DECLASSIFIED

BNWL-CC-702
June 13, 1966EVALUATION OF AN ULTRASONIC METHOD
FOR MEASURING REACTOR ALUMINUM PROCESS TUBE WALL THICKNESS

MASTER

by

D. O. Hunter

NDT Methods Development
Nondestructive Testing Section
Applied Physics and Electronics DepartmentClassification Cancelled (Change to
DECLASSIFIED)

AEC

by Authority of *H. E. Ransom*By *J. J. Jones 4-8-70**RL Classification Analyst 3-5-70*

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, 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 prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

INFORMATION CONCERNING USE OF THIS REPORT

PATENT STATUS

This document copy, since it is transmitted in advance of patent clearance, is made available in confidence solely for use in performance of work under contracts with the U. S. Atomic Energy Commission. This document is not to be published nor its contents otherwise disseminated or used for purposes other than specified above before patent approval for such release or use has been secured, upon request, from the Chief, Chicago Patent Group, U. S. Atomic Energy Commission, 9800 So. Cass Ave., Argonne, Illinois.

PRELIMINARY REPORT

This report contains information of a preliminary nature prepared in the course of work under Atomic Energy Commission Contract AT(45-1)-1830. This information is subject to correction or modification upon the collection and evaluation of additional data.

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

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

leg

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DECLASSIFIED

BNWL-CC-702

DISTRIBUTION

Battelle-Northwest

	<u>Bldg.</u>	<u>Area</u>
R. E. Benham	3201	3000
L. J. Chockie	3706	300
C. J. Denton (3)	326	300
G. E. Driver	326	300
G. C. Fullmer	3706	300
G. F. Garlick	326	300
E. M. Kartchner	326	300
V. I. Neeley	326	300
E. H. O'Claire	306	300
J. T. Russell	326	300
J. C. Spanner (2)	326	300
W. G. Spear	329	300
D. C. Worlton (2)	326	300
Technical Files (3)	3706	300

Douglas United Nuclear

T. W. Ambrose	1704-H	100-H
C. E. Bowers (5)	1706-K	100-K
T. L. Deobold	1720-K	100-K
A. K. Hardin	1704-D	100-D
C. G. Lewis	1720-K	100-K
R. J. Nicklas	1706-KE	100-K
C. B. Organ	1706-K	100-K
R. W. Reid	1760-D	100-D
D. E. Strege	1706-K	100-K

Extra (10)

EVALUATION OF AN ULTRASONIC METHOD FOR MEASURING REACTOR ALUMINUM PROCESS TUBE WALL THICKNESS

D. O. Hunter

INTRODUCTION

Reactor aluminum process tubes are subjected to a variety of uniform and localized corrosion and mechanical damage thinning mechanisms.⁽¹⁾ If undetected, thinning can lead to eventual penetration of the tube wall and consequent water leakage which in turn causes accelerated corrosion thinning of the tube exteriors. For this and other reasons, suspect tubes are replaced when nondestructive measurements have forecasted the end of usable tube life.

Eddy current methods (Probolog) have, for some time, been used to detect excessive thinning.⁽²⁾ Unfortunately, at any given cross section of a tube, the wall thickness of the entire annulus is averaged, thus preventing identification of top or bottom corrosion and furthermore preventing identification of heavy localized thinning from light uniform thinning. An eddy current sector gage method was developed to enable detection of localized areas,⁽³⁾ but failed to live up to expectations in reactor trials.

Ultrasonic methods were then considered⁽⁴⁾ and found to have some apparent advantages over eddy current methods: (1) capable of making measurements on localized areas, (2) relatively insensitive to temperature fluctuations, (3) not affected by the presence of graphite around the outer surface of the tubes, (4) relatively insensitive to inhomogeneities of the aluminum, and (5) capable of making measurements within the region of the "gun barrels". Pulse-echo ultrasonic techniques appeared to be preferable to resonance techniques since surface roughness was expected and fast testing was required. An "off-the-shelf" piece of commercial equipment was available and the decision was made to lease

the equipment for the purpose of establishing the feasibility of pulse-echo ultrasonic measurement methods.

