BNWL-1302

UC-37

2-

2-70

EVALUATION OF THE SPERRY ULTRASONIC
WHEEL INSPECTION UNIT

R. W. Smith
N. L. Johnson

February 1970

AEC RESEARCH &
DEVELOPMENT REPORT

ROUTE TO	FROM	LOCATION	FILE NUMBER

BNWL-1302

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

3 3679 00061 8845

BNWL-1302
UC-37, Instruments

EVALUATION OF THE SPERRY ULTRASONIC
WHEEL INSPECTION UNIT

by

R. W. Smith
N. L. Johnson

Nondestructive Testing Department
Systems and Electronics Division

February 1970

BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORIES
Richland, Washington 99352

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

EVALUATION OF THE SPERRY ULTRASONIC
WHEEL INSPECTION UNIT

R. W. Smith
N. L. Johnson

ABSTRACT

The Sperry wheel ultrasonic inspection unit, Model 50D467, was evaluated for remote surveillance of the FFTF pressure vessel during reactor shutdown. Facilities for testing transducers and transducer components in the FFTF environment were developed. A number of materials were tested for use in the projected FFTF environment.

The Sperry wheel has three drawbacks which make it unsuitable for use in the FFTF environment. These are: 1) it cannot be used on a dry surface, 2) a number of the components will not tolerate the projected environment, and 3) the acoustic noise level is too high for FFTF surveillance.

19	Comparison of Transducer Backing Members: (a) Standard Sperry Wheel Transducer, (b) Lavite Backed Transducer, (c) Sintered Metal Backing Member.	28
20	A Closer View of the Transducer of Figure 19, Showing the Damping Rate.	29
21	Ultrasonic Velocity of Sperry Fluid Versus Temperature.	35
22	Ultrasonic Wave Velocity of Polyglycol E-200 Versus Temperature . .	36
23	Ultrasonic Velocity of Polyglycol P-400 Versus Temperature. . . .	37
24	Ultrasonic Wave Velocity of Polyglycol P-1200 Versus Temperature. .	38
25	Ultrasonic Wave Velocity of Dowtherm A Versus Temperature	39
26	Ultrasonic Wave Velocity of Ambliflo H-149 Versus Temperature . .	40
27	Ultrasonic Wave Velocity of Fluorosilicone FS-1265 Fluid Versus Temperature	41
28	Ultrasonic Wave Velocity of Dow 710 Fluid Versus Temperature. . .	42
29	Device Used to Measure Ultrasonic Velocities of Fluids at High Temperatures	43
30	Rectangular Samples for Compatibility Tests of Silastic 52 and 82 .	47
31	Small Furnace	50
32	Temperature Profile of Small Furnace.	51
33	Large Furnace	52
34	Temperature Profile of Large Furnace.	53
35	Dynamic Tester.	54
36	Test Standards.	55

EVALUATION OF THE SPERRY ULTRASONIC
WHEEL INSPECTION UNIT

R. W. Smith
N. L. Johnson

INTRODUCTION

Our investigation specifically involves evaluating the Sperry Model 50D467 high temperature, ultrasonic wheel* (Figure 1) for the Fast Flux Test Facility (FFTF) in-service inspection, substituting improved materials where possible, and recommending modifications and additional development if deemed necessary. This unit was proposed by Westinghouse⁽¹⁾ for inspection of vessel belt welds and primary piping during reactor shutdown. Battelle-Northwest was requested to evaluate this unit for FFTF surveillance,^(2,3) as the projected FFTF environment exceeds the design specifications of the Sperry wheel.

This report outlines our evaluation procedures, reports the evaluation results and describes the facilities which we developed to test transducers in the projected FFTF environment.

*Automation Industries, Danbury Division, Danbury Conn.

FIGURE 1. Sperry Wheel Inspection Unit

SUMMARY AND CONCLUSIONS

We evaluated the Sperry ultrasonic wheel inspection unit which was proposed for the remote inspection of the FFTF reactor vessel and piping during reactor shutdown. Test facilities for evaluating the ultrasonic inspection unit were developed.

The high temperature Sperry ultrasonic wheel unit has three major drawbacks which make it unsuitable for use in the projected FFTF environment. These are:

- The inspection unit cannot be used on a dry surface.
- A number of the components will not tolerate the projected FFTF environment. These include 1) a velumoid gasket, 2) a teflon insulated coaxial cable, 3) a teflon electrical connector, 4) a teflon backing ring for the axle seals, 5) the axle seals, 6) the cable seal, 7) the transducer component, 8) the couplant fluid, and 9) the silicon rubber tire.
- The acoustic noise level is above acceptable limits for FFTF vessel surveillance.

We demonstrated the feasibility of dry coupling ultrasound into stainless steel. However, our tests show that a pressure of the order of 150 psi is necessary to dry couple ultrasound from a 50 durometer rubber into 304 stainless steel having a 125 μ in. surface finish. It is not possible to apply more than 5 psi with the Sperry wheel.

We were able to find improved materials for all of the unsuitable components. We feel that all of these components, with the exception of the tire, will operate for at least several hours at 500 °F. Compared to projected operating temperatures, we consider gamma radiation to be a minor problem. In our opinion, a fluid filled wheel inspection unit could be operated in the projected FFTF environment by cooling the coupling fluid below 400 °F. Our results indicate that, above 400 °F, elastomers suitable for use in the tire are not compatible with any of the coupling fluids which were tested.

Our recommendations for replacing the unsuitable components are:

- 1) Eliminate the velumoid gasket, or replace it with a metal gasket.
- 2) Substitute stainless steel sheathed cable with ceramic insulation for the teflon insulated cable.
- 3) Replace the teflon electrical connector with a ceramic insulated connector.
- 4) Replace the teflon backup ring with a metal ring.
- 5) Substitute commercially available Viton axle seals for the standard u-cup axle seals.
- 6) Use a Viton o-ring to seal around the coaxial cable.
- 7) Modify the transducer component by using a ceramic backing member to replace the standard slate-filled epoxy member.
- 8) Replace the couplant fluid with polypropylene oxide. A second choice for the couplant fluid would be Dow 710 fluid, a silicone oil. The polypropylene oxide has lower ultrasonic attenuation and slightly better compatibility with the elastomers tested, while Dow 710 fluid outgases much less due to radiation.
- 9) Use Silastic 52, a Dow Corning silicon rubber, for the tire. Of the materials tested, Silastic 52 is the most satisfactory in terms of the FFTF requirements. Viton or Fluorel compounds have better high temperature compatibility with the couplant fluids, however, they have high halogen contents.

The acoustic noise in the Sperry wheel is caused by reflections of the sound wave inside the wheel. Redesign of the wheel, taking steps to minimize these reflections, could substantially reduce this noise.

It its present form, the Sperry wheel is not suitable for the surveillance of the FFTF reactor vessel, and a major redesign of the wheel would be required to make it useable.

