE 10

Segmented Tube Support Plate

FIGURES 7-10. Waveforms of Single-Frequency Signals from Notches (7 and 8) and Solid and Segmented Tube Support Plates (9 and 10)

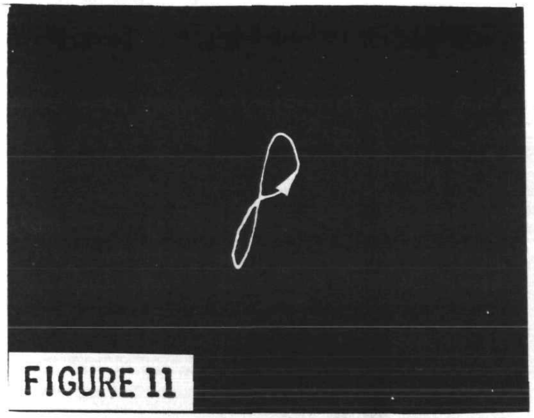

FIGURE 11

Sodium Deposit on Tube OD

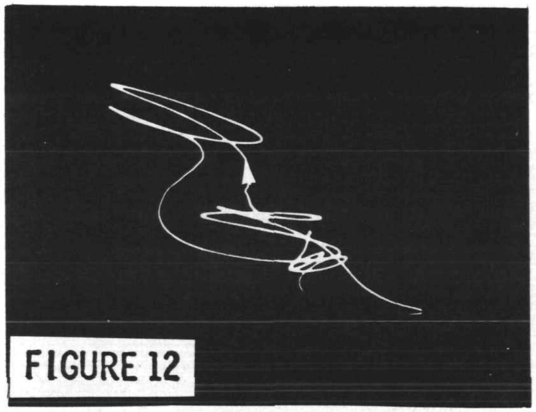

FIGURE 12

Irregular Sodium Deposit on Tube ID

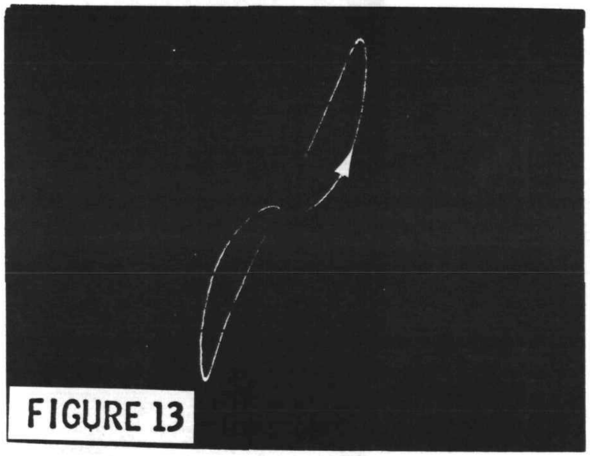

FIGURE 13

Solder Area on Tube OD

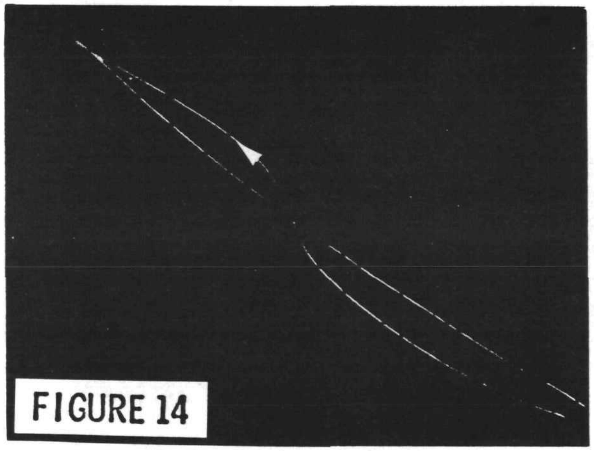

FIGURE 14

Solder Ring on Tube ID

FIGURES 11-14. Waveforms of Single-Frequency Signals from Sodium Deposits (11 and 12) and Solder Deposits (13 and 14).

Figures 15 through 18 show signals obtained from solder deposits over various diameter holes through the wall. These figures were made with approximately one-third the gain of Figures 3 through 8. Note that the general shape of the signals in Figures 15 through 18 bear the general characteristics of signals from sodium deposits rather than the characteristics of signals from holes.

The 100 kHz single frequency test has been shown to be sensitive to: (1) holes on the inner and outer surfaces and through the wall, (2) support plates, (3) sodium on the inner and outer surfaces, and (4) thinning on the tube outer surface due to support plate wear. Unfortunately, if more than one condition occurs at the same time, it may not be possible to correctly interpret the resulting signals. Signals from significant discontinuities can thus become hidden by signals from large irrelevant variables such as support plates or sodium deposits. For this reason, a 100 kHz single frequency test is not recommended for examination of sodium-contaminated IHX tubing.

If all sodium can be removed from the inner surface of the tubes, it may be useful to conduct a single frequency test at a higher frequency (approximately 1 MHz) to obtain reduced penetration. This test should detect discontinuities on the inner surface and some large discontinuities on the outer surface which penetrate nearly through the wall. This test might not detect all deep outer surface discontinuities because they could be filled with sodium. It should not be expected to detect minor discontinuities or support plate wear on the outer surface.

Multi-frequency Tests

Although they are extremely useful in many simple applications, single frequency eddy current tests are limited in their ability to separate variables which may occur simultaneously (such as signals from significant defects, support plates, sodium deposits, probe motion, etc.). Multi-frequency eddy current test techniques (sometimes referred to as "multiparameter" tests) offer the potential of better variable separation, because they use more independent driving functions but they are usually more complicated to set up and operate.

Multiparameter eddy current test equipment is not commercially available. The data for this study was obtained with HEDL laboratory equipment. This