SUMMARY

Ultrasonic thickness measurements were made on three tubes at D Reactor. Distorted echoes were received over substantial portions of each tube resulting in poor recordings for those portions. Despite poor recordings, some interpretation was possible and estimated thicknesses correlated reasonably well with actual measurements on two tubes removed and cut into pieces.

Four heavily filmed pieces were ultrasonically examined before and after film removal. Both film and closely spaced corrosion pits were found to contribute to distortion and loss of echoes needed for thickness measurement. Erroneous readings will result during measurement of heavily filmed areas even if good echoes are returned. Error will be reduced by operating on back surface echoes rather than a front and a back surface echo. Oscilloscope interpretation of RF pulse waveforms is preferable to a recorded readout.

Performance of the high resolution pulse-echo ultrasonic instrument can be improved through circuit modifications, but its greatest usefulness appears to be as a companion to, rather than a replacement of, the Probolog.

CONCLUSIONS

Corrosion product film and/or corrosion pits -- particularly closely spaced corrosion pits, i.e., when dimensions of pit and distance between adjacent pits approaches ultrasonic beam cross-section dimensions -- will distort echoes to the extent that continuous thickness readings throughout the length of a tube will be impossible.

When surface conditions are favorable, measurement accuracy -- according to the instrument manufacturer and largely substantiated -- will be ± 1 percent or better. Minimum aluminum thickness measurement ability is about 0.019 in.

Testing speed of up to 24 ft/min is possible although additional development would be needed to simultaneously test top and bottom areas using just one instrument. Circumferential width of a sector being tested is limited to about 0.080 in. for reasons related to transducer design. If sectors wider than 0.080 in. are required, multiple transducers on both top and bottom would be needed although a nominal increase in width may result from additional transducer development. Maximum length measured is the crystal beam dimension in the longitudinal direction, also about 0.080 in.

IN-REACTOR TUBE THICKNESS MEASUREMENT

A. Procedure

Multiple runs were made on each of three tubes -- #1485, a relatively new core tube, and #4573 and #4583, relatively old fringe tubes. Each run consisted of a manual pull-through of the ultrasonic probe assembly beginning at about 4 to 5 ft from the rear Van Stone flange and ending at about 7 to 9 ft from the front Van Stone flange. Pull-through speed varied from 14 ft/min to 24 ft/min. Three crystals were mounted on the probe -- at $22-1/2^\circ$, 180° , and $337-1/2^\circ$, referenced to the tube's top, (See Figure 1 for crystal aiming geometry.) Only one crystal was electrically connected for each run. A number of runs for each crystal were required to optimize the amplifier sensitivity setting as an evaluation of reproducibility. Readout was recorded on a strip chart recorder.

B. Results

The greater part of all three tubes returned poor echoes to the extent that considerable interpretation was necessary. In general, better echoes were returned from upstream and middle portions than from downstream portions. The apparent dominant echo distorting condition was a multiple front surface reflection which caused readings considerably thinner than true thickness.

FIGURE 1

Wall Thickness Measurement Ultrasonic Probe - Crystal Locations

A rough front surface is the most likely cause of a multiple peaked reflection. Other signal distorting situations such as loss of all echoes and loss of echoes following the front surface echo also occurred. Readout under such circumstances would fluctuate from minimum to maximum. Interspersed with distorted echoes were enough good echoes that, with some interpretation, thickness estimates could be made.

Tube thickness profile charts are shown in Figures 2 through 7. The dashed and crossed parts of the curves indicate regions where estimating was necessary. Actual measured thicknesses -- where available -- are also shown as comparison profile charts.