It is felt that additional development work should evaluate other transducer concepts as well as the fluid filled wheel transducer, with consideration of the FFTF weld inspection requirements such as weld configurations, defect size and orientation, transducer positioning capability, etc. Additional transducer configurations which could be considered are:

1. Solid wedge transducer
2. Solid wheel transducer
3. Fluid filled wedge

EVALUATION

The projected FFTF environment requires that an inspection unit function properly for an extended period in a 10^5 R/hr gamma field at 500 °F. The unit must be operated remotely and can present no danger of halogen contamination which could induce stress corrosion cracking in the vessel. Also, no residue can be left after the inspection; therefore, the inspection unit cannot be ultrasonically coupled to the pressure vessel with a fluid. We evaluated the Sperry wheel, which was suggested for this application by Westinghouse, on the basis of the above requirements. These requirements exceed the design specifications for the Sperry wheel.

The high temperature Sperry wheel inspection unit, Model 50D467, is essentially an ultrasonic transducer (2.25 MHz nominal frequency) mounted inside a fluid filled silicone rubber tire. The transducer is mounted on the axle of the wheel and is held in a fixed position relative to the test surface while the wheel rotates freely. The transducer is coupled to the tire with a mixture containing 50% water and 50% ethylene glycol. In operation the wheel is rolled over the area to be inspected. Normally, water is used to ultrasonically couple the tire with the test surface and to cool the unit. The wheel specifications are given in Appendix A.

The beam incident angle of the transducer can be varied in both the side and the forward/reverse directions. The side angle is variable from 0° to 50° and the forward/reverse angle is variable from -15° to +15°. Both angles are measured from perpendicular to the test surface. The commonly used mode of testing with the Sperry wheel is shear wave inspection. The shear wave is generated in the test specimen by mode conversion of the longitudinal wave at the specimen surface. The refracted wave angle in the test specimen is determined by the ultrasonic velocities of the couplant fluid and the test material, according to Snell's law. Incident angles above the critical angle for longitudinal waves are commonly used since then only shear waves will be present in the specimen, making test results easier to interpret.

TEST PROCEDURES

The Sperry wheel transducer was tested for accuracy and sensitivity, and the individual wheel components were evaluated for service in the projected environment. Recommendations were made for replacement materials. The investigation procedure is summarized below.

1. Procure the Sperry wheel, Model 50D467, and develop the facilities required to test and evaluate this transducer for the projected environment.
2. Conduct a literature search for the effects of radiation and temperature on materials and components used in the wheel.
3. Evaluate the wheel components for service in the projected environment on the basis of information in the literature.
4. Test the wheel components and replace inadequate components with satisfactory substitutes.
5. Design and fabricate a standard test block to test the sensitivity of the ultrasonic wheel unit.
6. Determine the sensitivity of the ultrasonic wheel unit.
7. Determine the accuracy and reproducibility of the ultrasonic wheel unit.
8. Determine the effect of specimen surface finish on the sensitivity of the ultrasonic wheel unit.
9. Test the ultrasonic wheel unit at 500 °F.

The investigation proceeded in this sequence, generally. Item 9 was not completed because the wheel unit did not meet the requirements for this application. The major problems with the wheel unit in its present form are that it will not operate in a 500 °F environment, it cannot be used on a dry surface, and it has a high noise level which makes it difficult to use effectively.

A detailed account of the evaluation procedures is included in the following sections. The topics are not discussed in the chronological order of the investigation listed above, but rather in their approximate order of importance.

TRANSDUCER SENSITIVITY

The response of the Sperry wheel unit to the defects drilled vertically into the 32 μ in. surface test block (see Test Facilities section) is illustrated by Figures 2 and 3. The test setups for these measurements are shown in Figure 4. The Sperry wheel was water coupled to the test surface and driven by a Nortec NDT-100 pulser. A 45° (approximately) shear wave was generated in the stainless steel. Figure 4a shows the test configuration for Figure 2. In this test the ultrasound was reflected off the back surface of the test plate once before reaching the test hole. The ultrasonic path length was about 5 in. one way in the stainless steel. For the results shown in Figure 3 the sound was reflected off the back surface twice (Figure 4b), traveling about 10 in. one way in the stainless steel. Figure 4c is a photograph of the test setup.

The noise in the Sperry wheel is caused by reflections inside the wheel and makes the unit difficult to use effectively. It would be difficult to detect the 1/16 in. diameter test hole if we did not know 1) that it was there and 2) its exact location. A future transducer design utilizing the wheel concept should minimize this noise.

Attempts to use the Sperry wheel on a dry surface were not successful. We could not apply enough pressure to get good acoustic coupling between the tire and the test block. However, using a conventional 5 MHz PZT transducer and a flat piece of silicon rubber we were able to couple sound quite effectively into a 250 μ in. surface (see Figure 5). No liquid couplant was necessary. The 1/4 in. diameter longitudinal transducer was pressed against the surface of the stainless steel test block with a 1/16 in. thick piece of silicon rubber sandwiched between the transducer and the block. Figures 6a and 6b show the response to the flat bottom of a 1/8 in. diameter and a 1/16 in. diameter test hole, respectively. The transducer is "looking" through 1-1/2 in. of stainless steel. A pressure

FIGURE 2. Sperry wheel responses to 1/2 in. deep flat bottom holes in stainless steel. The tire is water coupled to the test block. (a) Response to a 1/4 in. diameter hole. (b) 1/8 in. diameter hole. (c) 1/16 in. diameter hole. (d) No flaw. The test setup is shown in Figure 4a. Sweep speed is 20 $\mu\text{sec/division}$.

FIGURE 3. Sperry wheel responses to 1/2 in. deep flat bottom holes in stainless steel. The tire is water coupled to the test block. (a) Response to a 1/4 in. diameter hole. (b) 1/8 in. diameter hole. (c) 1/16 in. diameter hole. (d) No flaw. The test setup is shown in Figure 5b. Sweep speed is 50 $\mu\text{sec/division}$.

FIGURE 4. (a) Test Arrangement for Figure 2, (b) Test Arrangement for Figure 3, (c) Photograph of Test Setup

FIGURE 5. Test Arrangement for Dry Coupling Ultrasound into Stainless Steel

FIGURE 6. Flaw detection with a drysilicone rubber couplant using the test setup in Figure 5. (a) 1/8 in. flat bottom hole. (b) 1/16 in. flat bottom hole. Sweep speed 5 μ sec/division. NDT-100 gain 10 Vernier 7, high damping, low bandwidth.

of 150 psi or greater is necessary to reliably dry couple ultrasound from the 50 durometer rubber into the 250 μ in. surface.

The ultrasonic coupling as a function of pressure was measured for Silastic 52 (a 50 durometer silicone rubber) and for Silastic 82 (an 80 durometer silicone rubber) on 32, 63, 125, and 250 μ in. surface finishes. The amplitude of the first back surface echo was taken as a measure of the ultrasonic coupling. Figure 7 shows the coupling versus pressure relationships for Silastic 52 and 82 on the 32 μ in. surface, and for Silastic 52 on the 125 μ in. surface. Note that the coupling increases with increasing pressure until finally a point is reached where an increase in pressure does not increase the coupling. Ultrasonic testing should be done in the region above this "knee" of the curve for reliable results.