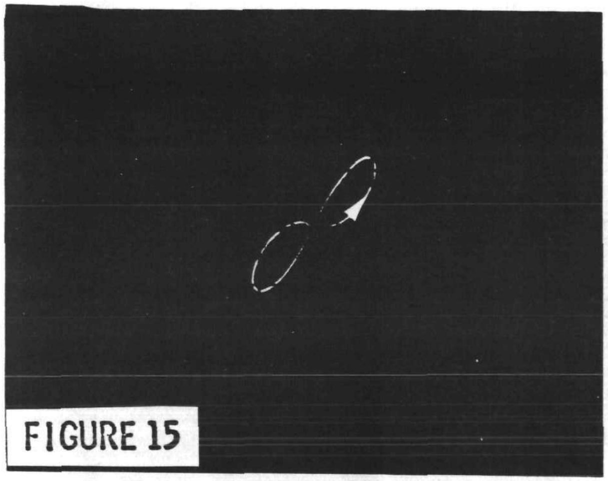

FIGURE 15

Solder over 1/32" Dia. Hole

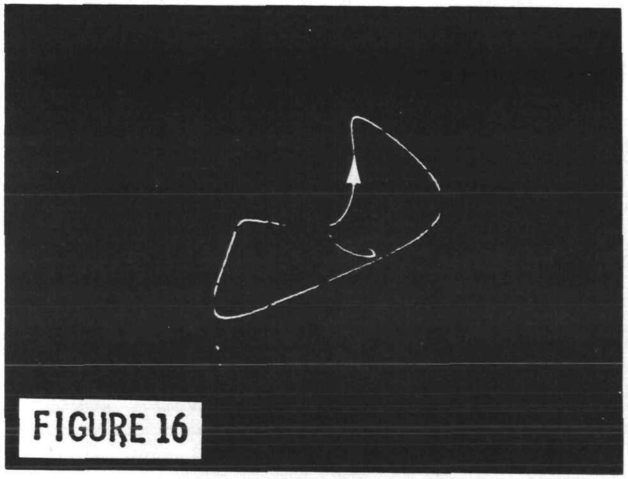

FIGURE 16

Solder over 1/8" Dia. Hole

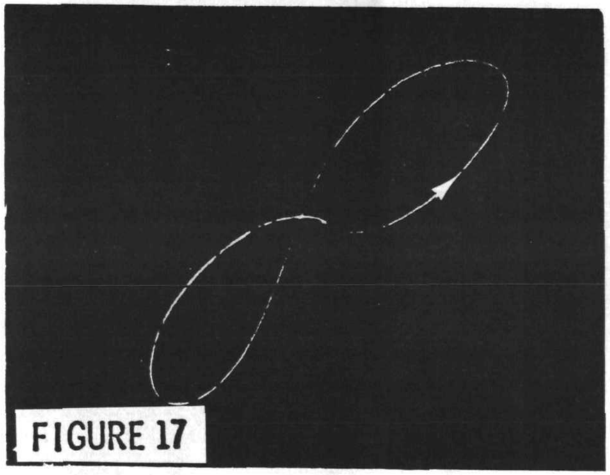

FIGURE 17

Solder over 1/16" Dia. Hole

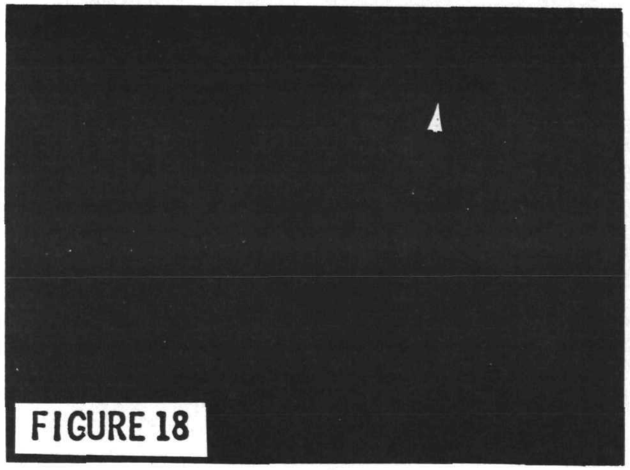

FIGURE 18

Solder over 1/4" Dia. Hole

FIGURES 15-18. Waveforms of ET Single-Frequency Signals from Solder Deposits over Holes through Wall.

equipment, which is capable of operation at any combination of the following frequencies: 31.25, 62.5, 125, 250, and 500 kHz, and 1 MHz, is shown in Figure 19. The probe and comparison samples used were the same as used with the single frequency test.

A two-frequency technique which could discriminate against signals from support plates and solder deposits on the OD was demonstrated earlier. Although this technique worked well in straight tubing, subsequent evaluation in bend tube comparison samples showed that probe motion would probably make this technique impractical in the bend region of IHX tubing.

A four-frequency technique, which also discriminates against the signals from support plates and solder deposits but which is less effected by probe motion, was demonstrated. A block diagram of this test is shown in Figure 20. Figures 21 through 24 show the signals obtained from four holes of different diameters through the tube.

The signals obtained from solid and segmented tube supports are shown in Figures 25 and 26. Note that nearly all output in these figures has been restricted to the horizontal axis and practically no vertical output is obtained. These two figures demonstrate that signals from solid and segmented tube support plates can be eliminated. Similarly, Figures 27 and 28 demonstrate that signals from a solid support plate soldered to the tube and a small soldered area on the outer tube surface can also be eliminated. With the tester adjusted to obtain minimum vertical output from irrelevant variables such as support plates or solder deposits on the outer tube surface discontinuities in the wall can be detected by the fact that they produce vertical output. Figures 29 through 32 show the signals obtained from holes through the tube wall, centered under solid support plates. These are the same holes shown without support plates in Figures 21 through 24. Figures 29 through 32 demonstrate that the four-frequency test can detect holes under support plates without interference from the support plates. Figures 33 through 36 show similar data for simulated wear bands machined around the outer surface of the tube. Each wear band is rectangular in cross-section and positioned under a solid support plate. Note that increasing the size of holes or wear bands increases the vertical signals obtained. This should allow estimates of the size of unknown holes or wear bands.