Examples of actual chart recordings are shown in Figures 8 through 17. Figures 8 and 9 are examples of good results; poor results are just starting to appear at about 25 ft. These two figures also typify reproducibility of identical runs. Figures 10 and 11 are examples of poor results. After tube removal, 4 pieces from the region included in Figures 10 and 11 were ultrasonically re-examined. A discussion of results appears elsewhere in this report. Optimum sensitivity setting varies from crystal to crystal. The effect of too high sensitivity is seen when Figure 12 is compared to Figure 13 -- both recordings of the same region. The most likely cause of the fluctuations in the thin direction in Figure 12 is the rough surface echoes forming a multiple peaked front surface echo. Time measurements are incorrectly made on these peaks rather than on the front surface and back surface echoes. An explanation of rough surface effects on instrument readout follows under the Discussion Section, page 23. The effect of too low sensitivity is shown in Figure 14. The excursions in the thick direction are caused by loss of echoes subsequent to the front surface echo. Recordings of tube # 1485, the one

FIGURE 2

Thickness Profile, Top - Tube No. 4573-D

FIGURE 3

Thickness Profile, Bottom - Tube No. 4573-D

FIGURE 4

Thickness Profile, Top - Tube No. 4583-D

FIGURE 5

Thickness Profile, Bottom - Tube No. 4583-D

FIGURE 6

Thickness Profile, Top - Tube No. 1485-D

FIGURE 7

Thickness Profile, Bottom - Tube No. 1485-D

FIGURE 8
Example of Good Results

wall
thickness
in inches

FIGURE 9
Example of Good Results

FIGURE 10
Example of Poor Results

· wall
thickness
in inches

FIGURE 11
Example of Poor Results

FIGURE 12
Sensitivity Too High

wall
thickness
in inches

FIGURE 13
Same Region as in Figure 12, Correct Sensitivity

FIGURE 14

Sensitivity Too Low

wall
thickness
in inches

FIGURE 15

Bottom of Tube No. 1485-D — Opposite to Thin Region

FIGURE 16

Thin Region, Top of Tube No. 1485-D

wall
thickness
in inches

FIGURE 17

Thin Region, Top of Tube No. 1485-D

not removed from the reactor, are shown in Figures 15, 16, and 17. Figures 16 and 17 are examples of fair results with some poor results regions.

EXAMINATION OF PIECES FROM REMOVED TUBE

A. Procedure

The cause of poor echoes from large portions of the three tubes involved in the in-reactor trial was thought to be closely spaced corrosion pits and/or film. Two tubes, #4573 and #4583, were removed and partly cut into small pieces for micrometer measurement. Four heavily filmed top and bottom pieces were selected from poor echo regions of tube #4573 for additional ultrasonic examination. Original locations of these pieces were at 10 ft 9 in. and at 7 ft 9 in. from the rear Van Stone flange. Each piece was examined at a number of regions using a crystal identical to those used in the in-reactor trial. Film was then removed and the examination of each piece repeated at the same amplifier sensitivity setting as used before film was removed. See Figures 19 through 26 for photos of the four pieces before and after film removal. Manipulating equipment was such as to prevent re-examination of the precise regions examined before film removal. Nevertheless, there was a degree of uniformity on each piece permitting an evaluation of the general effects of film and corrosion.

B. Results

Lighter colored film apparently causes less signal distortion than does darker colored film. Clean echo waveforms were common on light film areas, but practically nonexistent on dark film areas. See Figures 27 and 34 for examples of echoes from light film areas. Time base on photos of Figures 27 through 46 is 200 nanoseconds per large division.

