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DEVELOPMENT OF ULTRASONIC TECHNIQUES FOR THE REMOTE MEASUREMENT OF THE HRT CORE VESSEL WALL THICKNESS

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INTRODUCTION

The Homogeneous Reactor Experiment which has been operated at the Oak Ridge National Laboratory consists of a 5-Mw test reactor designed and constructed to study the many facets of aqueous fuel reactor technology. The heart of this reactor is a welded pear-shaped core vessel fabricated from Zircaloy-2 with a wall thickness of approx 5/16 in. There was concern over the possibility of corrosion or erosion causing excessive thinning of the vessel wall. For this reason, it was necessary to develop inspection techniques to measure this wall thickness at periodic intervals during shutdown for maintenance. The ultrasonic method was chosen as the most promising solution for this difficult problem. Among the obstacles encountered were the high irradiation background with the obvious necessity of remote techniques and the very small access ports through which the operation could be conducted. Figure 1 is a diagram of the central portion of the Homogeneous Reactor. This shows the relative size and position of the core vessel and surrounding blanket region and the access ports into both sections. This paper describes the various stages of equipment and technique development, i.e., the evolution of a remote ultrasonic inspection technique.

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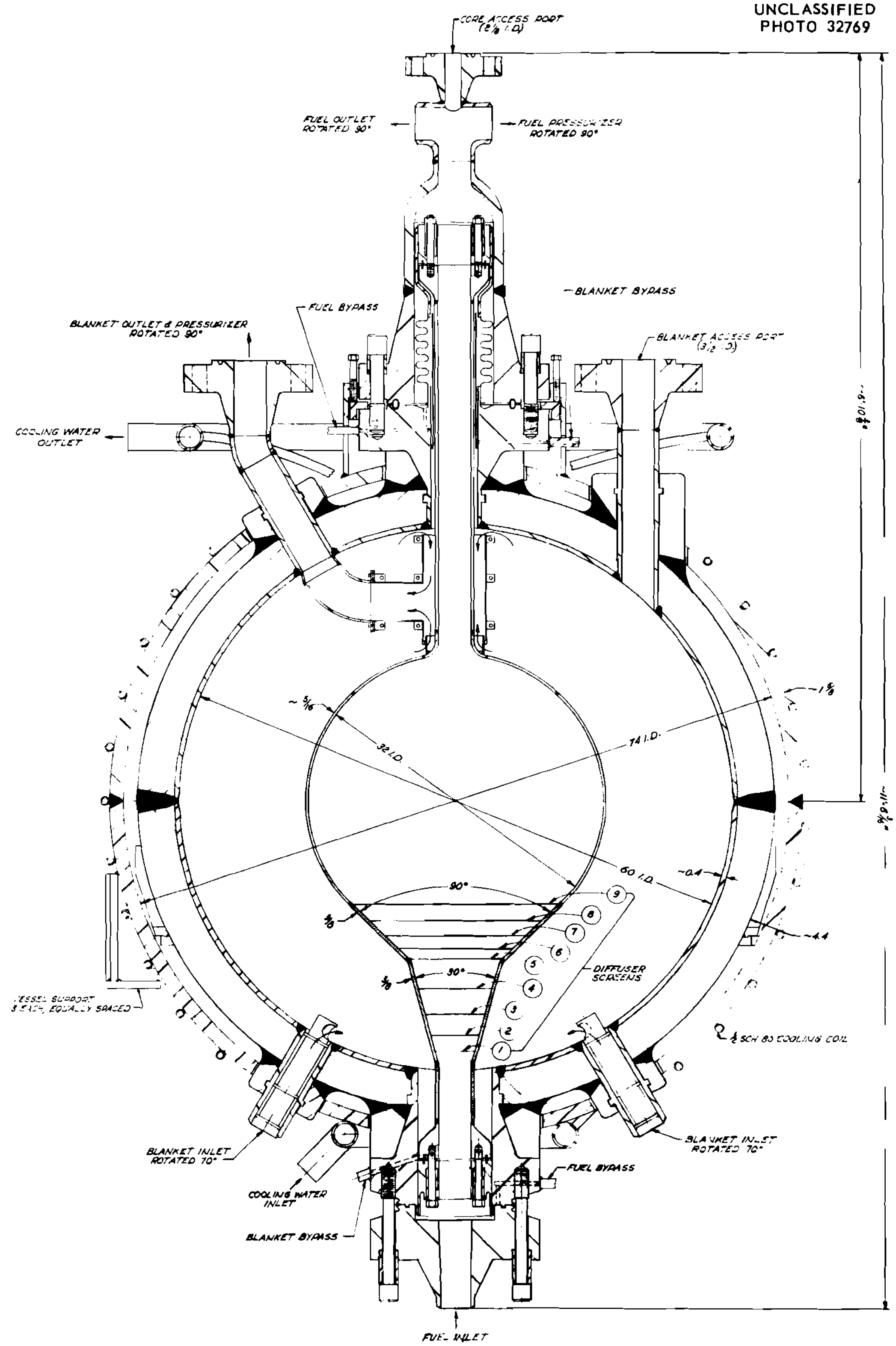

Fig. 1. Cross Section of the HRT Core Vessel and Surrounding Areas.