The curves in Figure 7 generally indicate that better coupling is obtained with the softer silicone rubber on a smooth surface. Silastic 52 couples into the 32 rms surface at 70 or 80 psi, Silastic 82 requires a about 250 psi, and a pressure of 120-130 psi is required to couple Silastic 52 with a 125 μ in. surface. The differences in the final

FIGURE 7. Ultrasonic Coupling Versus Pressure for Silastic 52 and Silastic 82 Silicone rubbers

amplitudes of these curves are attributed primarily to transducer alignment which was a problem during the experiment. A transducer misalignment of 1.25° reduces the return signal by 30%. Figure 8 shows the coupling/pressure relationship for Silastic 52 on a $63 \mu\text{in.}$ surface. Several curves were obtained for each block at different locations on the blocks. The differences are attributed to transducer alignment and

FIGURE 8. Dry Coupling Ultrasound from Silastic 52 into a 63 μin. Stainless Steel Surface

to local variations in the surface finish. The high and low curves for both Silastic 82 and 52 on a 250 μin. surface were compared in Figure 9. Note that Silastic 52 couples at about 150 psi, while the knee in the curves for Silastic 82 are never reached.

FIGURE 9. Comparison of the Ultrasonic Coupling Properties of Silastic 52 and Silastic 82

The pressure required to dry couple ultrasound across the stainless steel/silicone rubber interface was determined with the apparatus shown in Figure 10. This device was clamped to the test block with the silicone rubber touching the surface of the test block. The transducer was coupled to the silicone rubber with water or a high temperature fluid, and air

FIGURE 10. Device for Measuring Ultrasonic Coupling Pressure

pressure above the fluid forced the silicone rubber against the test block. The pressure of the silicon rubber against the test block was varied by adjusting the air pressure above the fluid. A Wallace and Tiernan 0-300 psi absolute pressure gauge measured the air pressure.

To measure the degree of coupling between the silicone rubber and the test block, the transducer was operated pulse-echo, and the amplitude of the first reflection off the back surface was noted. Figure 11 shows the response of a 5 MHz 1/4 in. diameter PZT-5 transducer operated in this test setup. The important reflections are indicated on the photograph.

FIGURE 11. Pressure coupling measurement, showing the important reflections. The test setup is shown in Figure 10. Sweep speed 10 $\mu\text{sec/division}$, NDT-100 gain 1, vernier full C.W., high damping, low bandwidth.

CALIBRATION AND REPRODUCIBILITY

Calibration of the Inspection Angle

The angle of the transducer element in the Sperry wheel unit has two adjustments. Specifications for the Sperry wheel indicate that the ultrasonic beam angle can be varied from 0° to 50° to one side of the wheel and -15° to $+15^\circ$ in the forward/reverse direction. These angles are illustrated in Figure 12.

The calibration curves and reproducibility of these adjustments were determined experimentally. Figure 13 shows the calibration curve for the side angle. Here the beam angle is plotted as a function of the dial setting. This angle is adjustable from -7° to $+53^\circ$. The maximum backlash on this adjustment is about $1\text{-}1/2^\circ$. The forward angle is plotted as a function of the dial setting in Figure 14. This angle is adjustable from -16° to $+12^\circ$, and the backlash is less than 0.2° . The beam angle on these calibrations is the angle of the ultrasonic beam inside the tire.

FIGURE 12. Beam Incident Angle Adjustments
(a) Side Angle, (b) Forward/Reverse Angle

FIGURE 13. Side Angle Calibration

FIGURE 14. Forward/Reverse Angle Calibration

The test arrangement used to make these measurements is shown in Figure 15. The tire is shown installed; however, the curves in Figure 14 were obtained with the tire off the wheel unit and with the transducer element submerged in a tank of water. The transducer was operated pulse-

FIGURE 15. Test Arrangement for Transducer Calibration and Accuracy Measurements

echo, and the sound was reflected off the 1/2 in. diameter ball bearing. The transducer was mounted at the center of the accurately calibrated D ring, with the ball bearing mounted on the D ring. After setting the ball at some angle, the return signal was peaked by adjusting the transducer angle.

Inaccuracies in the Inspection Angle

A temperature change in the ultrasonic coupling fluid used in an ultrasonic wheel unit can cause a shift in the inspection angle in the test specimen if the ultrasonic velocity of the couplant fluid is temperature dependent. Most fluids do have an ultrasonic velocity which decreases with temperature. It is therefore necessary to know the temperature dependence of the velocity to correct for this shift. The magnitude of this temperature-induced beam shift was calculated and is shown in Figure 16. Here, the increase in the shear wave angle in stainless steel induced by a 10 °F increase in the couplant temperature is plotted as a function of the shear wave angle in the stainless steel. A constant shear wave velocity in the stainless steel and a temperature of 500 °F is assumed, and the velocity versus temperature curve of one of the potential coupling fluids is used. This curve indicates that a temperature induced shift in the beam angle can be significant, particularly at large inspection angles.

The ultrasonic velocity of the couplant fluid also affects the magnitude of the inspection angle error caused by mechanical tolerance in the system. The possible error in the inspection angle is larger with a low velocity fluid than with a higher velocity fluid. This error was calculated and is shown in Figure 17 where the angular beam shift of a shear wave in stainless steel caused by a 1° shift in the incident beam is plotted as a function of the angle of the shear wave in the stainless. This curve is essentially the error in the shear wave angle caused by a 1° error in the incident wave. Two curves are shown, one for a fluid velocity of 0.030 in./μsec and one for a fluid velocity of 0.060 in./μsec. The error increases with decreasing ultrasonic velocity and with large inspection angles.

FIGURE 16. Change in the Angle of a Shear Wave in Stainless Steel Caused by a 10 °F Change in Temperature of Couplant

FIGURE 17. Change in the Shear Wave Angle in Stainless Steel
Caused by a 1 °F Change in the Incident Angle

Thus, the ultrasonic velocity of the coupling fluid used in the ultrasonic wheel unit has a significant effect on the accuracy of the unit. Because of this, the velocity of any potential coupling fluid was measured as a function of the fluid temperature. This measurement is discussed in a later section on Fluids and Elastomers.

TRANSDUCER COMPONENTS

Transducer components were initially evaluated on the basis of a literature search and manufacturers' specifications. Questionable parts were then tested, and recommendations were made for replacement materials which would operate satisfactorily in the projected environment.

We conducted a literature search to support the evaluation effort. We obtained information about radiation and temperature tolerances of materials used in the wheel components, specifically the organic materials and piezoelectric crystals.

For the organic materials the most severe environmental parameter is the 500 °F temperature. Most of the organic materials can tolerate the projected radiation level much longer than they will tolerate the high temperature. Information about the ultrasonic properties of organic materials at high temperature and about the compatibility of the components at high temperature is generally not available in the literature or from the manufacturer. Consequently, a significant testing effort was required.