FIGURE 19
7'9" Top
Before Film Removal

FIGURE 20
7'9" Top
After Film Removal

FIGURE 21
7'9" Bottom
Before Film Removal

FIGURE 22
7'9" Bottom
After Film Removal

FIGURE 23
10'9" Top
Before Film Removal

FIGURE 24
10'9" Top
After Film Removal

FIGURE 25
10'9" Bottom
Before Film Removal

FIGURE 26
10'9" Bottom
After Film Removal

FIGURE 27

7'9" Top, Light Film, Good Echoes

FIGURE 28

7'9" Top, Dark Film, Two Part Front Surface Echo

FIGURE 29

7'9" Top, Dark Film, Loss of All Echoes

FIGURE 30

7'9" Top, Dark Film, Loss of First Back Surface Echo

FIGURE 31

7'9" Top, Dark Film, Loss of all Back Surface Echoes

FIGURE 32

10'9" Bottom, Dark Film, Loss of Front Surface Echo

FIGURE 33

7'9" Top, Edge of Dark Film Area, Two Part Front Surface Echo

FIGURE 34

7'9" Top, Light Film, Typical

FIGURE 35

7'9" Top, Dark Film, Typical

FIGURE 36

7'9" Top, Light Film, Immediately Adjacent to Area of Figure 35

FIGURE 37

7'9" Bottom, Dark Film, Typical

FIGURE 38

7'9" Bottom, No Film, as Close as Possible to Area of Figure 37

FIGURE 39

10'9" Top, Film Removed, Typical

FIGURE 40

7'9" Top, Film Removed, Typical

FIGURE 41

10'9" Bottom, Film Removed, Two-Part Front Surface Echo

FIGURE 42

10'9" Bottom, Film Removed, Good Echoes Immediately Adjacent to
Area of Figure 41

FIGURE 43

10'9" Bottom, Film Removed, Two Part Front Surface Echo

FIGURE 44

0.065 in. Standard

FIGURE 45

0.035 in. Standard (Etched Surface)

FIGURE 46

0.021 in. Standard

All known signal distorting situations were found on the film covered samples:

1. Multiple peaked front surface echo which causes a false reading in the thin direction (See Figure 28).
2. Loss of all echoes -- which causes a false reading in the thin direction (See Figure 29).
3. Loss of first back surface echo -- which causes a false reading in the thick direction (See Figure 30).
4. Loss of back surface echoes -- which causes a false reading in the thick direction (See Figure 31).
5. Loss of front surface echo but presence of subsequent reverberations -- which generally results in near correct readings (See Figure 32).

Signal distorting situations occur in about half the area; most frequent situations were Nos. 1, 2, and 4.

Further indications of film properties are seen in Figure 33. The crystal was maneuvered to the edge of a dark film area. The two-part surface echo indicates dark film thickness of about 0.003 in. greater than adjacent area. Film thickness of the adjacent area cannot be determined from Figure 33. A typical echo from dark film is seen in Figure 35. A light film echo from an area close to that of Figure 35 is shown in Figure 36. Note that signal waveform is less distorted over light film than over dark film.

Little corrosion was present on the 7 ft 9 in. bottom sample. Echoes from this sample were substantially better with film removed than with film present. For example, Figure 38 shows the improved waveform obtained at the approximately same location as Figure 37 after film has been removed. Etch type corrosion was present on both top samples. Echoes from light film

regions of these samples generally became worse after film was removed. See Figures 39 and 40 for examples.

Corrosion areas in the 10 ft 9 in. bottom sample were more widely spaced compared to the top pieces. Echoes from this piece were about the same with or without film -- sometimes good, sometimes bad. See Figures 41, 42, and 43. A two-part surface echo has resulted from the rough corroded surface as seen in Figure 43.

Thickness readings were slightly greater before film removal than after film removal. This and the multiple peaked surface echoes at the edges of dark film substantiate the premise that film will cause a false reading. It was noted also, with film present, that time between front surface and back surfaces echoes' leading edges was greater than the time between first and second back surface echoes. With film removed, these times were the same.

Echo waveforms from micrometer measured standards are shown in Figures 44, 45, and 46.

DISCUSSION

Considerable interpretation of test results was found to be necessary to establish estimated thickness readings. A high level of recorder fluctuation was responsible for lack of readily definitive recordings. Recorder fluctuation was caused primarily by a rough inner surface due to film and corrosion. The predominant effect on echoes from the rough surface was to cause a multi-peaked front surface echo. If spacing between peaks was great enough, the instrument would interpret the peaks as front and back surface echoes and a false reading would result. (A discussion of instrument operation is found in the Appendix under Principle of Operation, page ii.) These false readings will be on the thin side of actual thickness with probably a large proportion at the minimum limit setting of 0.019 in.