PREINSTALLATION MEASUREMENTS

A complete survey of the vessel wall thickness was made after construction at the fabrication plant at Newport News[1] using the resonance ultrasonic method.[2] Figure 2 will assist in describing the principles of this method. A continuous wave of ultrasound which is generated by a piezoelectric or electrostrictive transducer is transmitted through a thin film of couplant into a metal specimen. Reflections are obtained at interfaces such as presented by the surfaces of the specimen. If the frequency of the generated sound wave, the sound velocity, and specimen thickness have the proper relation, a resonant or standing wave condition will be established. If the fundamental or harmonic frequencies and the sound velocity are known, the thickness may be calculated. The inspection was performed with a small portable instrument, the Audigage, which is manufactured by Branson Instruments, Inc., of Stamford, Connecticut. This small instrument has a manually variable frequency and the resonant condition which causes increased loading on the transducer is noted as a meter deflection and/or an increase in volume of an audible signal. This first survey with complete accessibility to the entire surface area offered assurance that the starting wall thickness was within the specified tolerances.

BLANKET REGION MEASUREMENTS

The vessel was installed and put into operation as a two-region system with fuel inside the vessel and a heavy-water blanket surrounding the vessel. To reduce the contamination problem which would arise from inserting and removing the mechanical apparatus, examination was restricted to the blanket region. Thus, the access was limited to a

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[1]Fabrication History of HRT Core Tank, ORNL CF-58-12-6, p 211.

[2]Robert C. McMaster (ed.), Nondestructive Testing Handbook, pp 50.1—50.42, Vol. II, Section 50, The Ronald Press Company, New York, 1959.

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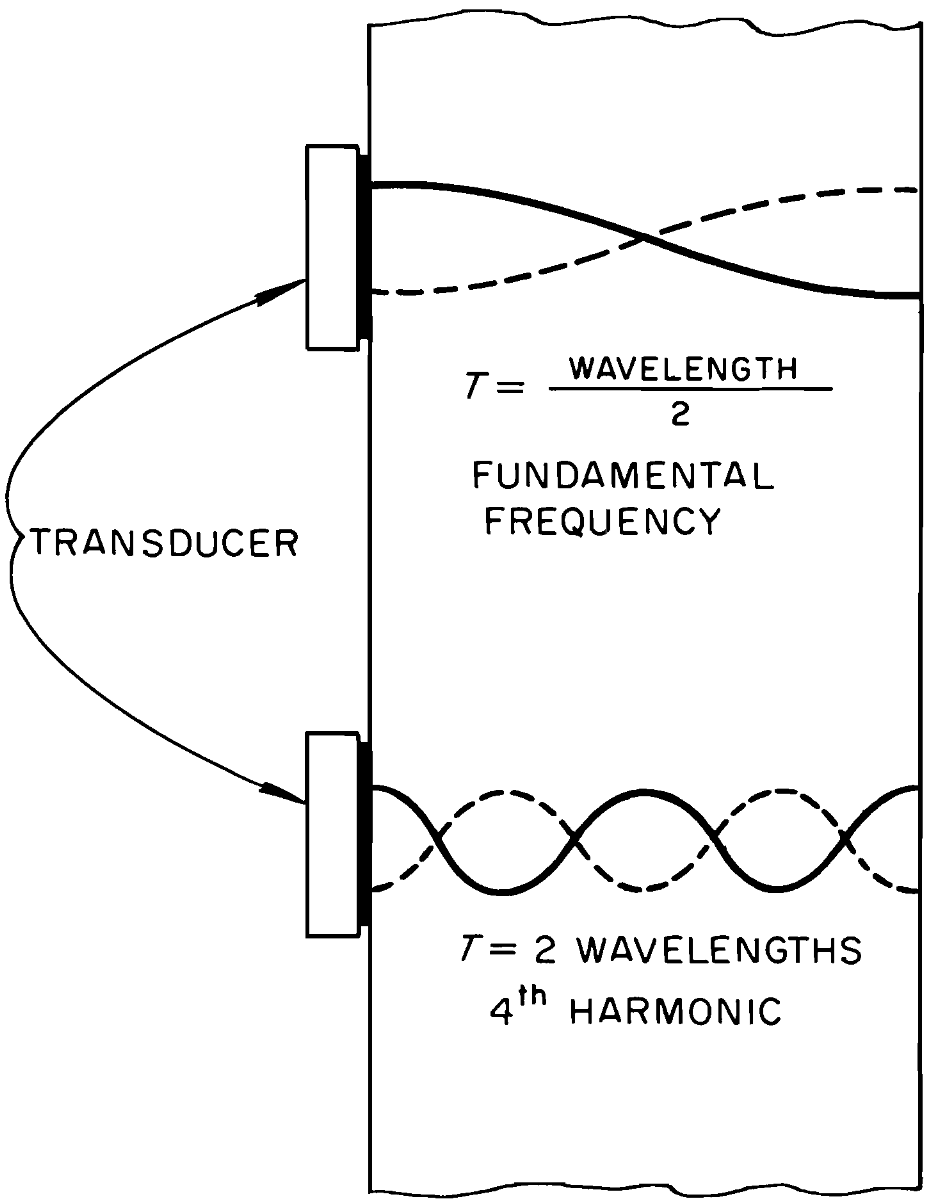