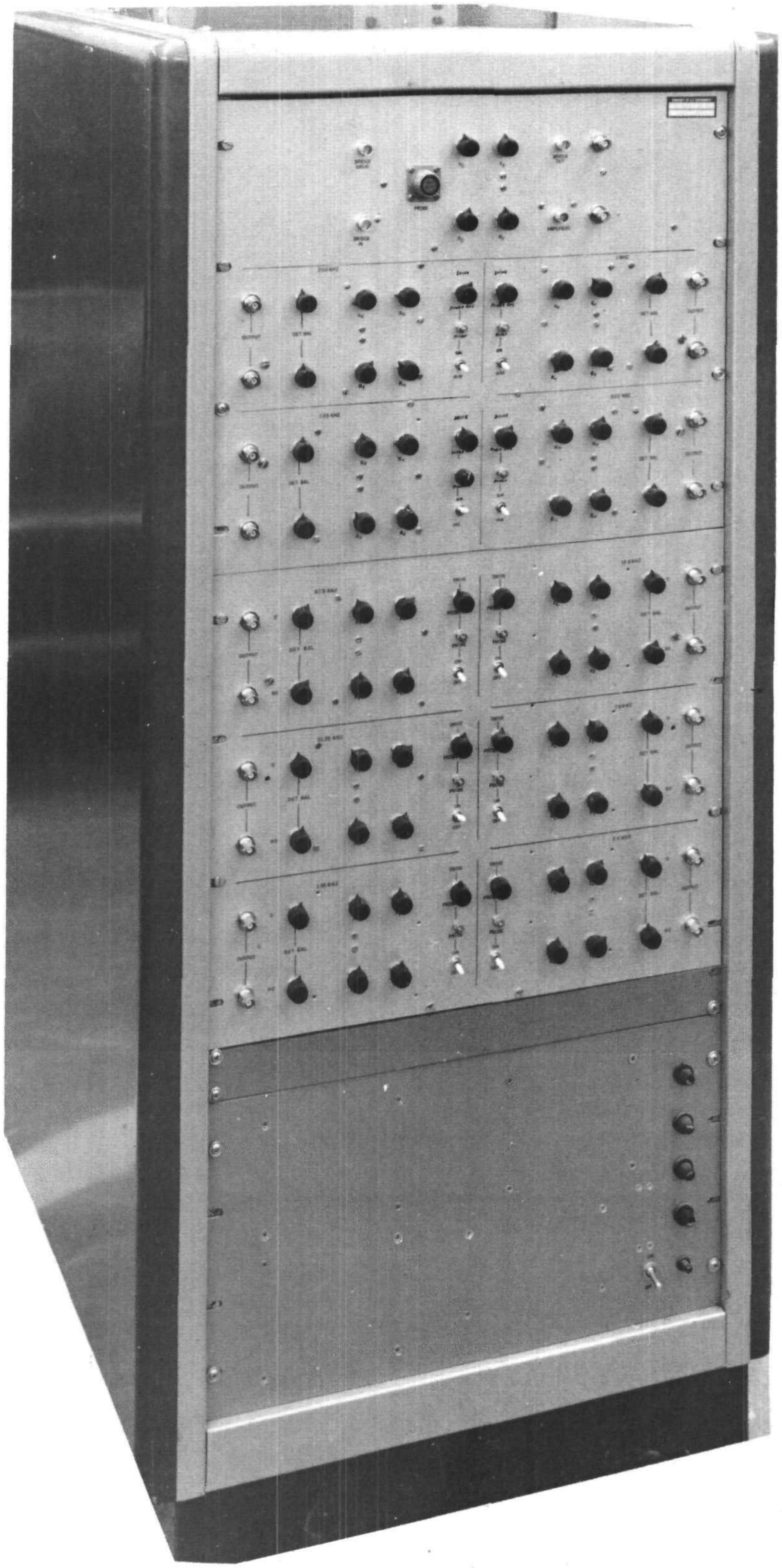

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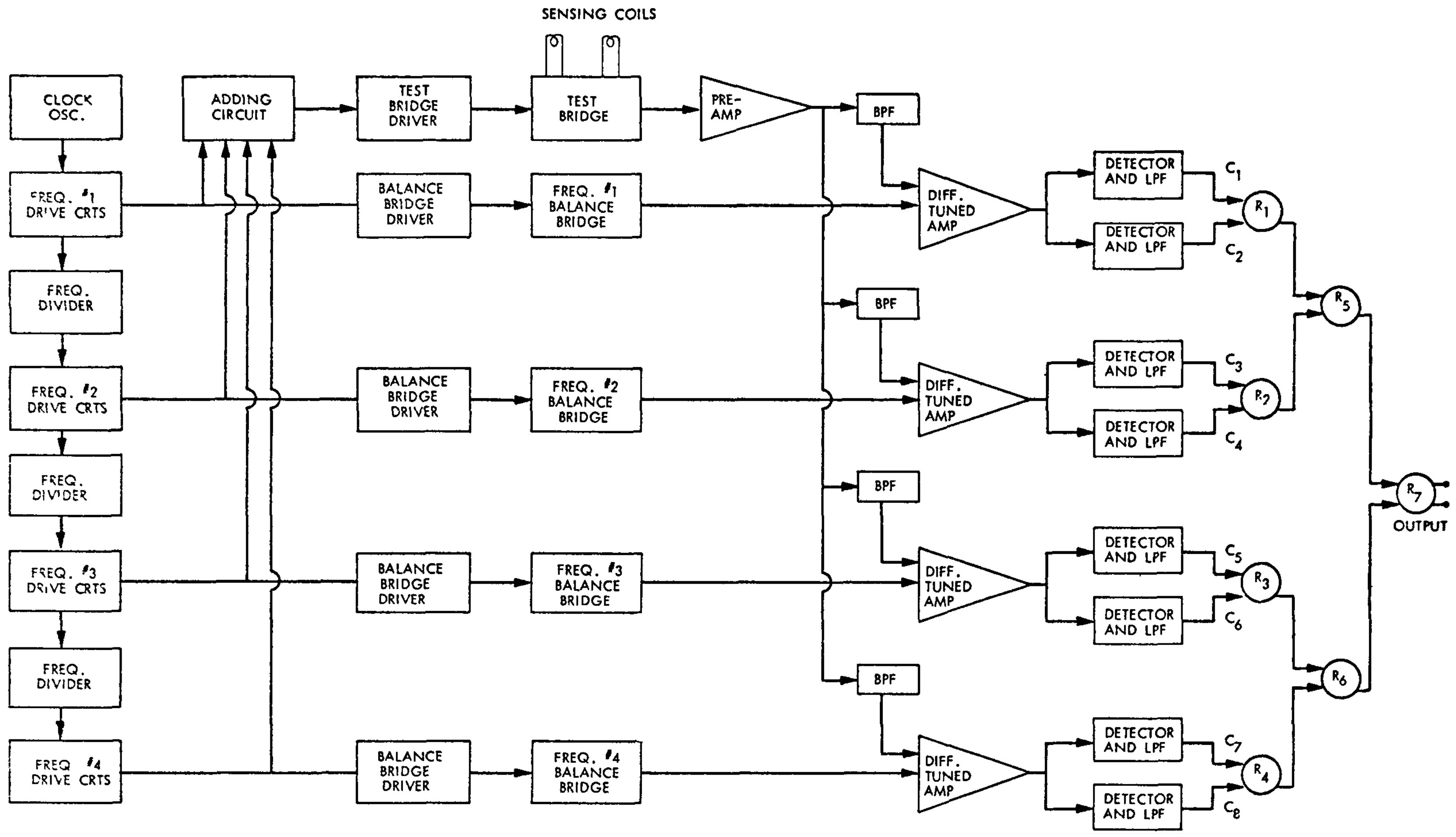
FIGURE 19. Multiparameter Eddy Current Test Equipment.



HEDL 7306-18.1 Modified

FIGURE 20. Block Diagram of Four-Frequency Multiparameter Eddy Current Test

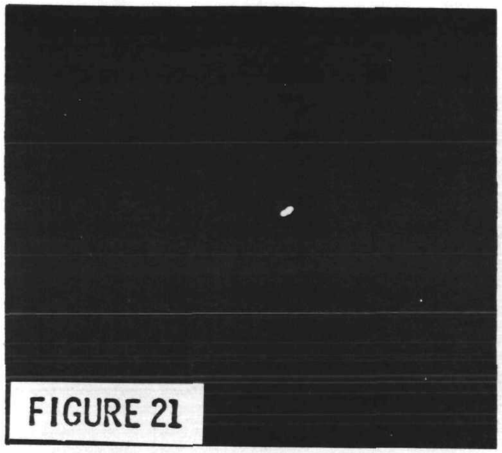


FIGURE 21

1/32" Dia. Hole

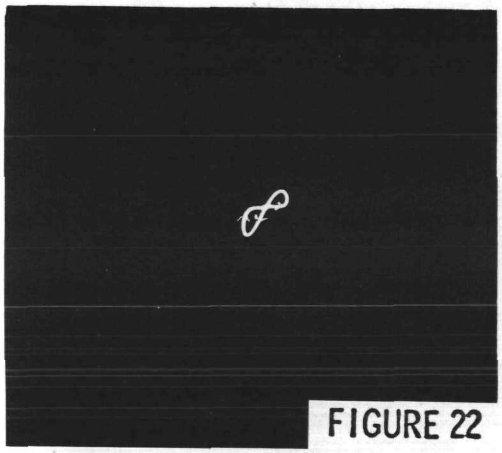


FIGURE 22

1/16" Dia. Hole

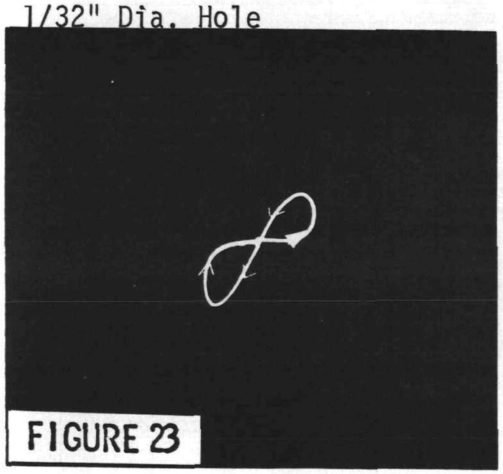


FIGURE 23

1/8" Dia. Hole

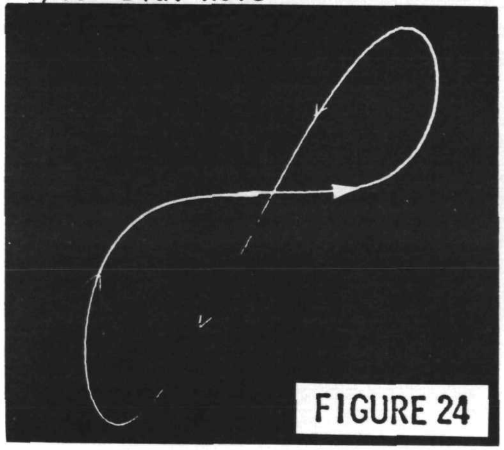


FIGURE 24

1/4" Dia. Hole

FIGURE 21-24. Waveforms of Four-Frequency Signals from Four Holes through the Tube Wall.