See Figure 47 for an illustration of the effects of rough surface. If wall thickness is 0.060 in. with no roughness, time between front and back surface echoes is 0.48 μ sec. With a wall thickness of 0.025 in. echo time spacing will be 0.20 μ sec. If a surface depression should intercept a portion of the ultrasonic beam, a multi peaked surface echo will result. In Figure 47, time spacing between front surface echo peaks is 0.205 μ sec as a result of a 0.006 in. deep corrosion pit. A false reading of about 0.025 in. wall thickness will occur whereas minimum thickness is actually 0.054 in. If echo b' blended into echo a' so that a single wide front surface echo was returned, the readout would be 0.060 in. rather than 0.025 in. or 0.054 in. since the readout circuitry will operate on the leading edges of the surface echoes.

Beam diameter of crystals used in this project was about 0.060 in. to 0.080 in. -- too large to fit within most individual pits and thereby reduce multi peaked surface echoes. Smaller diameter beams are possible but not recommended due to expected excessive beam scatter.

Time did not permit determination of the elastic properties of corrosion product film, but ultrasonic examination of the four cut pieces proved that film is not transparent to ultrasound. The extent of reflection at a film interface will be dependent on its characteristic impedance, Z_o . If film's Z_o is considerably less than that of aluminum but considerably more than that of water, as thought to be, then echoes will occur at the water-film interface and at the film-aluminum interface. Echo amplitude at both interfaces; however, will be less than that from a water-aluminum interface. The longitudinal velocity of film is thought to be about that of water (58,500 in./sec). With such a slow velocity, the effect of film on measurement accuracy would be

FIGURE 47

Ultrasonic Reverberation Patterns in Aluminum with and Without Corrosion Pit

appreciable since the first echo components of the front surface echo will be from the water-film interface. The probable effect of film is illustrated in Figure 48. Echoes from the film-aluminum interface will confuse the readout circuitry.

Accuracy will improve with thinning film as the film-aluminum echoes will die out before the back surface echo arrives. The problem of multi-peaked front surface echoes, as caused by rough film and significant echoes from the film-aluminum interface, will still cause measurement error. Accuracy will be improved by utilizing the back surface echoes -- echoes d and h in figure 48 -- since they do not include error due to film thickness t_1 .

RECOMMENDATIONS

A number of instrumentation improvements may be made to improve readout. Inasmuch as undistorted echoes appeared no less than at least once per half inch of longitudinal travel, a basis exists for thickness measurement of half inch increments. A problem of discriminating between actual thinning and false indicated thinning can be reduced by increasing the measurement system's amplifier response time constant; this would have the effect of blending together the multiple peaks of a front surface echo. Such would be accomplished at the expense of resolution. For example, minimum thickness resolution might become 0.030 to 0.040 inch in order to eliminate a significant amount of multiple peaking.

Further improvement can be made by modifying the readout circuitry and using a faster responding recorder. Since most distorted echo situations result

FIGURE 48

Ultrasonic Reverberation Patterns (Simple) in Film Covered Aluminum

in recorder fluctuations in the thin direction, a longer time constant should be imposed in the thin direction. A fast recorder, such as a light-galvanometer recorder, would respond at the slow driving rate of the ultrasonic instrument's readout circuitry -- in the thin direction -- but would return very quickly to the correct thickness reading. An undesirable effect of such changes would be to increase the minimum length of a corrosion thinned area that may be detected. For example, minimum length, as established by recorder transient response time, could be increased to about one inch.

Multiplexing of a multiple crystal array and corresponding amplifier, readout, and other circuitry, while technically feasible, is judged to be too complex and potentially troublesome for use in an in-reactor environment. If simultaneous measurement of both top and bottom are desired, multiple instrumentation would be preferred. Some circuit functions need not be duplicated and packaging for a two or three sector test instrument would not be difficult.

Other techniques -- not recommended at this time -- could improve readout accuracy. Some of these techniques are: (1) one-inch interval recycling multi-channel pulse height analysis of the readout thickness analog waveform which would show a large percentage of total count at one thickness -- presumably the correct thickness, (2) gating on the first two back surface echoes rather than on the first front surface echo and the first back surface echo; or develop a dual gating concept whereby the better of two readings is selected for the recorded readout, and (3) logarithmic or automatic gain control.