Fig. 2. Resonance Ultrasonic Method for Thickness Measurement.

3-1/2-in.-diam opening. The mechanical fixture shown in Fig. 3 was developed to place the ultrasonic transducer firmly on the equator of the spherical portion of the core vessel which was 20 ft below the operating floor level. The blanket region was filled with water to assure the constant presence of couplant between the transducer and the vessel wall. The resonance technique was continued using a more sensitive ultrasonic instrument, the Vidigage, also manufactured by Branson Instruments, Inc. This device automatically sweeps the ultrasonic frequency through a predetermined band, the conditions of resonance being displayed as vertical "pips" on the screen of a cathode-ray tube. Thus, for a material having a known ultrasonic velocity, the face of the screen can be calibrated directly in thickness. Several measurements were made in this fashion at intervals over a period of more than two years. However, this technique allowed measurements at only a single point. Obviously, such a system was not sufficient to give an overall view of the vessel wall thickness, and, in particular, could not detect the possible localized variations.

MEASUREMENTS FROM THE CORE VESSEL INTERIOR

After a period of operation as a two-region system, the reactor was converted to a one-region system with the fuel and blanket being combined both inside and outside the core vessel. This, coupled with the increased experience in contaminated region maintenance operations, aided in bringing about the next development. A new mechanical apparatus was designed which would place the ultrasonic transducer through the 2-in.-diam access opening which leads into the core vessel. Figure 4 is a photograph of the transducer end of the device. The elbow was positioned at the center of the spherical portion of the vessel. Thus, the transducer could be directed to any part of the vessel by adjusting the elbow angle and rotating the upper arm about its axis. For the measurement, the gimbal-mounted transducer was placed firmly against the vessel wall by means of a pneumatic piston. The core vessel was filled with water to provide adequate couplant between the transducer and wall. Special convex transducers were procured to match the inner-surface curvature of the core. There was concern over the possibility

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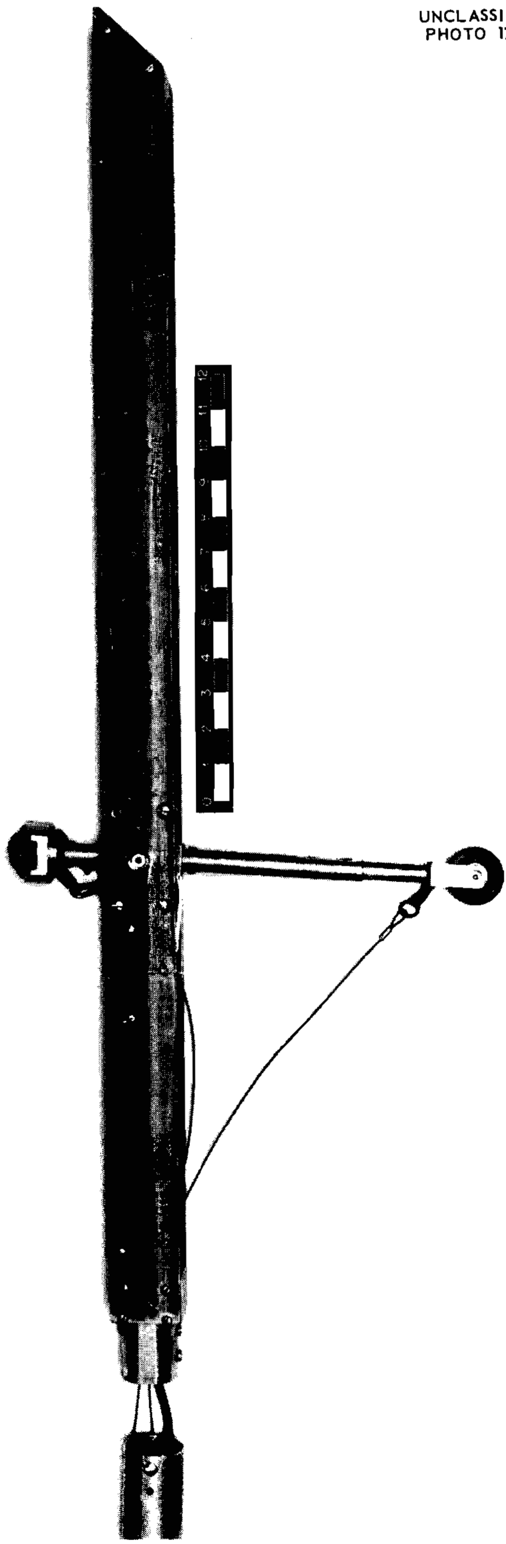

Fig. 3. Mechanical Fixture for Ultrasonic Resonance Measurements from the Blanket Region.