Radiation damage to piezoelectric crystals and ceramics has not been extensively studied, and information in the literature is not conclusive. From a preliminary report by Kesselman⁽⁴⁾ in 1963, it appears that PZT is relatively radiation resistant and at the projected dose levels, radiation damage would not be a problem. We conducted a test (described under Transducer) which also indicates that radiation damage to the PZT-5 active element in the ultrasonic wheel unit will be negligible.

Component Evaluation

The ultrasonic wheel unit was disassembled, and the individual transducer components were evaluated for use in the FFTF environment. Our evaluation was based on information obtained in a literature search, on

information supplied by Sperry and other manufacturers, and on our test results. The most severe operating parameter proved to be the 500 °F operating temperature. Most of the components had enough radiation tolerance, and we were able to find satisfactory substitutes for those that did not.

The standard wheel components which are unsatisfactory for this application are (see Figure 18): 1) a velumoid gasket, 2) a teflon insulated coaxial cable, 3) a teflon electrical connector, 4) a teflon backup ring for the u-cup axle seals, 5) the u-cup axle seals, 6) an o-ring used to seal around the coaxial cable (not shown), 7) the transducer component, 8) the standard fluid couplant used inside the tire, and 9) silicon rubber tire. We can recommend replacements which will tolerate the projected environment for all of these components except the silicone rubber tire, and we can recommend an improved tire material which will tolerate the environment if cooling is provided for the coupling fluid. The specific parts are evaluated in the following paragraphs. Detailed testing and evaluation of elastomers and coupling fluids is discussed in a separate section, Fluids and Elastomers.

Velumoid Gasket

The velumoid gasket has a maximum useful temperature of 300 °F. At 500 °F the material chars and quickly becomes useless. This gasket serves no important function if the transducer is used in a dry environment. It could be replaced with a metal gasket, however.

Teflon Parts

The teflon parts, namely the coaxial cable, the backup ring for the axle seal, and the electrical connector will stand the 500 °F temperature. However, the projected gamma radiation level will quickly cause them to fail. A suitable replacement for the standard cable is a stainless steel sheathed coaxial cable, similar to the type manufactured by Electronic Specialties. A coil of this cable would allow repeated adjustment of the transducer angle. Standard high temperature cable connectors, supplied

FIGURE 18. Disassembled View of Sperry Wheel

with the cable, can replace the electrical connector. A metal backup ring can replace the standard teflon backup ring.

Transducer

Information in the literature about radiation damage to PZT ceramics is not conclusive. Therefore, a PZT transducer was operated in a gamma field (cobalt-60) to check the effect of radiation damage. A 1/4 in. diameter 2 MHz crystal was soldered to a 3/4 in. diameter by 1 in. stainless steel cylinder and operated pulse-echo. The element was pulsed continuously throughout the test, and the echos from the end of the cylin-

der were observed periodically. No significant change was noted after a total dose of 4×10^8 R. The dose rate was 5×10^5 R/hr.

Since the Curie temperature of PZT-5A is about 690 °F, this material can withstand the 500 °F temperature satisfactorily. We operated PZT-5A transducers at 500 °F to measure the ultrasonic velocity of the coupling fluids, as discussed in the section on Elastomers and Fluids.

The lead-zirconate lead-titanate (PZT-5) piezoelectric ceramic used as the active transducer element in the Sperry ultrasonic wheel unit is satisfactory; however, the material used to back the transducer (Hysol type I slate filled epoxy) will not withstand temperatures above 250 °F. Therefore, the transducer was redesigned.

Important requirements for the transducer backing member are that it withstand the 500 °F temperature, that it be compatible with the coupling fluid, and that it be highly attenuative to ultrasound. For this application, it is also desirable that the acoustic impedance of the backing member match as closely as possible the impedance of the PZT-5 active element, to minimize transducer ringing.

Three materials were tested as possible replacements for the standard transducer backing member used in the Sperry wheel. These materials were 1) sintered metal, 2) lavite, a high temperature ceramic, and 3) polyimide. The lavite backing members were the most satisfactory, as the polyimide samples cracked on heating, and the sintered metals did not have a sufficiently high attenuation to ultrasound.

The lavite backing members were machined out of the ceramic and then fired to harden them. The transducer active element was fastened to the backing member with Sauereisen cement.

The sintered metal backing members were made by sintering mixtures of powdered metals and insulators together. Mixtures of aluminum, tungsten and silicon dioxide in a copper matrix were used. It is possible to adjust the acoustic impedance with this technique by varying the relative amounts of the component materials. Table 1 shows the acoustic impedances for a group of materials prepared by sintering. The acoustic impedances range from 33×10^5 to 55×10^5 g/cm²-sec. The ultrasonic attenuation for these materials was too low, however.

TABLE 1. Acoustic Impedance of Sintered Backing Material

<u>Metal</u>	<u>Sintered Formulation</u>	<u>Particle Size, μ</u>	<u>Longitudinal Acoustic Impedance, $\text{g/cm}^2\text{-sec}$</u>
50%	Copper	44	41.4×10^5
20%	Tungsten	44-54	
15%	Aluminum	10-44	
15%	Silicon dioxide	10	
70%	Copper	44	38.9
10%	Tungsten	44-54	
10%	Aluminum	10-44	
10%	Silicon dioxide	10	
75%	Copper	44	55.4
25%	Tungsten	44-54	
85%	Copper	44	51.9
15%	Tungsten	44-54	
90%	Copper	44	40.4
10%	Silicon dioxide	10	
80%	Copper	44	33.2
20%	Silicon dioxide	10	40.1
85%	Copper	44	
15%	Silicon dioxide	50-200	
	PZT-5		35

Figures 19 and 20 compare the responses of a lavite backed transducer, the standard transducer supplied with the Sperry wheel, and a sintered-metal backed transducer. The sintered-metal backing member was fabricated from an 85% copper/15% silicon dioxide mixture. The transducers were operated pulse-echo in water, and the pulse was reflected off a brass surface. In Figure 19 noise signals can be seen, in both the standard transducer and the sintered-metal backing member, between the transmit pulse and the first surface echo from the brass. This noise indicates the ultrasonic attenuation in the backing member is too low. No noise is seen in the lavite backed transducer. Note also that the signal amplitude of the sintered-metal backed transducer is considerably lower than the other two.

FIGURE 19. Comparison of transducer backing members. The ultrasonic pulse was reflected off brass in water. (a) Standard Sperry wheel transducer, (b) lavite backed transducer, (c) sintered metal backing member. Sweep speed 20 μ sec/div. NDT-100 gain 0.1, low damping high bandwidth.

Figure 20 is a closer look at the first and second echos from the brass (front and back surface), showing the damping rate of the transducers. Both the standard transducer and the sintered-metal backed transducer damp out faster than the lavite backed transducer. However, the lavite backed transducer is better than the sintered-metal backed transducer because of the higher signal level and the lower noise level. The damping rate of the lavite backed transducer can be improved with a destructive lens on the front surface of the element.

(a)

(b)

(c)

FIGURE 20. A closer view of the transducers of Figure 19, showing the damping rate. (a) The standard transducer, (b) lavite backed transducer, (c) sintered metal backed transducer. Sweep speed 4 $\mu\text{sec/div.}$, NDT-100 gain 0.1, low damping, high bandwidth.