If no additional development is wanted at this time, considerable usefulness nevertheless would be obtained from using the instrument as-is with an operator readout for interpretation of the RF pulse-echo waveforms on a monitoring oscilloscope. Inasmuch as a visual interpretation can only be made with the probe at rest, the operator interpretation technique would be most applicable in inspecting suspect regions located with the Probolog.

REFERENCES

1. D. E. Strege, J. R. Young, Reactor Process Tube Damage, HW-68222, March 1, 1961.
2. J. M. Fouts, The Probolog's Role in the Measurement of Reactor Process Tubes, HW-62124, December 28, 1961.
3. R. V. Dulin, A System for Measurement of Wall Thickness of Corroded Aluminum Reactor Process Tubes, HW-SA-3106, October 11, 1963.
4. R. L. Brown Jr., Study of Feasibility of Aluminum Process Tube Wall Thickness Measurement, TM-MEMO-65-1, February 1, 1965.

APPENDIX

MEASUREMENT REQUIREMENTS

Measurement requirements are defined in L. V. Barker's letter to D. C. Worlton, dated October 9, 1964. They are summarized as follows:

1. The developed instrument shall be capable of making in-reactor measurements of (a) 90° to 120° top sector, and (b) the bottom sector between tube ribs (about 60°).
2. Minimum thickness resolution is 0.035 in.
3. Measurement error shall be no greater than ± 0.002 in.
4. Local corrosion areas such as 0.375 in. diam by 0.010 in. deep should be detectable.
5. Maximum length of measured sections should not exceed 1.0 in.
6. Measurements to be conducted top and bottom simultaneously at a probe pull-through speed of 12 to 24 ft/min.

Allowances were included for modification of requirements according to operational needs and instrument characteristics.

LIST OF EQUIPMENT

A. Leased Equipment

1. Sperry UM721 Display and Timer Chassis
2. Sperry 50E568 TR Thickness Module
3. Automation Industries 57C3815B Pulser Amplifier Module

B. Purchased Equipment

1. Three special transducers -- 22 MHz damped, spherically focused lithium sulphate
2. One special transducer - 22 MHz damped wedge focused lithium sulphate

C. Laboratory Equipment

1. Tektronix 551 Oscilloscope, Type L Plug-in.
2. Tektronix C-12 Oscilloscope Camera

3. Probe assembly designed and fabricated by BNW Testing Methods personnel
4. Sanborn Dual-Channel Strip Chart Recorder Model 320
5. Portable test tank and crystal manipulator for irradiated specimens

D. Test Specimens

1. Flat and curved aluminum plates of various thicknesses
2. Sections of unirradiated process tubes of various thicknesses
3. A process tube section with machined o.d. steps in 0.004 in. increments to cover the thickness range from 0.019 in. to 0.067 in.
4. Mock-up reactor tube at 108-B Building -- composed of "new-thickness" sections, a clear plastic section and eleven short sections of varying thicknesses, all taped and clamped together to make one continuous tube. Vertical and horizontal displacement of the tube's central regions were adjustable to simulate reactor tube's bowing and warp.
5. Reactor process tubes of "D" reactor: #4573, 4583, 1485.
Reactor process tubes of "B" reactor (mechanical tests only).
6. Cut-up pieces from reactor tube #4573: top and bottom pieces at 7 ft 9 in. and 10 ft 9 in. from rear Van Stone flange.

PRINCIPLE OF OPERATION

A high frequency (about 22 MHz) crystal is pulsed with a narrow time duration (about 35 μ sec) pulse. The resultant ultrasound pulse travels to the process tube wall where a portion of it reflects from the front surface. Another portion penetrates the wall and then reflects from the back surface. A part of this latter energy trails the front surface echo back to the crystal. The spacing between the two pulses is a measure of the wall thickness. Analog

circuits operate on the two pulses to provide a voltage readout -- the amplitude of which is proportional to wall thickness. Readout voltage to a recorder occurs at the pulse repetition rate (normally 2000 pulses/sec) enabling an independent thickness reading for every pulse. Averaging takes place at the instrument's thickness meter resulting in a smooth indication.