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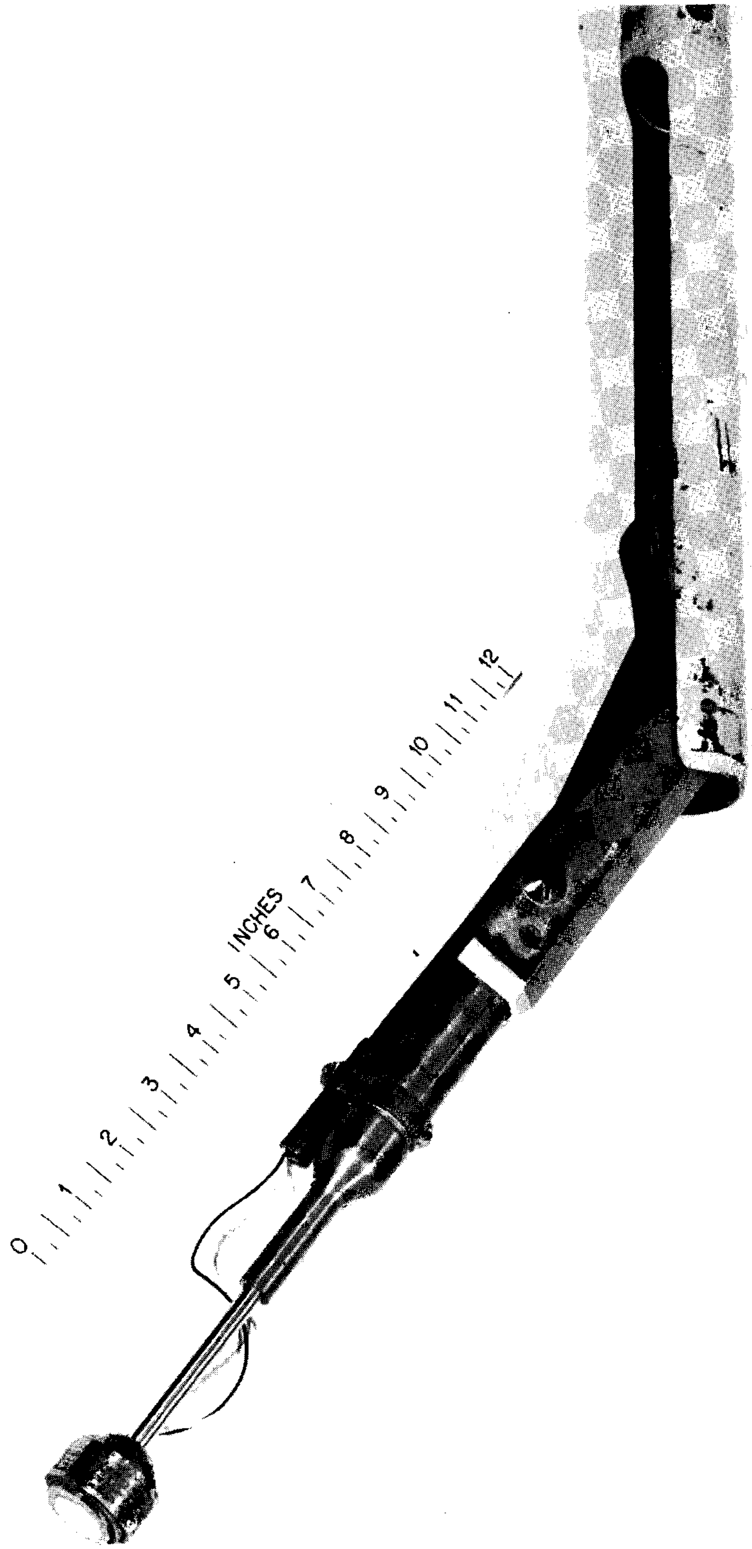

Fig. 4. Mechanical Device to Place Ultrasonic Transducer at any Point on Spherical Portion of the Vessel.

of gamma-irradiation damage to the transducers when placed in the core. For this reason, one of the transducers was irradiated with x rays for a total exposure of 10^6 r. Operation of this transducer during and after the exposure revealed no significant changes. The only observable difference was a slight discoloration of the plastic backing material.