Elastomer Parts

The elastomer components used in the Sperry wheel are two Buna N u-cup packing seals used to seal around the axles, A Buna N o-ring which seals around the coaxial cable, and the silicone rubber (Union Carbide K1305B) tire. Since the maximum recommended service temperature for Buna N compounds is 250 °F, this material will not withstand the projected environment. The standard tire is not compatible with couplant fluids at 500 °F. Suitable replacements for these materials are discussed in the section on Fluids and Elastomers.

Sperry Fluid

A mixture of 50% water and 50% ethylene glycol (Sperry fluid) is used to fill the silicone rubber tire. This mixture ultrasonically couples the transducer with the tire. Sperry fluid boils at a temperature under 300 °F and is, therefore, not a suitable fluid for this application. Replacements for the Sperry fluid are discussed in the section on Fluids and Elastomers.

Fluids and Elastomers

As noted above, the standard elastomer components and the coupling fluid are not suitable for operation at 500 °F. We conducted a market survey and testing program to find satisfactory substitutes for these materials. In this way we were able to 1) determine the feasibility of modifying the Sperry wheel from a materials standpoint, and 2) evaluate a number of materials for use in other transducer configurations.

Criteria for Selection of Fluids and Elastomers

Elastomers for use in an ultrasonic wheel inspection unit for this application must have 1) compatibility with any couplant fluid used, 2) high resistance to gamma radiation, and 3) the ability to tolerate temperatures up to 500 °F. In addition, elastomers for the tire should have 4) the ability to conform intimately to a 250 μ in. surface finish, 5) low halogen content, and 6) low attenuation to ultrasound.

Important properties of an ultrasonic couplant fluid for this application are 1) thermal stability and low vapor pressure at 500 °F or above, 2) low attenuation to ultrasound, 3) compatibility with the other transducer components, 4) low halogen content, and 5) an ultrasonic velocity of 0.030 in./μsec or higher at 500 °F. Most of these properties for both the fluids and the elastomers are not specified by the manufacturer or discussed in the literature. Consequently, an extensive testing effort was required to determine these unknown parameters.

Market Survey

An extensive market survey was conducted to find elastomers and fluids suitable for use in a fluid-filled ultrasonic inspection unit. Manufacturers of fluids and elastomers were asked to recommend materials which would meet the requirements outlined above. These manufacturers included a number of companies engaged in compounding elastomers for special applications, as well as manufacturers of base polymers.

Elastomers

The 500 °F temperature requirement eliminates most elastomers from further consideration. The only elastomers which are generally used at this temperature are fluorocarbon rubbers (Viton, Fluorel), fluorosilicone rubbers, and silicone rubbers. Even these materials are generally not recommended for long term use at 500 °F with organic fluids. The low halogen content required for the tire eliminated the fluorocarbon and fluorosilicone rubbers from consideration as tire materials (they should be useful seal materials, however).

Samples of the materials which were recommended by manufacturers were obtained and tested for this application along with the standard elastomers used in the ultrasonic wheel unit. These materials include:

1. Viton A, a fluorocarbon, Parker compound 77-545
2. Silicone rubber, Parker compound S604-7
3. Silastic 52, a silicone rubber, Dow Corning
4. Silastic 82, a silicone rubber, Dow Corning

5. Silicone rubber, Union Carbide K1305B, the material used in the standard high temperature tire
6. Buna N rubber, the material used in the standard seals.

All of these elastomers were tested for compatibility with the couplant fluids at high temperature, and the halogen content of the silicone rubbers was determined. These properties are discussed in later sections.

The effect of gamma radiation on the elastomers is indicated in Table 2. It is felt that these materials would be useful to radiation levels of 10^7 R. Some of these data were obtained from Harrington,⁽⁵⁾ as noted. Data on the Parker S604-7 and the Union Carbide K1305B silicone rubbers were obtained by pulling irradiated o-rings on an Instron tensile testing machine.

Fluids

As with the elastomers, the high environmental temperature is the most important factor in evaluating coupling fluids for this application. Most fluids have a high vapor pressure or decompose at 500 °F. The fluids considered for this application are listed in Table 3 by chemical name as well as trade name. These fluids were evaluated by measuring their ultrasonic velocity, halogen content, and compatibility with elastomers. For the two best fluids, Ambiflo and Dow 710, the ultrasonic attenuation was measured, and the gas evolved during irradiation was determined.

Velocity Measurements. The ultrasonic velocities of the coupling fluids as a function of temperature are shown in Figures 21 through 28. Since an open system was used for the velocity measurements, the temperature was kept below the flash point of the fluids. Note that with the exception of Sperry fluid the ultrasonic velocity decreases linearly with increasing temperature.

The velocities were measured in a furnace in an open stainless steel beaker with the device shown in Figure 29. This apparatus has two 5 MHz PZT-5 crystals (a transmit and a receive crystal) soldered to stainless

TABLE 2. Effect of Gamma Radiation on the Properties of Elastomers

<u>Material</u>	<u>Dose, R</u>	<u>% Increase In Elongation at Break</u>	<u>% Increase In Ultimate Tensile Strength</u>
Silastic 80 ^(a)	3×10^6	-13	14
	6	-40	9
	30	-56	24
	60	-78	48
	90	-81	62
Silastic 50 ^(a)	3	-13	16
	6	-27	17
	30	-55	36
	60	-78	6
	90	-82	-10
Viton A-2 ^(a)	5	-32	-13
	50	-87	-12
	100	-87	22
Union Carbide K1305B	10	-28	- 9
	100	-78	-36
	1000	o-rings broke easily	
Parker S604-7	10	- 5	-41
	100	-56	
	1000	o-rings broke easily	

-
- a. These data were taken from R. Harrington, Part II: Effect of Gamma Radiation on Heat-Resistant Elastomers, Rubber Age, Vol. 82, No. 3, December, 1957. The newer compounds, Silastic 82 and Silastic 52 have similar properties to Silastic 80 and Silastic 50.

TABLE 3. Fluids Evaluated for Use in the Sperry Wheel

<u>Chemical Name</u>	<u>Trade Name</u>
Polypropylene oxide	Ambiflo
Polypropylene glycol	Polyglycol P-400
Polypropylene glycol	Polyglycol P-1200
Polyethylene glycol	Polyglycol E-200
26.5% diphenyl in diphenyl oxide	Dowtherm A
Fluorosilicone oil	Dow FS-1265
Silicone oil	Dow 710 fluid
A mixture of 50% water 50% ethylene glycol	Sperry fluid

FIGURE 21. Ultrasonic Velocity of Sperry Fluid Versus Temperature

FIGURE 22. Ultrasonic Wave Velocity of Polyglycol E-200 Versus Temperature

FIGURE 23. Ultrasonic Velocity of Polyglycol P-400 Versus Temperature

FIGURE 24. Ultrasonic Wave Velocity of Polyglycol P-1200 Versus Temperature

FIGURE 25. Ultrasonic Wave Velocity of Dowtherm A Versus Temperature

FIGURE 26. Ultrasonic Wave Velocity of Ambliflo H-149 Versus Temperature

FIGURE 27. Ultrasonic Wave Velocity of Fluorosilicone FS-1265 Fluid Versus Temperature

FIGURE 28. Ultrasonic Wave Velocity of Dow 710 Fluid Versus Temperature

FIGURE 29. Device Used to Measure Ultrasonic Velocities of Fluids at High Temperatures

steel cylinders. Spacing between the transmitter crystal and the receiver crystal was accurately established with the gauge shown in the photograph, and the time for the ultrasonic pulse to travel between the crystals was accurately measured on a calibrated oscilloscope.