DEVELOPMENT PRECEDING IN-REACTOR TRIAL

Ultrasonic Instrument - See Figure 49

Circuit modifications were necessary to enable usage of 50 ft cables connecting the pulser-amplifier to the probe crystal. Purpose of the modifications was to eliminate "ringing" of the cable and consequent false readouts, and was accomplished by impedance matching the instrument to the 70 ohm cable. See Figure 50 for an illustration of echo waveforms before and after impedance matching. Series inductive peaking was also added at the crystal end of the cable: about 0.8 μ Henry in shunt with 220 ohm resistance.

Amplifier modifications were made in an attempt to reduce a tendency to form a multiple peaked front surface echo. One RF amplifier stage was tuned, and detector and pulse amplifier stages' time constants were increased. See Figures 51 and 52 for echo waveforms before and after amplifier modifications. Due to the nature of the amplifier's design and layout, more extensive modifications were not feasible (on leased equipment) and the problem of multiple peaked front surface echoes, although improved, was not entirely corrected.

An additional small measure of improvement was observed by increasing water path from about 0.2 in. to about 0.4 in. A water path of about 0.2 in. is fixed in the present probe design, but in the event of redesign, water path should be increased to 0.4 to 0.5 in.

FIGURE 49

Sperry Ultrasonic Thickness Measurement Instrument

Top - RF Echo Pulses with Cable Impedance Matching

Bottom - RF Echo Pulses Without Cable Impedance Matching

FIGURE 50

Reverberations with Multiple Peaked Front Surface Echo

Top - Video Output

Bottom - RF Output

FIGURE 51

Reverberations with Single Peak Front Surface Echo - After Circuit Modifications

Top - RF Output

Bottom - Video Output

FIGURE 52

Probe Design and Development

The probe was designed to carry an array of eight crystals -- 5 on the top and 3 on the bottom. See Figures 53 and 54 for photos of the probe. Alignment was maintained by spring loaded shoes located on the top side of each end pushing the end blocks against the tube ribs. See Figure 55 for an illustration of an end block cross section. Fixed position guide blocks located within the ribs maintain circumferential position. The probe is assembled to be water tight; electrical matching networks are located within the probe body. Sealtight flexible electrical conduit is used to seal the probe end, protect the electrical cable, and provide a means to push and pull the probe through the reactor tubes. Distances were marked off at 6 in. increments so that position within the reactor could be determined. A nozzle adapter seals the end of a reactor tube while water pressure, inserted at the adapter, helps push the probe down the tube. Water flow is maintained during pull back to insure that continuous water coupling exists between crystals and tube that ultrasonic pulses may not be interrupted. Water channels located on the side of the end blocks are slanted so that water flow will assist the spring loaded shoes in maintaining probe alignment.

Difficulty was experienced during trial runs at the 108-B mock-up facility. The probe would frequently twist out of the ribs' guide track in thin wall regions and then become stuck when thicker wall regions were reached. As a result of these experiences, the fixed position guide block was widened and deepened, and the edges on the spring loaded shoe were rounded to permit freer rocking motion. In addition, stronger springs and rounded end guide blocks (See Figure 53) were made up but not used.

A noninstrumented probe trial was conducted at B-Reactor to evaluate probe design before the instrumented trial at D-Reactor was to be done. Although

FIGURE 53

Wall Thickness Measurement Ultrasonic Probe - Probe Head

FIGURE 54

Wall Thickness Measurement Ultrasonic Probe Assembly

FIGURE 55

Wall Thickness Measurement Ultrasonic Probe - Support and Positioning Methods

the probe became stuck in one of the six tubes tried, it was dislodged without damage and after minor modifications was judged to be of satisfactory design for the instrumented trial. Future probe sticking was to be minimized by keeping torsional forces on the probe at a minimum.

Although the probe was manually pushed and pulled throughout its various trials, a constant speed mechanized puller is recommended for future usage if recordings are to be made.