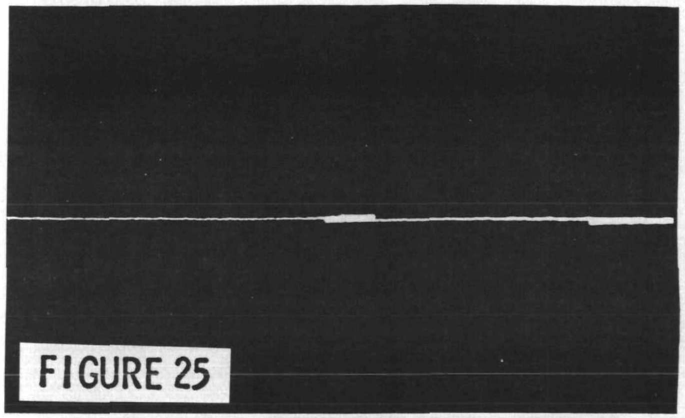


FIGURE 25

Solid Tube Support Plate

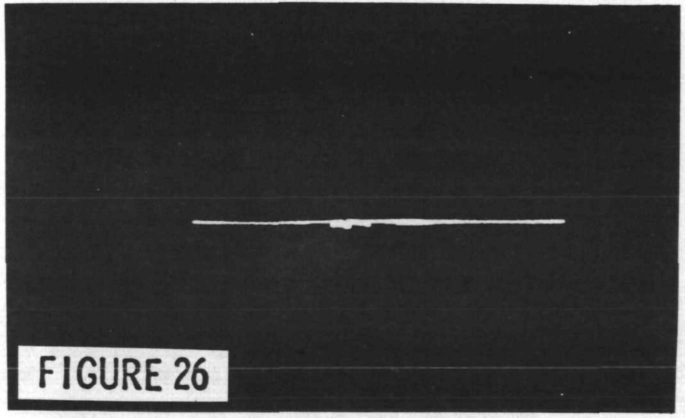


FIGURE 26

Segmented Tube Support Plate

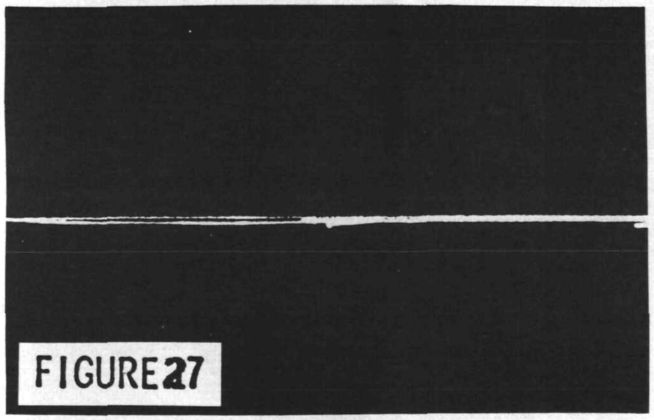


FIGURE 27

Soldered Solid Tube Support Plate

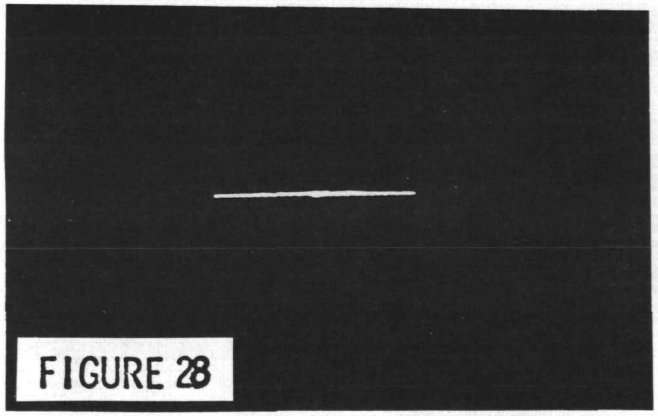


FIGURE 28

Soldered Area on Tube OD

FIGURES 25-28. Waveforms of Four-Frequency Signals from Solid and Segmented Tube Supports.