It had been planned originally to continue with the resonance ultrasonic technique. However, intermediate studies had indicated some possibilities for measurement errors. As has been mentioned previously, the ultrasonic equipment establishes fundamental or harmonic resonant conditions which are then related to the specimen thickness. These resonances are affected, in part, by the coupling between the transducer and specimen and by the thickness and ultrasonic velocity of the specimen. In practice, calibration is made on a standard of the test material of known thickness and the instrument is adjusted to display the proper thickness value. For conditions of identical coupling and ultrasonic velocity, very accurate thickness measurements can be made. These two conditions exist in most cases; however, velocity variations as great as 3% have been observed in Zircaloy-2. In addition to this, there were known variations in the inner-surface roughness of the core vessel which would prevent consistent coupling thickness. With the existing equipment, these two factors could produce a significant error due to interpretation difficulties.

PULSE-REFLECTION TECHNIQUE

To overcome this interpretation problem, a pulse-reflection technique was substituted.[3] The drawing in Fig. 5 illustrates this technique. A pulse of ultrasound is projected into the sample with reflections being received from the far surface. Continued reverberation of the sound between the wall surfaces will present multiple echoes. Measurement of the time between successive reflections will permit the simple calculation for thickness if a nominal value for ultrasonic velocity is known.

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[3]Robert C. McMaster (ed.), Nondestructive Testing Handbook, pp 43.1–43.53, Vol. II, Section 43, The Ronald Press Company, New York, 1959.

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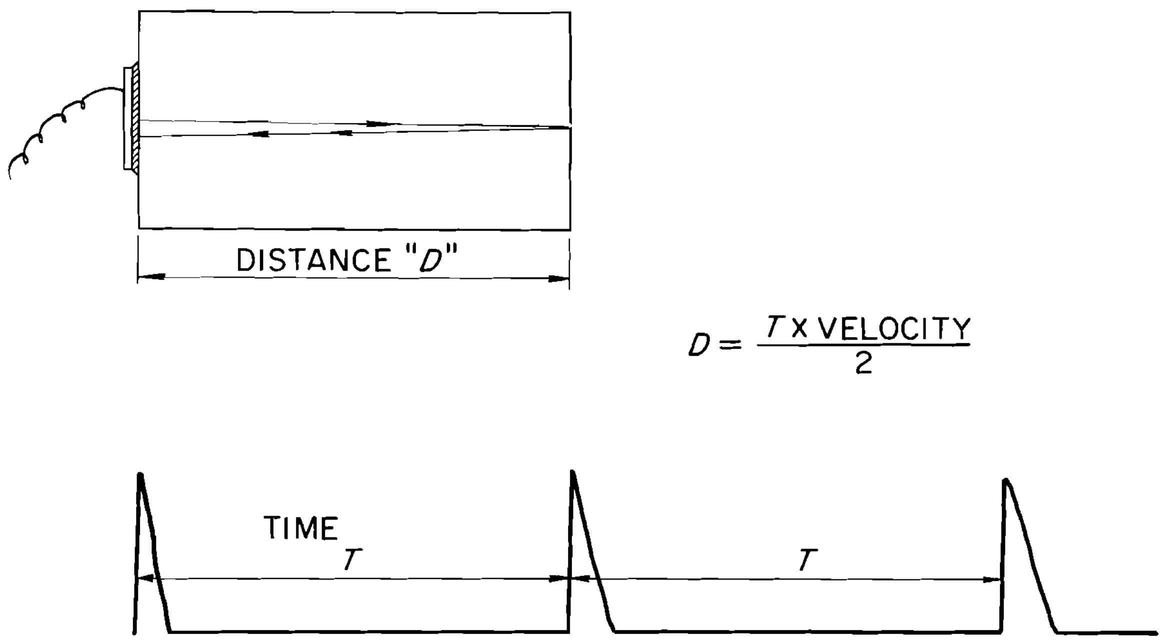

Fig. 5. Pulse-Echo Ultrasonic Measurement of Thickness.

The multiple echo pattern was displayed on an oscilloscope and the time between successive reflections was measured with a calibrated delay line. However, measurements taken directly on the oscilloscope were somewhat laborious and time consuming, particularly if many were to be taken. For this reason, further development was accomplished to allow the assembly of the equipment outlined in Fig. 6. The instrument in the lower left portion of the diagram generates the electrical signal which produces the transmitted ultrasonic pulse and detects, amplifies, and displays the received echoes. Measurement of the time interval between the selected echo pulses is expedited by means of the electronic gating circuitry shown in the upper left portion of the drawing. As may be seen in the representation of the cathode-ray tube screen, the normal procedure was to select pulses and the associated intervening time to represent several traverses or reverberations of the ultrasonic pulse between the surfaces of the sample. This instrument "feeds" the selected pulses in the proper time relationship to an electronic counter which is shown at the right of the gating circuitry. The first pulse to the counter starts the counting and displays in digital form the number of cycles of a very precise 10 Mc oscillator. The second pulse into the counter stops the counting, thus providing a digital read-out of the total elapsed time between the selected pulses. A reset counter was used to allow an automatic accumulation or integration of a large number of separate measurements of the selected interval. This, of course, greatly reduced the statistical error. A rather interesting operational technique permitted the direct digital display of the wall thickness. The normal calculation for thickness was by use of the equation

$$D = \frac{tV}{K}$$

where D = thickness

t = the measured time between selected pulses

V = ultrasonic velocity

K = the number of trips the pulse made across the wall thickness during the measured interval.