Additional probe details may be found on Hanford drawing H-3-85872.

Ultrasonic Crystal Transducers

Photos of the crystals are seen in Figures 53 and 54. Additional details may be found in Hanford drawing H-3-25873. Two of the crystals used in the reactor trial ($22\text{-}1/2^\circ$ and 180°) were spherically focused whereas the $337\text{-}1/2^\circ$ crystal was wedge focused with the long axis in the longitudinal direction. A significant reduction in multiple peaked front surface echoes was noted by using the wedge focused crystal during a trial in the 108-B mock-up tube. Better results, in general, were also obtained during the reactor trial from the wedge focused crystal than from the spherically focused crystal. Improvement is attributed to a reduced effect from tube curvature.

Laboratory Experiments

Laboratory experiments were intended to provide depth resolution data and to uncover possible obstacles to the anticipated in-reactor application. Readout accuracy is specified by the manufacturer to be ± 1 percent of the difference between upper limit and lower limit settings. The readout was noted to be accurate, but no attempt was made to verify 1 percent accuracy. Not only was accuracy capability considered to be of secondary importance during the development phase, but also there is some ambiguity exceeding 1 percent normally attached to measurements on pitted curved surfaces.

Measurements were successfully taken on flat and curved aluminum specimens as thin as 0.019 inch. See Figure 56 for a recording of a process tube sample with sections machined in 0.004 in. increments. The manufacturer provided a chart recording as evidence that the instrument could measure as thin as 0.016 inch. Aluminum specimens as thick as 0.125 inch were also measured. 0.125 inch is by no means an upper limit, but merely the thickest specimen used during laboratory experiments.

108-B Mock-Up Experiments

A simulated reactor process tube was made available at 108-B Building. The tube consisted of eleven small aluminum sections and a clear lucite section taped to each other and also to longer sections, one of which was attached to a front face gun barrel. Thicknesses of the sections varied from about 0.031 inch to about 0.064 inch. The sections are supported in such a manner that up to about 2 inches of curvature can be put into the assembled tube to simulate drooping and buckling that exists in actual reactor tubes. A large number of trials were made at the facility. Probe mechanical improvements were made as a result of early tests. Some instrument modifications were also made based on findings from mock-up experiments. See Figure 57 for a recording of the bottom part of the mock-up tube.

FIGURE 56

Recording of a Process Tube Section with O.D. Machined in 0.004 in. Steps

xii

FIGURE 57

Recording of Bottom (180° Crystal) of 108B Mock-up Tube

BIBLIOGRAPHY

1. Letter from C. G. Lewis to D. C. Worlton, August 27, 1964.
2. R. L. Brown Jr., TM-MEMO-64-18, Review of the Sector Wall Thickness Gauge, September 24, 1964.
3. Letter from L. V. Barker to D. C. Worlton, October 9, 1964.
4. Letter from J. C. Spanner to C. G. Lewis, October 21, 1964.
5. Letter from J. C. Spanner to C. G. Lewis, January 25, 1965.
6. Letter from R. L. Brown Jr. to J. R. Spink, January 25, 1965.
7. R. L. Brown Jr., TM-MEMO-65-1, Study of Feasibility of Aluminum Process Tube Wall Thickness Measurement, February 1, 1965.
8. Letter from C. G. Lewis to J. C. Spanner, February 16, 1965.
9. D. O. Hunter, Trip Report, BNWL-CC-168, July 11, 1965.
10. Letter from C. E. Bowers to J. C. Spanner, August 23, 1965.
11. D. O. Hunter, Trip Report, Testing Methods Engineering, September 17, 1965.
12. Letter from B. E. Dozer to C. E. Bowers, October 6, 1965.
13. Letter from D. O. Hunter to C. E. Bowers, April 12, 1966.
14. Letter from D. O. Hunter to C. E. Bowers/C. B. Organ, May 9, 1966.
15. Laboratory Record Book, BNW-234, D. O. Hunter.
16. Monthly Report Notebook, D. O. Hunter, May 1965 through June 1966.