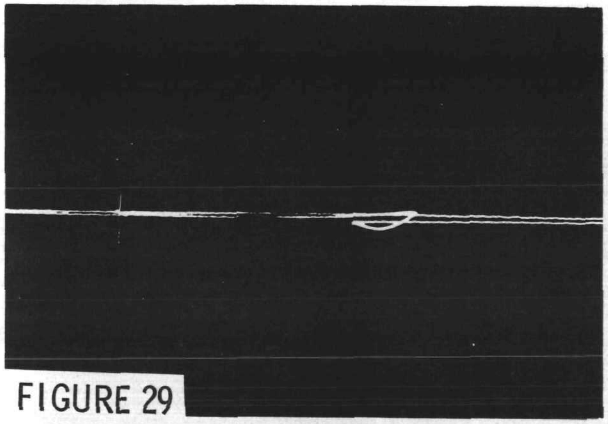


FIGURE 29

1/32" Dia. Hole

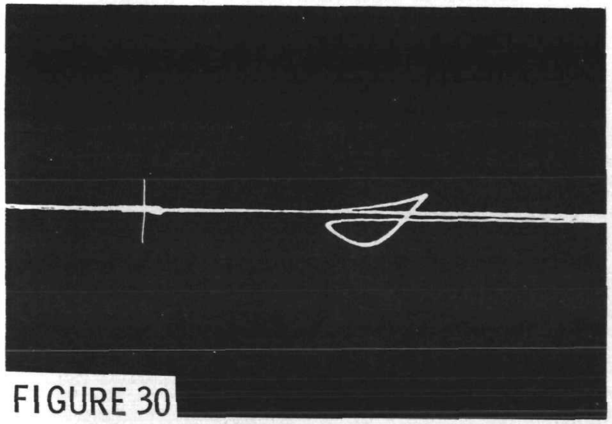


FIGURE 30

1/16" Dia. Hole

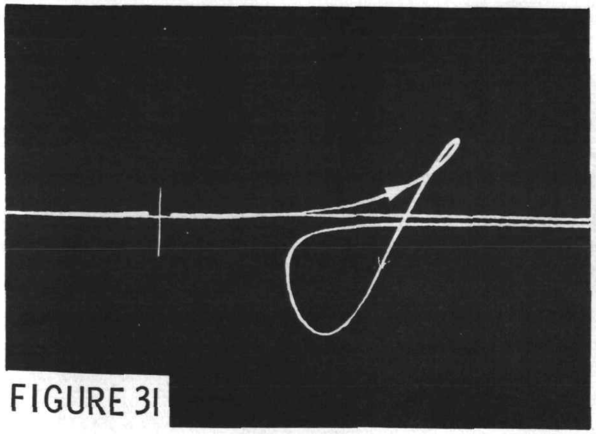


FIGURE 31

1/8" Dia. Hole

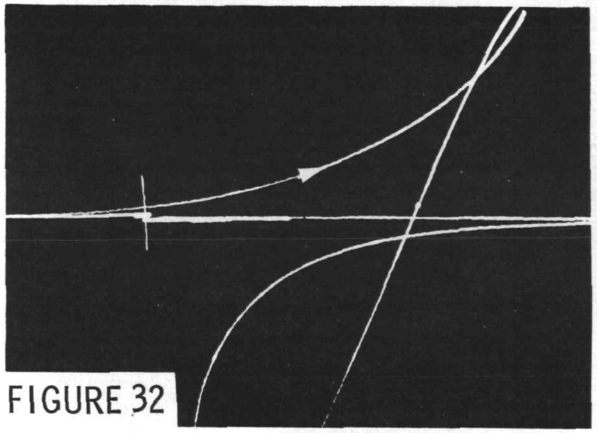


FIGURE 32

1/4" Dia. Hole

FIGURES 29-32. Waveforms of Four Frequency Signals Showing Detection of Holes Under Solid Support Plate Without Interference from Plates.

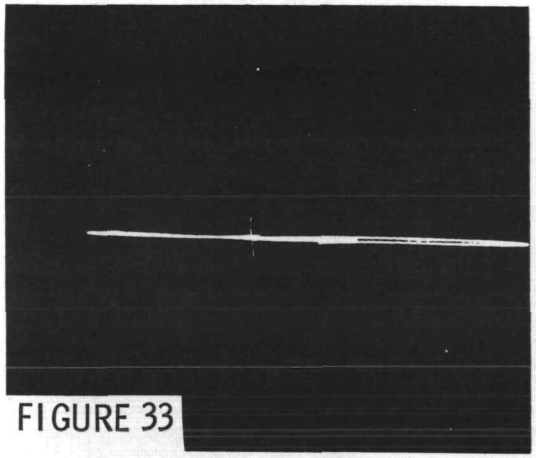


FIGURE 33

0.004" in Depth

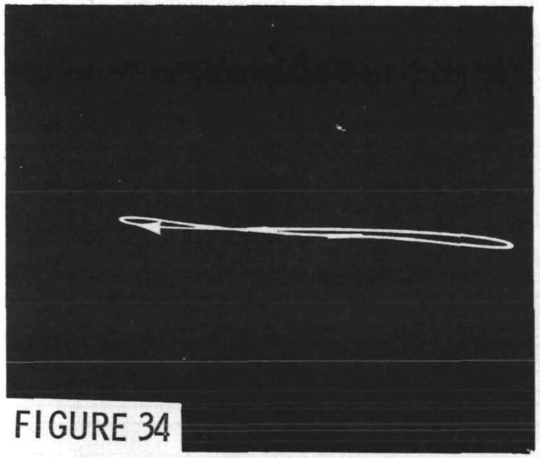


FIGURE 34

0.008" in Depth

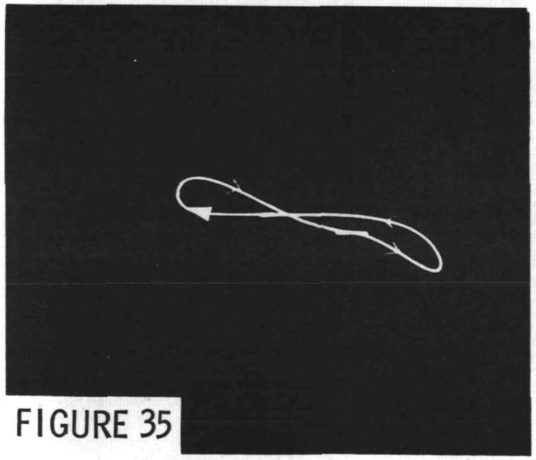


FIGURE 35

0.016" in Depth

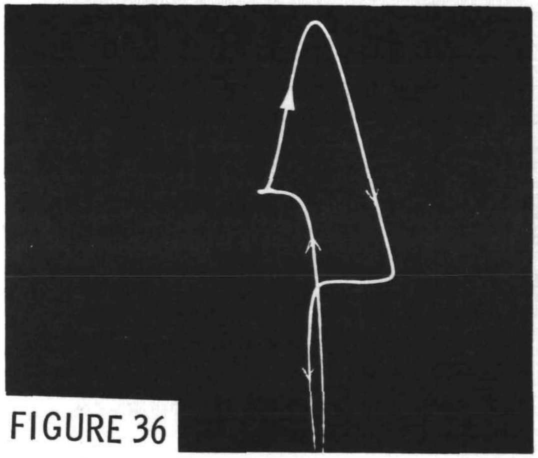


FIGURE 36

0.032" in Depth

FIGURES 33-36. Waveforms of Four-Frequency Signals Showing Detection of Wear Bands Machined Around Outer Tube Surface.

Unfortunately, there was one irrelevant variable, sodium (or solder) on the inner tube surface, which also produced significant vertical signals. Figures 37 and 38 show the signals obtained from a soldered area on the inner tube surface and a soldered ring around the inner surface of the tube. Note that these signals have a significant vertical component. Note also that the signal from solder on the inner tube surface starts out by going down to the left, while the signal from a hole starts out by going up to the right.

The signal from solder on the inner tube surface can cancel some of the signal from a significant discontinuity, such as a hole, which occurs simultaneously. Because of this cancellation, the resultant of the two signals may appear less significant than either signal taken separately. Figures 39 through 42 show the signals obtained from holes through the tube wall filled with solder from the outer surface. These holes are the same size as those used to obtain Figures 21 through 24. Note that the vertical components of the signals are reduced, and the directions of the loops are more characteristic of solder on the inner surface than clean holes. This demonstrates that signals from simultaneously occurring holes and solder (or sodium) on the inner tube surface cannot be separated, and can produce a signal which does not have much vertical component. This problem does not occur if the inner surface of the tube is cleaned of all sodium.

Probe Design

The ideal eddy current probe for in-service inspection of IHX tubing would meet the design criteria of Table II. Although a given practical probe might not meet all of these criteria, they serve as a useful guide for the design or selection of a probe. Although a single probe can be used, experimental data indicates that the use of two different probes (one selected for use in straight tubing and one selected for use in the bend region) should give better test results. The use of two different probes should nearly double the required testing time.