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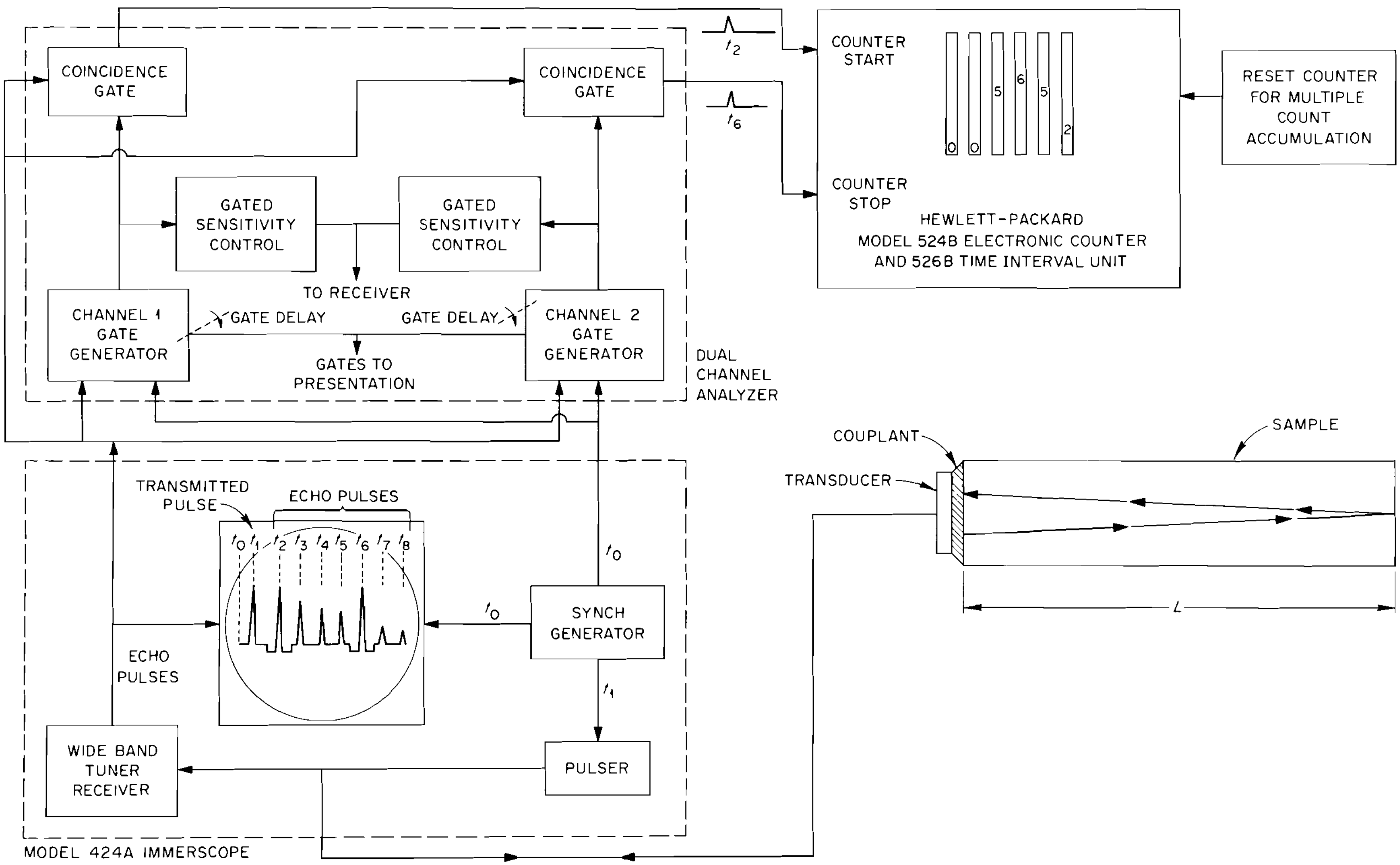

Fig. 6. Block Diagram for Digital Display of Pulse-Echo Ultrasonic Thickness Measurements.

The obvious short cut is to accumulate a number of measurements equal to the value of V/K, thus electronically performing the multiplication and providing the digital read-out of thickness. This integration is performed very rapidly since cumulative measurements are made at the pulse repetition rate of the ultrasonic generating device (about 600 pulses/sec). Figure 7 is a photograph of the equipment which has been described. In the lower left is the instrument which generates and displays the ultrasonic pulses; above it is the gating circuitry; on the lower right is the electronic counter and above it is the preset counter used for measurement accumulation.