Ultrasonic Attenuation. An indication of the relative ultrasonic attenuation of Dow 710 and Ambiflo fluids was obtained using the transmit-receive system, with the crystals 0.70 in. apart. The amplitude of the receive pulse in these fluids and in water was noted at room temperature and compared with the amplitude of the receive pulse in Dow 710 and

Ambiflo at 400 °F. The amplitude of the receive pulse in Dow 710 at room temperature was 12% of the receive pulse in water at room temperature. At 400 °F the amplitude increased to 38% compared to water at room temperature. In Ambiflo, the amplitudes relative to water at room temperature were 42% at room temperature and 47% at 400 °F. Thus, Ambiflo fluid has lower ultrasonic attenuation than Dow 710.

Outgassing in a Radiation Field. Ambiflo and Dow 710 fluids were subjected to gamma radiation at high temperature, and the gas evolved was measured. We found that for a total dose of 10^8 R, Ambiflo fluid liberates 6.4 ml of gas per milliliter of fluid and Dow 710 fluid liberates 0.34 ml of gas per milliliter of fluid. The measurement was performed in a closed system at 480 °F for Ambiflo and 500 °F for Dow 710 fluid. After being heated and irradiated, the liquid was allowed to cool to room temperature. The volume of gas liberated was calculated from pressure measurements before and after irradiation.

Fluid Elastomer Compatibility

Compatibility at high temperature is an important factor in evaluating both fluids and elastomers. Our tests to determine the compatibility of the fluids and elastomers are summarized in Table 4. These results were obtained by exposing several of each of the elastomer samples to the conditions noted in the table and then pulling them on an Instron tensile testing machine to determine the elongation at break, the ultimate tensile strength, and the elastic modulus at 100% elongation. The samples were exposed in airtight containers in a furnace, immersed in the fluids.

The primary purpose of these tests was to determine the effect of the couplant fluids on the various elastomers, not to accurately measure the ultimate elongation, tensile strength, and modulus. The effect of the liquids on the elastomers is determined by comparing the test results before and after exposure.

TABLE 4. Compatibility of Fluids and Elastomers

Material	Test Conditions	Ultimate Tensile Strength, kg/cm ²	Elongation at Break, %	Modulus at 100% Elongation, kg/cm ²
Parker S604-7 silicone rubber	As-received	89	97	94
	20 hr @ 500 °F in air	97	112	43
	" " " " " Ambiflo	7	79	--
	" " " " " Sperry Fluid		Dissolved sample	
	" " " " " Polyglycol P400		"	
	" " " " " FS-1265	11	60	--
	" " " " " Dowtherm	26	113	24
	" " " " " Dow 710	<2	<50	--
	20 hr @ 400 °F in Dowtherm A	14	69	
	" " " " " Polyglycol P400		Samples easily broken by hand	
	" " " " " Ambiflo	25	73	--
	" " " " " Dow 710	28	96	--
	As-received	54	223	14.9
	20 hr @ 500 °F in air	45	238	11.2
Union Carbide K1305B o-rings	" " " " " Ambiflo		Dissolved	
	" " " " " FS-1265		"	
	" " " " " Polyglycol P400		"	
	" " " " " Dowtherm A		"	
	" " " " " Sperry Fluid		"	
	6-1/2 hr @ 500 °F in Dow 710		Soggy & weak, o-rings broken	
	4 hr @ 500 °F in Ambiflo	12	208	5.1
	" " " " " Polyglycol E200		Broken on removal from capsule	
	" " " " " Polyglycol P400		"	
	" " " " " Polyglycol P1200		"	
	20 hr @ 400 °F in Ambiflo	35	227	10.2
	" " " " " Polyglycol E200	28	184	9.3
	" " " " " Polyglycol P400	32	240	7.2
	" " " " " Polyglycol P1200	13	154	6.2
Buna N o-rings	As-received	138	211	55
	20 hr @ 500 °F in air	28	0	--
	" " " " " Ambiflo	176	40	--
	" " " " " Sperry Fluid	73	50	--
	" " " " " FS-1265	121	29	--
	" " " " " Polyglycol P400	12	26	--
	" " " " " Dowtherm A		Dissolved	
	As-received			

TABLE 4. Compatibility of Fluids and Elastomers (Continued)

Material	Test Conditions	Ultimate Tensile Strength, kg/cm ²	Elongation at Break, %	Modulus at 100% Elongation, kg/cm ²
Dow Corning Silastic 82	As-received	76	150	54
	20 hr @ 500 °F in air	62	75	104.1
	" " " " Dow 710		Broke when bent 180°	
	6-1/2 hr @ 500 °F in FS-1265		Broke when bent 180°	
	20 hr @ 400 °F in Dowtherm A		Samples dissolved	
Dow Corning Silastic 52	" " " " Polyglycol P400	58	Samples broken on removal from chamber	50
	" " " " Ambiflo	50	120	40
	" " " " Dow 710			
	As-received	68	320	14
	20 hr @ 500 °F in air	58	240	19
Viton Parker Compound 77-545	" " " " Ambiflo		Samples softened and crumbly	
	" " " " Polyglycol E200		" " "	
	" " " " Polyglycol P400		Samples dissolved	
	" " " " Polyglycol P1200		Samples softened and crumbly	
	" " " " Dow 710		Samples softened, broke when bent 180°	
	20 hr @ 400 °F in Dowtherm A		Samples dissolved	
	" " " " Polyglycol P400		Samples broke when bent 180°	
	" " " " Ambiflo	50	320	12
	" " " " Dow 710	52	380	8.6
	As-received	113	227	39
Viton Parker Compound 77-545	20 hr @ 500 °F in air	116	198	49
	" " " " Sperry Fluid	66	96	--
	" " " " Ambiflo	60	242	29
	" " " " FS-1265	45	242	14
	" " " " Polyglycol P400	19	227	6
	" " " " Dowtherm	24	104	23
	6 hr @ 500 °F in Dow 710	74	117	62
	20 hr @ 500 °F in Dow 710	65	92	52
	20 hr @ 400 °F in Dow 710	104	204	39
	" " " " Dowtherm A	79	238	24.2
	" " " " Ambiflo	79	200	32.6
	" " " " Polyglycol P400	48	262	14

Standard o-rings, 0.549 in. nominal ID and 0.103 in. nominal width, served as test samples for all of the materials tested except the Silastic 82 and 52 silicone rubber compounds. O-rings were not readily available in these compounds, so rectangular samples (see Figure 30) were used.