Remote Tube Probing Equipment

RDT Standard E 4-6T required that the IHX be designed to provide access for surveillance and in-service inspection. IHX drawings indicate that access

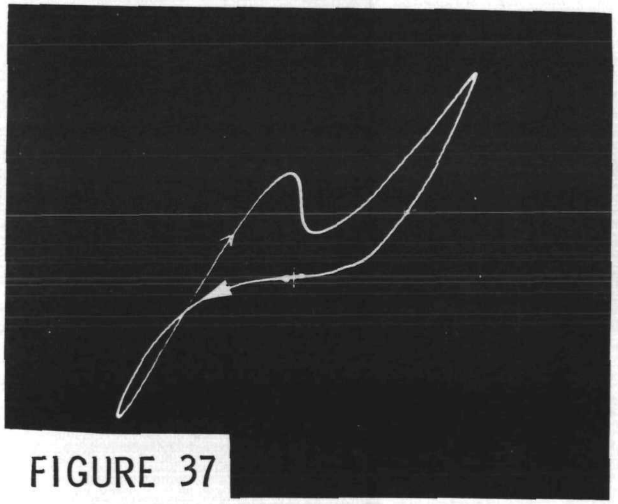


FIGURE 37

Soldered Area

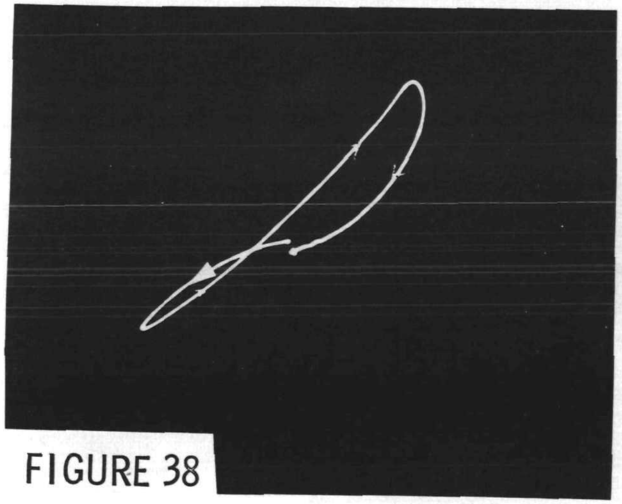


FIGURE 38

Soldered Ring

FIGURES 37 and 38. Waveforms of Four-Frequency Signals from Localized Solder Area on Inner Tube Surface (37) and from Soldered Ring on Inner Tube Surface (38).

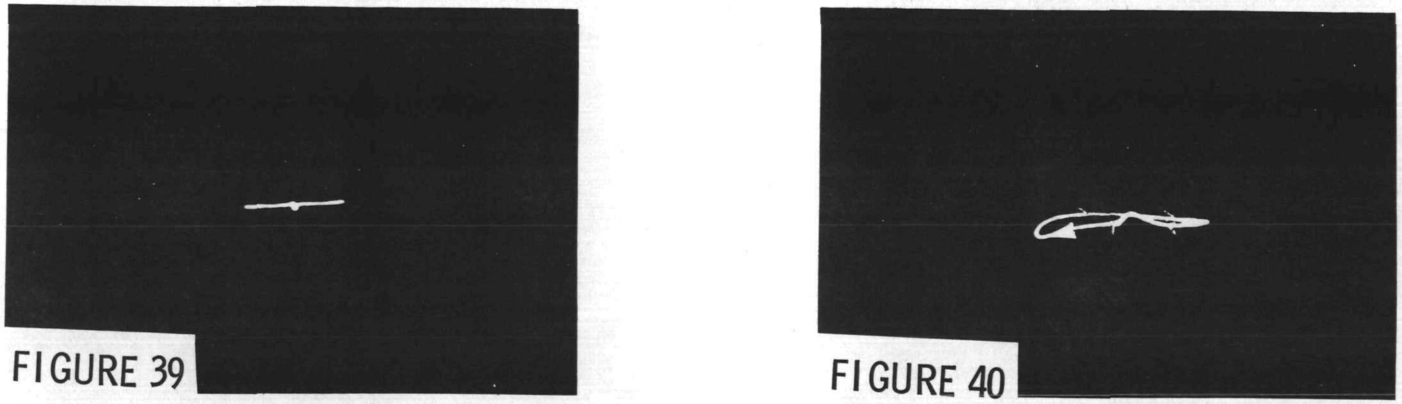


FIGURE 39

1/32" Dia. Hole

FIGURE 40

1/8" Dia. Hole

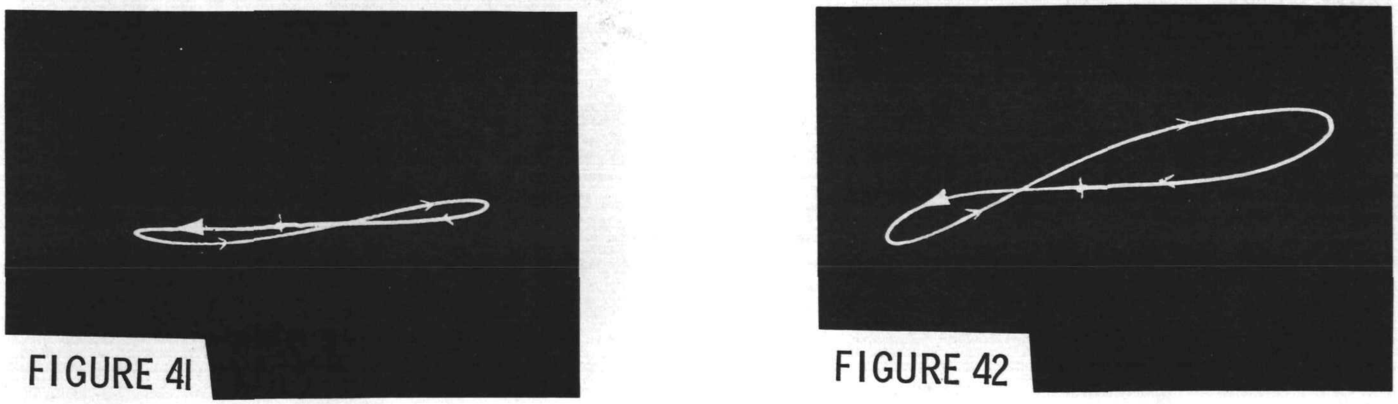


FIGURE 41

1/16" Dia. Hole

FIGURE 42

1/4" Dia. Hole

FIGURES 39-42. Waveforms of Four-Frequency Signals from Holes through Tube Wall Filled with Solder from Outer Surface.

TABLE II

DESIGN CRITERIA OF SENSING PROBE FOR IN-SERVICE ET EXAMINATION OF IHX TUBING

1. Mechanical Requirements Related to Passing Probe Through Tube
    a. Probe must pass sodium deposits.*
    b. Probe must pass around bends (Note: Tube cross-section becomes elliptical in bend region.).
    c. Probe must pass internal bore welds.
    d. Probe must pass any layers of material built up on inner surface of tube.
    e. Probe must not get caught at the bottom of the tube.
2. Mechanical Requirements Related to the Eddy Current Test
    a. Sensing coils should be centered within the tube as much as possible.
    b. Probe should allow minimum lateral motion.
    c. Probe should be pulled at nearly constant speed (if differentiated data recording is used).
    d. Probe must not be corroded by sodium or sodium oxides.
3. Mechanical Requirements Related to Convenience and Safety of IHX and Personnel
    a. Probe must not scratch tubes.
    b. Probe must not get stuck or break off in the IHX.
    c. Probe must not leave corrosion or contamination in the IHX.
    d. Probe must not get too radioactive or thermally hot to handle during testing.
    e. Probe must be capable of decontamination after use.
    f. Probe must be compatible with automatic probe insertion equipment, if used.
    g. Probe must be rugged enough to withstand mishandling.

---

*Only applies if sodium cannot be cleaned from the tube ID.

TABLE II (Cont'd.)