Even though the mechanical fixture was designed for contact inspection, investigation demonstrated that the transducer could be removed from intimate contact with the surface, thus sending the sound pulse through the water which fills the vessel into the wall. As a matter of fact, it was necessary to operate in this fashion when surface roughness prevented adequate coupling by the contact method.

After the perforated screens were removed from the conical section of the core vessel, it was desired to measure the wall thickness in this region. To this end, the mechanical fixture shown in Fig. 8 was developed. As may be seen, this apparatus retains the transducer near the vertical axis of the vessel. Adjustments were made on the ultrasound beam direction by changing the transducer angle in the vertical plane and by raising or rotating the apparatus along its long axis. Thus the transducer angle may be fixed in portions of the conical section which have constant included angles. Relocation to subsequent measuring points is accomplished by adjustment of the boom. Vertical movements along the axis will change the distance between the transducer and vessel wall, but it has been demonstrated that such changes do not affect the accuracy of the measuring system. The conical section has regions of both 90 and 30 deg included angles. Successful measurements were made in both. This device was also tested for its ability to make measurements on the spherical section of the vessel by placing the transducer near the vessel center. Very good results were obtained despite the fact that separation between the transducer and vessel wall

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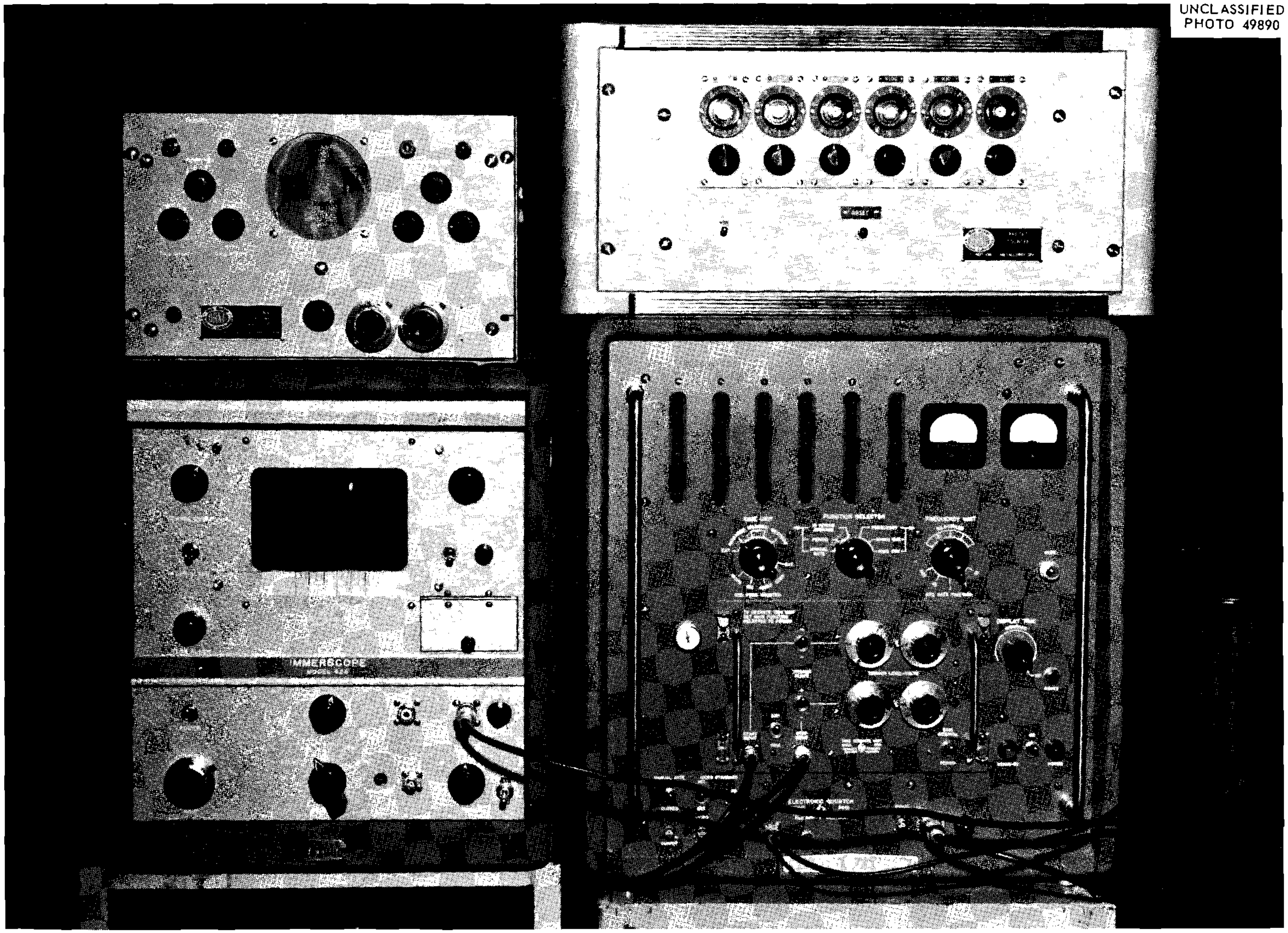

Fig. 7. Photograph of Equipment Outlined in Fig. 6.