FIGURE 30. Rectangular Samples for Compatibility Tests of Silastic 52 and 82

The samples were tested initially at 500 °F for 20 hr with the fluids. Subsequent tests were run at 400 °F for some fluids and elastomers. All of the polyglycol fluids were not tested with each of the elastomers, as these fluids are similar. Most of the testing was done with Polyglycol P-400.

Table 4 reveals that Viton is the only elastomer which withstood the compatibility tests at 500 °F, and even this material was strongly affected. At 400 °F the silicone rubbers Silastic 52 and Silastic 82 appear to be useable with Dow 710 fluid and Ambiflo fluid. The Union Carbide K1305B silicone rubber appears better with Ambiflo (not tested with Dow 710) than the other fluids. All of the elastomers except Buna N and the Parker S604-7 silicon rubber easily withstood 20 hr at 500 °F in air.

Halogen Content of Fluids and Elastomers

It is important to use materials having low halogen content for the inspection unit components which may come in direct contact with the test surface. These elements can induce stress corrosion cracking in the

vessel. The tire will come in direct contact with the vessel during testing and the fluid couplant may come in contact with the vessel in the event of a failure. Therefore, we determined the halogen content of materials for these components.

Materials for these two components were tested for total halogen content by Schwarzkopf Laboratories in New York. The results are shown in Table 5. Viton and the fluorosilicone fluid (FS-1265) are halogenated compounds with high fluoride contents. They are considered unsuitable replacements for the tire and fluid couplant and were not tested. Buna N rubber and Sperry fluid were not tested as they will not tolerate the projected environment.

We made dual determinations for most of the materials, and there is a substantial variation between the two determinations for some materials. The fluids generally contain several thousand parts per million chloride and 1 to 150 ppm fluoride. The silicone rubbers have 200 to 800 ppm chloride and 10 to 200 ppm fluoride.

TEST FACILITIES

We developed special facilities for radiation and temperature testing of the Sperry wheel and its components. These facilities are suitable for the evaluation of other transducers in this environment, as well as for the Sperry wheel. The facilities include a small furnace for testing transducer components and materials in a gamma radiation field at high temperature, a large furnace for testing complete inspection units in a gamma field, a facility designed to dynamically test the wheel unit in a gamma field, and a series of test blocks to determine the transducer sensitivity as a function of surface roughness.

Small Furnace

The small furnace is shown in Figure 31. This furnace is made primarily of lavite, a ceramic material, and is heated by a nichrome element. It will fit inside the 2 in. diameter stainless steel tubes at the gamma facility, and it can be used at temperatures in excess of 1000 °F. Figure 32 shows a temperature profile along the center of the furnace.

TABLE 5. Halogen Content of Fluids and Elastomers

<u>Material</u>	<u>Sample</u>	<u>Fluorine, ppm</u>	<u>Clorine, ppm</u>
Dowtherm A		150	700
Ambiflo H-149	1	< 1	1800
	2	< 1	3800
Polyglycol E-200	1	< 1	4500
	2	< 1	2300
Polyglycol P-400	1	<10	300
	2	< 5	900
Dow 710	1	50	1180
	2	40	1030
Parker S604-7	1	<10	770
silicone rubber	2	<10	530
Silastic 82	1	<10	260
silicone rubber	2	<10	400
Silastic 52	1	130	800
silicone rubber	2	210	500
K1305B	1	<20	300
silicone rubber	2	170	200

FIGURE 31. Small Furnace

FIGURE 32. Temperature Profile of Small Furnace

Large Furnace

Figure 33 shows a photograph of the large furnace. This furnace is essentially a large waterproof box sealed with a tin-lead gasket. An oven inside the box serves as the heating chamber. Control and test leads are fed through a 2 in. stainless pipe in the top of the chamber. Tests show

FIGURE 33. Large Furnace

the chamber to be waterproof. The temperature profile for this furnace (measured in the center of the furnace, bottom to top) is shown in Figure 34. The temperature fluctuation is indicated in Figure 34 by the arrows.

FIGURE 34. Temperature Profile of Large Furnace

Dynamic Tester

Figure 35 shows a photograph of the apparatus for dynamically testing the ultrasonic wheel unit at 500 °F. The 10 in. diameter 1/2 in. thick stainless steel drum is turned at 4.4 rpm from outside the furnace chamber. The drum serves as the test sample and has a 1/16 in. deep rectangular groove cut in the outside diameter to reflect an ultrasonic signal. Additional defects could be cut in the drum as required. The dynamic tester operates satisfactorily at 500 °F.

FIGURE 35. Dynamic Tester

Test Standards

Figure 36 shows three of the test standards used to determine the transducer sensitivity. The standards are a series of four 9x12x2 in. 304 stainless steel blocks, each having a different surface finish. The finishes are 32, 63, 125 and 250 μ in. rms. Two series of test holes serve as artificial defects in the blocks. One series of 3/8 in. deep flat bottom holes is drilled into the side of each block at 45°. This series has hole diameters of 1/32, 1/16, 1/8 and 3/16 in. Another series of flat bottom holes is drilled into the top surface. These holes are 1/2 in. deep and have diameters of 1/16, 1/8 and 1/4 in.

The 32 and 63 μ in. finishes were obtained on a surface grinder, and the 125 and 250 μ in. finishes were made with a Bayflex grinder. The finishes were checked on a profilometer.

FIGURE 36. Test Standards.

ACKNOWLEDGMENTS

The authors wish to thank Larry Kopf and Joe Harris for their assistance in assembling and conducting the experimental work. Many thanks to Janice Sletager for her help in preparing this manuscript.

REFERENCES

1. J. J. Buggy, D. L. Dill, E. Paxson, "Surveillance and In-Service Inspection Recommendations for the FTR: Techniques, Program, Development," WARD 3977-1.
2. Unpublished Data, Battelle-Northwest, Richland, Washington, February 7, 1969. (Letter from E. R. Astley to J. M. Shivley, FFTF Scope of Work Task IC-19, Surveillance Sensors, BNW/FFTF 69310).
3. Unpublished Data, Battelle-Northwest, Richland, Washington, March 19, 1969. (Letter from M. Shaw to D. G. Williams, FFTF Scope of Work Task IC-19, Surveillance Sensors, RDT:PE:l-095/AEC 69328.)
4. R. Kesselman, Preliminary Report on Nuclear Radiation Effects in Piezoelectrics, PA-TR-3045, Dover, New Jersey, January 1963.
5. R. Harrington, "Part II: Effect of Gamma Radiation on Heat-Resistant Elastomers," Rubber Age, Vol. 82, No. 3, December 1957.