4. Electrical Requirements

   a. Probe must be electrically compatible with tester.

   b. Probe must have high sensitivity.

   c. Probe must have high resolution.

   d. Probe must have high signal/noise ratio (this usually requires that the probe fit the tube as closely as practical).

   e. Probe must be relatively immune to electrical transients.

is to be obtained by cutting circumferentially around the top head at an elevation of 8 feet, 7-1/2 inches below the operating floor, and extracting a portion of the head plus the inner and outer liner. This would provide access to the upper tube sheet and all 1,540 tubes. All equipment and personnel to be positioned on the upper tube sheet would have to pass through a 47-3/4 inch circular opening.

A recent HEDL study(2) predicted the radiation fields in this area to be high enough to interfere with contact maintenance. This study indicated that: (1) the radiation levels due to activated corrosion products will probably be in the range of 1-15 R/hour for points within the heat transport system (HTS) cell, and (2) the dose rates near the IHX are among the highest in the HTS cell because the IHX contains about 70% of the deposition area in the HTS cell.

A previous HTS engineering maintenance study showed that 200 mR/hour must be regarded as an upper limit for radiation exposure because "it is administratively impractical to perform maintenance work in radiation fields of 200 mR/hour or greater."

These factors suggest that, if eddy current in-service examination of a significant number of IHX tubing is to be performed, special techniques and equipment will be required. The design criteria for remote tube probing equipment that could be positioned on the upper tube sheet to perform eddy current testing with minimum personnel exposure is given in Table III.

An artist conception of this equipment in operation is shown in Figures 43 and 44.

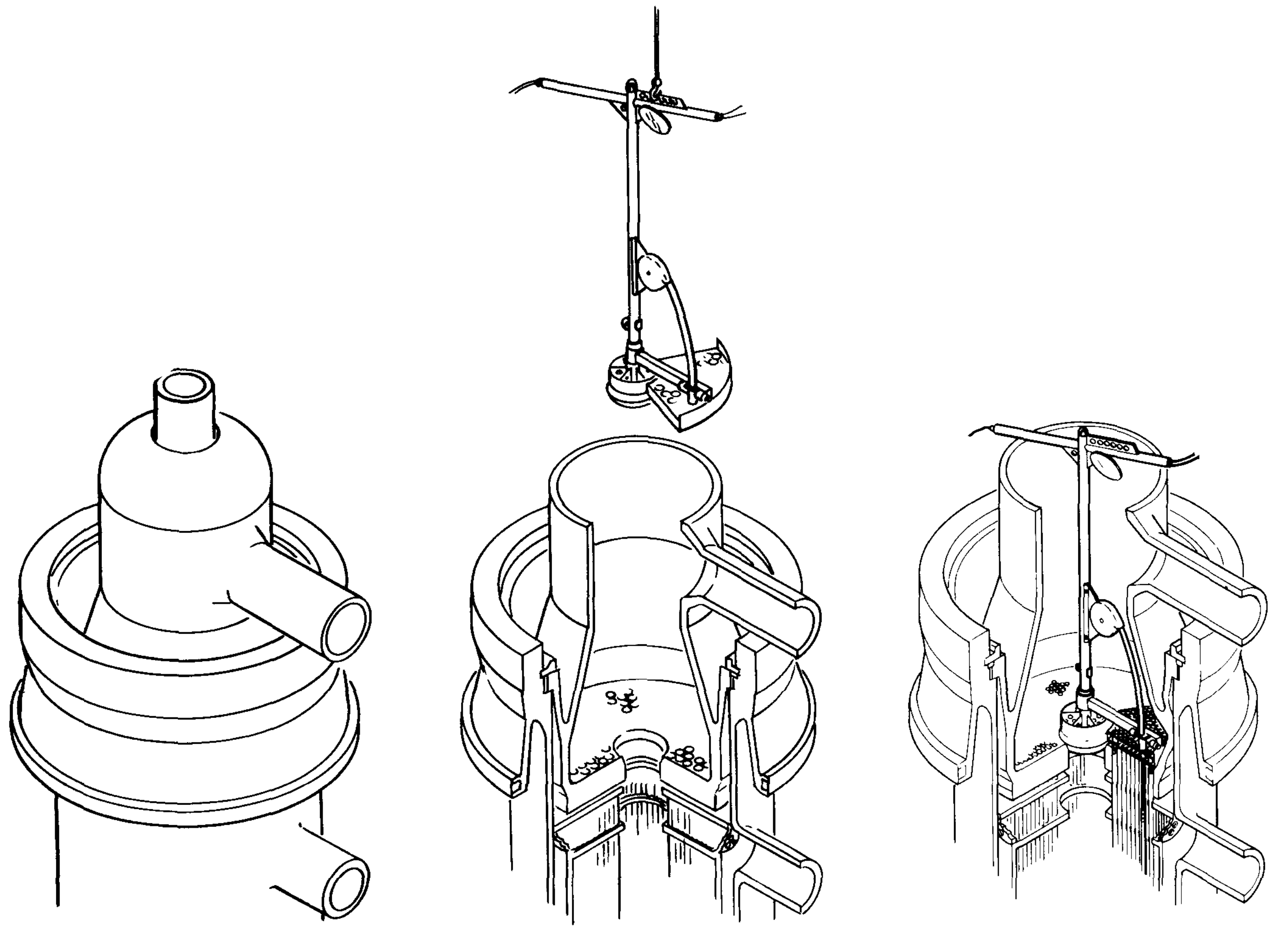
Physical Standards

Physical standards or comparison samples containing artificial discontinuities with known shapes and dimensions are necessary as a basis for estimating the size of the natural discontinuities detected. Table IV gives criteria for the design or selection of physical standards for ET examination of IHX tubing.

TABLE III

DESIGN CRITERIA OF REMOTE TUBE PROBING EQUIPMENT FOR IN-SERVICE ET EXAMINATION OF IHX TUBING

1. All equipment to be used in the IHX must pass through a 47-3/4 inch diameter opening at the cut line.
2. The equipment should be easily set in place on the upper tube sheet and aligned with the tube pattern.
3. The equipment should be capable of remotely inserting and withdrawing the eddy current probe through the tubes.
4. The equipment should be capable of remotely indexing from row to row and from tube to tube. Although manual indexing is required, automatic sequential indexing from row to row, and tube to tube, is desirable to reduce potential operator error.
5. Remote readout of tube and row number is required.
6. Remote readout of probe location (distance from top of tube sheet) is required.
7. The equipment must be designed and fabricated so that no parts may become detached to be left in the IHX.
8. A take-up reel system is required to control the location of the probe cable at all times.
9. It is desirable to design the probe and cable take-up reel as a replaceable unit to minimize maintenance time.
10. If this equipment is to be used in sodium-contaminated tubing, it should be designed to prevent the buildup of sodium on the probe and other parts.
11. Safe transportation containers are required for the probes and for the entire unit. These containers are required to minimize fire hazards during transit from the test site to the decontamination site. These containers may also assist in the decontamination.
12. The entire unit must be able to operate in either the vertical or horizontal position.