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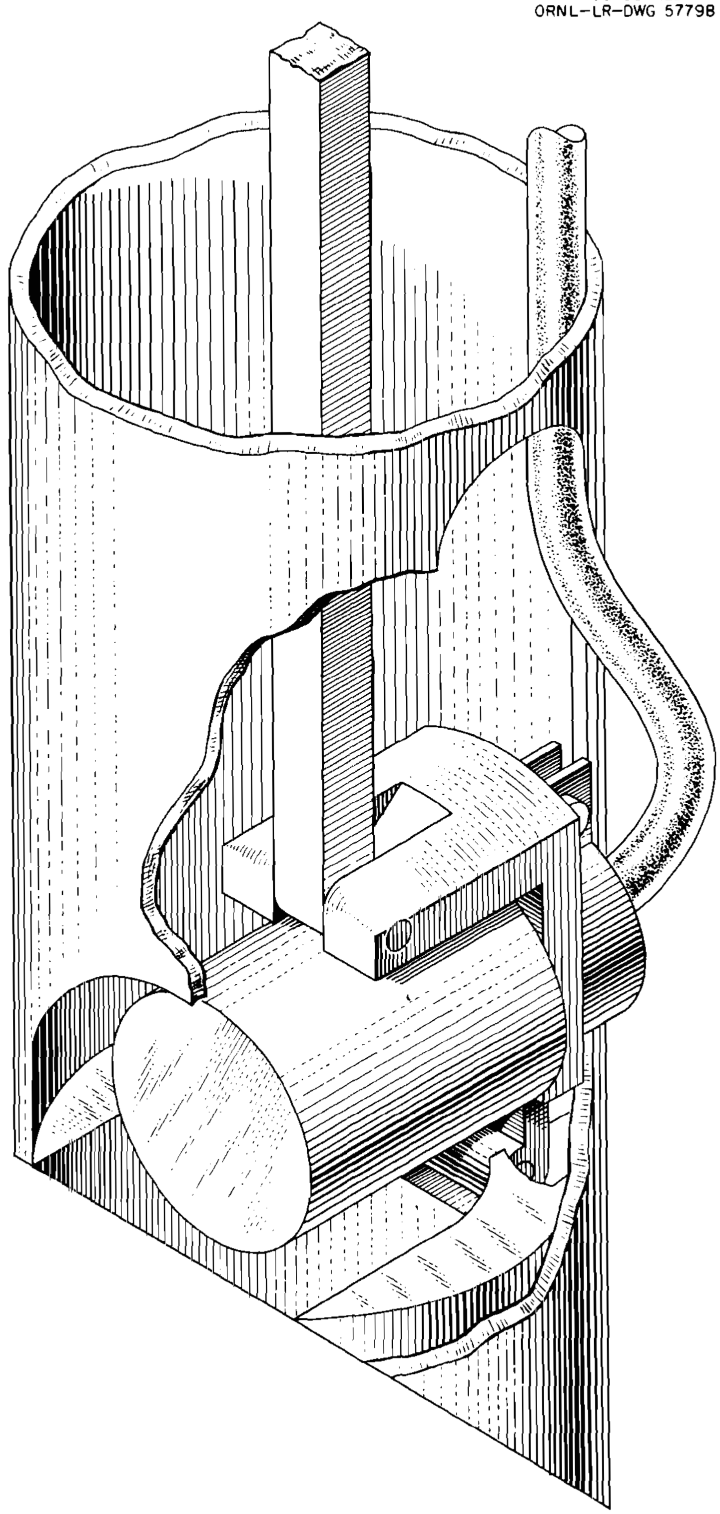

Fig. 8. Mechanical Fixture Designed for Ultrasonic Thickness Measurements in Conical Section of HRT Core Vessel.

was approx 15 in. The same pulse reflection and counting instrumentation was used.

CONCLUSIONS

The mechanical fixture which retains the transducer in a position along the vertical axis of the vessel is the simplest to fabricate and operate, the most versatile, and, in addition, it provides the most accurate positional data of any of the devices discussed. When combined with pulsing and counting instrumentation, it constitutes an excellent tool for the remote measurement of the wall thickness. By simple modification or redesign of the mechanical apparatus, similar measurements could probably be made on other vessel configurations. Ignoring possible velocity variations, the accuracy of the present electronic system for thickness measurements is better than ± 1%. Some of the limitations on present accuracy are due to the pulse-shaping circuitry in the ultrasonic generating equipment which was originally designed for flaw detection and not for such precise applications. These circuits could be improved somewhat; however, for the problem at hand, the possible error due to an unknown velocity change overshadows the instrumentation difficulties. The mechanical and electronic reproducibility and sensitivity of the present arrangement have provided data with a variation of less than ± 1%.

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