BIBLIOGRAPHY

1. James G. Carroll and Robert O. Bolt, "Radiation Effects," Nucleonics, September 1960.
2. W. E. Chapin, J. E. Drenman, D. J. Hamman, "The Effect of Nuclear Radiation on Transducers," REIC Report No. 43, October 31, 1966.
3. D. D. Glower, D. L. Hester, and D. F. Warnke, "Effects of Radiation-Induced Damage Centers in Lead Zirconate Titanate Ceramics," J. of the American Ceramic Society, Vol. 48, No. 8, August 1965.
4. R. Harrington, "Elastomers for Use in Radiation Fields," Rubber Age, Vol. 81, No. 6, September 1957.
5. R. Harrington, "Part IV: Effects of Gamma Radiation on Miscellaneous Elastomers and Rubberlike Plastics Materials," Rubber Age, June 1958.
6. R. Harrington, "Part III: Effects of Gamma Radiation on Elastomers," Rubber Age, Vol. 82, No. 6, March 1958.
7. R. Harrington, "Part V: Effect of Gamma Radiation on Nitride Elastomers," Rubber Age, Vol. 85, No. 6, September 1959.
8. R. Harrington, "Radiation Resistance of the Neoprenes," Rubber Age, February 1960.
9. Parker Seal Company, "Seal Compound Manual," July 1964.

BNWL-1302

APPENDIX A

SPECIFICATIONS OF SPERRY WHEEL - MODEL 50D467

APPENDIX A

SPECIFICATIONS OF SPERRY WHEEL - MODEL 50D467

Type: SOZ
Frequency: 2.25 MHz
Crystal Size: 1/2 x 1 in.
Beam: Side 0-50°
Forward 0-15°
Backward 0-15°

This wheel is designed for inspection of materials with surface temperatures up to 500 °F. This wheel will provide a normal beam; however, due to the short (1 in.) liquid path it is more useful for side angle longitudinal, shear, Rayleigh, and Lamb waves. Its 0 to 50° incident side angle makes it especially useful for Lamb wave inspection of thin sheet. Lamb waves, optimum for thin copper and brass sheet are frequently produced by incident angles in the 40° to 50° range with this wheel. Since both side and forward angles are concurrently variable, a helical beam path properly directed for the detection of mill defects in tubular products can be attained.

DISTRIBUTIONOFFSITENo. of
Copies

1	<u>AEC Chicago Patent Group</u> G. H. Lee, Chief
31	<u>AEC Division of Reactor Development and Technology</u> M. Shaw, Director, RDT Asst. Director for Nuclear Safety Analysis & Evaluation Branch, RDT:NS Environmental & Sanitary Engineering Branch, RDT:NS Research & Development Branch, RDT:NS Asst. Director for Plant Engineering, RDT Facilities Branch, RDT:PE Components Branch, RDT:PE Instrumentation & Control Branch, RDT:PE Liquid Metal Systems Branch, RDT:PE Asst. Director for Program Analysis, RDT Asst. Director for Project Management, RDT Liquid Metals Projects Branch, RDT:PM FFTF Project Manager, RDT:RE Asst. Director for Reactor Engineering, RDT Control Mechanisms Branch, RDT:RE Core Design Branch, RDT:RE (2) Fuel Engineering Branch, RDT:RE Fuel Handling Branch, RDT:RE Reactor Vessels Branch, RDT:RE Asst. Director for Reactor Technology, RDT Coolant Chemistry Branch, RDT:RT Fuel Recycle Branch, RDT:RT Fuels & Materials Branch, RDT:RT Reactor Physics Branch, RDT:RE Special Technology Branch, RDT:RT Asst. Director for Engineering Standards, RDT EBR-II Project Manager, RDT:PM
1	<u>AEC Idaho Operations Office</u> <u>Nuclear Technology Division</u> C. W. Bills, Director
1	<u>AEC San Francisco Operations Office</u> <u>Director, Reactor Division</u>

No. of
Copies

4	<u>AEC Site Representatives</u> Argonne National Laboratory Atomics International General Electric Company Westinghouse Electric Corporation
214	<u>AEC Division of Technical Information Extension</u>
3	<u>Argonne National Laboratory</u> R. A. Jaross LMFBR Program Office N. J. Swanson
1	<u>Automation Industries</u> Boulder, Colorado J. Posokony
1	<u>Atomic Power Development Association</u> Document Librarian
5	<u>Atomics International</u> FFTF Program Office
2	<u>Babcock & Wilcox Company</u> <u>Atomic Energy Division</u> S. H. Esleeck G. B. Garton
1	<u>BNW Representative</u> R. M. Fleischman (ZPPR)
1	<u>Combustion Engineering</u> Mrs. Nell Holder, Librarian
5	<u>General Electric Company</u> <u>Advanced Products Operation</u> Karl Cohen (3) Nuclear Systems Program D. H. Ahmann (2)

<u>No. of Copies</u>	
2	<u>Gulf General Atomic Inc.</u> General Atomic Division D. Coburn
1	<u>Idaho Nuclear Corporation</u> J. A. Buckham
1	<u>Liquid Metal Engineering Center</u> P.O. Box 1449 Canoga Park, California 99304 R. W. Dichinson
2	<u>Liquid Metal Information Center</u> P.O. Box 1449 Canoga Park, California 99304 A. E. Miller
1	<u>Oak Ridge National Laboratory</u> W. O. Harms
2	<u>Southwest Research Institute</u> A. G. Pickett
1	<u>Stanford University</u> Nuclear Division Division of Mechanical Engineering R. Sher
1	<u>United Nuclear Corporation</u> Research and Engineering Center R. F. DeAngelis
5	<u>Bechtel Corporation</u> J. J. Teachnor
10	<u>Westinghouse Electric Corporation</u> Atomic Power Division Advanced Reactor Systems D. C. Spencer

ONSITENo. of
Copies

1	<u>Bechtel Corporation</u>	
	M. O. Rothwell (Richland)	
1	<u>Westinghouse Electric Corporation</u>	
	R. Strzelecki (Richland)	
3	<u>AEC Program Office - PNL</u>	
	T. A. Nemzek	
2	<u>AEC, RDT Site Representative</u>	
	P. G. Holsted	
3	<u>AEC Richland Operations Office</u>	
	J. M. Shivley	
	C. L. Robinson	
1	<u>AEC Chicago Patent Group</u>	
	R. K. Sharp (Richland)	
3	<u>Battelle Memorial Institute</u>	
73	<u>Battelle-Northwest</u>	
	E. R. Astley	R. J. Squires
	A. L. Bement	C. R. Swanson
	W. L. Chase	J. C. Tobin
	J. C. Cochran	J. H. Westsik
	D. L. Condotta	B. Wolfe
	R. R. Cone	D. C. Worlton
	J. H. Cox (5)	Legal - 703 Bldg.
	K. O. Creek	Legal - ROB, 221-A
	G. J. Dau	Technical Information (5)
	J. F. Erben	Technical Publications (2)
	E. A. Evans	FFTF File (703) (10)
	J. W. Helm (5)	FFTF TPO (703)
	P. L. Hofmann	
	H. E. Little	
	W. B. McDonald	
	J. S. McMahon	
	H. N. Pedersen	
	R. W. Smith (20)	
	J. M. Seehuus	
	J. C. Spanner	