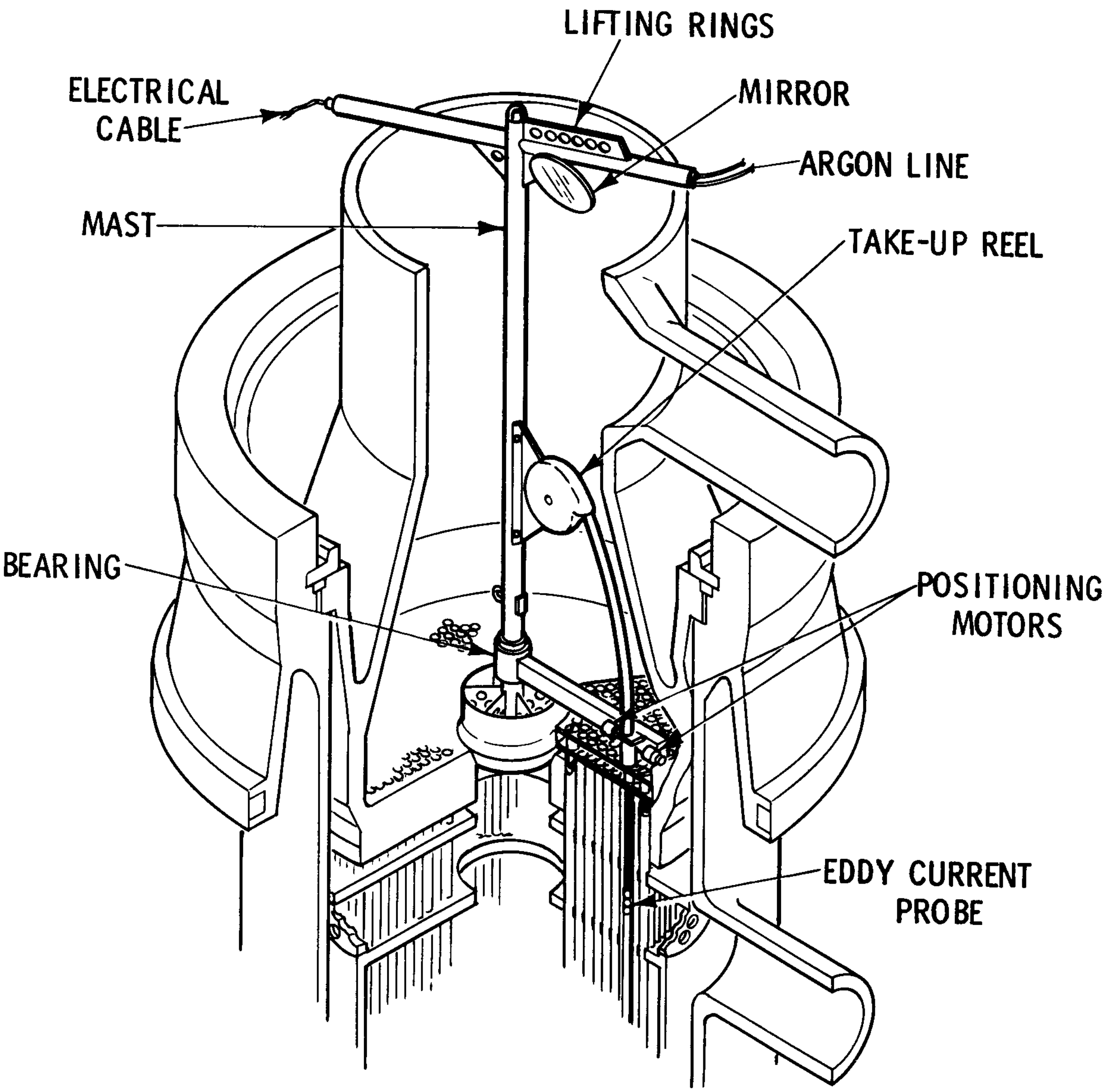
(a) BEFORE HEAD REMOVAL

(b) HEAD REMOVED

(c) PROBING EQUIPMENT IN PLACE

HEDL 7501-34.2

FIGURE 43. Conceptual Sequence for Eddy Current Examination of IHX Tubing.



HEDL 7501-34.3

FIGURE 44. Conceptual Remote Tube Probing Equipment in Place.

TABLE IV

DESIGN CRITERIA OF PHYSICAL STANDARDS FOR IN-SERVICE ET EXAMINATION OF IHX TUBING

1. Physical standards should be constructed to be as representative of the tubing to be tested as possible. (Use same outer and inner diameter, wall thickness, material, forming methods, heat treatment, etc.). It is desirable to use tubing from the same lot of material, if possible.

2. If more than one type of tubing is to be tested, a separate physical standard should be made for each type.

3. The physical standards should include artificial discontinuities of known dimensions, shaped similar to anticipated natural discontinuities such as:

Possible Natural Discontinuity	Artificial Disontinuity
a. Tube/support plate interface wear	Rectangular bands machined around the outer circumference of the tube
b. Intergranular attack	Hemispherical surface pits or drilled holes
c. Handling damage	Punch or file marks
d. Circumferential cracking due to vibrational bending and fatigue	Circumferential electrodischarge machined notches
e. Longitudinal splits due to excess pressure	Longitudinal electrodischarge machined notches

4. Selection of the artificial discontinuities to be included in the physical standards should be the responsibility of the organization responsible for the operation and maintenance of the IHX in consultation with NDT personnel.

5. If the bend region is to be tested, the physical standards should include a bend region representative of the smallest radius to be encountered. Appropriate artificial discontinuities (of known size and shape) should be located in the bend region of the physical standard to ensure that they can be reliably detected in the presence of the bend.

TABLE IV (Cont'd.)

6. A physical standard which includes soldered areas to simulate sodium deposits on the inner and outer tube surfaces should be fabricated to train operators to recognize signals from sodium deposits.
7. Physical standards should be designed to be compatible with remote tube probing equipment, if used.

CONCLUSIONS

1. Single and multiple frequency eddy current tests were both found to be capable of detecting discontinuities in sodium-free IHX tubing. The location and size of gross discontinuities (depth > 20% of wall thickness) can be estimated from the size and angular orientation of the signals produced. The accuracy of these estimates can be effected by probe motion and discontinuity shape.

2. The presence of baffles, bends, kinks, and sodium deposits interferes with the interpretation of signals and degrades the accuracy of the results. This is particularly true of the single frequency test in sodium-contaminated tubing. A single frequency test of the inner surface only can be conducted using a frequency high enough to minimize sensitivity to support plates and/or sodium on the outer tube surfaces.

3. A two-frequency multiparameter technique reduced the effect of signals from the tube support plates and sodium on the outer tube surface, but was too sensitive to probe motion for practical use in this application.

4. A four-frequency multiparameter technique reduced the effect of signals from tube support plates, sodium on the outer surface, and probe motion. This technique should be usable for the examination of IHX tubing if the inner surface of the tube can be cleaned of sodium. It should be noted, however, that, even though the multiparameter technique can be used to discriminate against signals from support plates and sodium deposits on the outer surface, it is possible for sodium which has flowed into a discontinuity to reduce or modify the shape of the signal from that discontinuity. Thus, it is possible that a significant sodium-filled discontinuity might not be detected.

5. No eddy current technique was found during this investigation which was insensitive to the presence of sodium on the inner tube surface.

6. For the best eddy current test results, the tubes should be thoroughly cleaned, at least on the inner surface, prior to examination.

REFERENCES

1. R. L. Brown and C. R. Wandling, "A Feasibility Study on In-Service Inspection of Sodium-Contaminated IHX Tubing with Single Frequency Eddy Current NDT Equipment," HEDL-TME 72-152, December 1, 1972.

2. T. J. Kabele, W. F. Brehm, and D. R. Marr, "Activated Corrosion Product Radiation Levels Near FFTF Reactor and Closed Loop Primary System Components," HEDL-TME 72-71, May 15, 1972.

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