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MULTIELECTRODE ULTRASONIC TRANSDUCER
TEST TECHNIQUES FOR RADIOISOTOPE
ENCAPSULATION INSPECTION

February 1971

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ABSTRACT

Receiving ultrasonic transducers with 32 individual electrodes in a linear array on single piezoelectric chips have been fabricated. Linear densities of 32 electrodes per 4, 2.5, and 1.5 cm have been obtained on 5 MHz PZT-5. Electronic circuits for sampling and reading out the individual electrodes at rates of up to 2000 samples per second have been developed, along with the mechanical systems necessary for scanning and manipulating the transducers. The transducers have been used for rapidly testing radioisotope capsules for clad-to-core unbonds and core voids or porosities.

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INTRODUCTION

The safe use of radioisotope irradiation and heat sources necessitates nondestructive testing (NDT) to insure the fueled source containment vessel integrity. A program is in progress at Battelle-Northwest (BNW) to develop NDT methods and devices which can be implemented in the production of these sources and thus establish the source container and core integrity to permit reliable and confident source application. This program is sponsored by the Division of Isotopes Development of the United States Atomic Energy Commission.

The objective of this program is to develop nondestructive test methods, devices, and instruments that will assist the designer or fabricator of isotope encapsulations by

- Evaluating the as-fabricated encapsulation for comparison with designed parameters
- Helping to select and evaluate encapsulation materials and materials compatibility
- Developing faster, more economical, and more easily interpreted test methods.

The major subject of this report is the design and development of multielectrode ultrasonic transducers and the associated electronic and mechanical systems for implementing them. This technology can be applied specifically to the high speed

inspection of plate type sources for core and/or container anomalies. The electronics developed can improve general ultrasonic test instrumentation.

Actual development radioisotope source samples are used whenever possible to insure realistic NDT device and method development. These samples were provided by several AEC source development and fabrication facilities. These samples were supplied with knowledge that source anomalies existed and thus provided valuable references for NDT development. Many samples had anomalies that were either purposely fabricated or else were fabricated during the source developmental process. Thus, the results presented in this report are not to be construed as being indicative of the source quality of fully developed, fueled sources.

SUMMARY

A multielectrode transducer and electronic circuits to sequentially scan the electrodes have been constructed to facilitate rapid inspection of plate or strip type isotope heat sources. This is basically an ultrasonic imaging technique using the shadow imaging method and sampling a moving linear transducer array. In more conventional NDT language, it can be considered a through-transmission system with multiple receivers and C-scan readout.

Good resolution of the object anomalies has been obtained by keeping the object within a few wavelengths of the receivers, thus minimizing diffraction effects, and by constructing transducers with as many as 32 electrodes in 1.5 cm. The transducers are 5 MHz PZT-5 and the electrodes are vapor deposited layers of chrome, copper, and gold.

By sampling the electrodes at rates up to 2000 samples per second, test objects can be rapidly tested for unbonds between the cladding and the core, or for anomalies within the cladding or core.

Delayed or surface-following gating circuits allow particular planes of interest within the test object to be selected and displayed in the image. After passing through the gating circuits, the signal is peak detected (sometimes called pulse stretching) and this longer pulse can modulate the z-axis (intensity) on an oscilloscope or raise and lower the pen on an x-y recorder. The peak detectors are reset for each pulse. At this time, the oscilloscope readout is preferred for the multielectrode system because of its speed. Either maximum or minimum signals can enhance the intensity; the mode desired is selected by the test operator.

All of the above electronic system for implementing the multielectrode transducer was developed on this program. It can be used for single-transducer testing as well. The mechanical system for the multielectrode transducer was also developed. A block diagram of the transducer and electronic system is shown in Figure 1, along with typical readouts.

TRANSDUCER CONSTRUCTION

The key to the multielectrode mapping system is the transducer itself. Basically it is a solid piezoelectric crystal or ceramic with a common electrode strip down the center of one side and a linear array of individual electrodes on the other side and opposite the common electrode. The individual electrodes have separate leads so they can be read out individually.

FIGURE 1. Block Diagram of Multielectrode Transducer System and Typical Readouts

Figure 2a illustrates the back surface electrodes and lead connection pads. The lead connection pads were used to facilitate lead bonding and reduce the wire mass attached to the active electrode. Since the active area is only that part between the common and individual electrodes, interference from the lead pads is minimal.

The electrodes were vapor deposited on the piezoelectric chip in layers. First, 200 Å of chrome was deposited for good bonding, followed by 10,000 Å of copper and 2000 Å of gold to prevent the copper from oxidizing. The masks for the vapor deposition were made by simply wrapping very fine wire around two machine screws and letting each wire fall into a separate thread on the screw. The electrode width was controlled by using screws with various numbers of threads per inch. Different masks were used for the electrodes and the lead pads. The electrodes were connected to the lead pads with gold wire using a thermo-compression bonder; individual external leads were then soldered to the lead pads.

Transducers with 32 elements in 3.75, 2.5, and 1.5 cm (15, 1.0, and 0.6 in.) were fabricated. The transducer shown in Figure 2 was one of the middle size transducers; overall dimensions were nominally 1.2 by 2.5 cm (0.5 by 1.0 in.) with active center electrodes in the 0.3 by 2.5 cm (0.13 by 1.0 in.) center strip.

Figure 2b illustrates the back surface of the transducer with leads attached before mounting. In Figure 3a we see the transducer and leads about to be mounted in a brass case. Figure 3b shows the completed transducer, and illustrates the common front electrode. The transducer is potted in epoxy in the brass case. The ceramic used was PZT-5, 5 MHz.

(a)

Back of Transducer Showing Electrodes
Lead Bonding Pads and Connections

(b)

Lead Wires Attached to Bonding Pads

FIGURE 2. Multielectrode Transducer Construction

(a)

Multi-electrode Chip About to be
Mounted in Brass Case

(b)

Completed Transducer

FIGURE 3. Multi-electrode Transducer Construction

SYSTEMS FOR IMPLEMENTING THE MULTIELECTRODE TRANSDUCER

MECHANICAL SYSTEMS

There are two mechanical systems required for implementing the multielectrode system (or for any through-transmission system). One is a scanning system to move the test object between the transducers or the transducers across the object, and the other is the adjustments and manipulators needed on the transducers themselves.

Since our test objects were generally long strips narrower than the width of the transducer, and because the width is electronically scanned, we only had to arrange for one scan down the test object. This scanning was done on a modified lathe that had been used on previous projects. The lathe can be seen in Figure 4; the transducers are mounted on what was the tool holder. Potentiometers attached to the lathe provide an output signal linearly proportional to the position of the transducers for the readout system.

Several degrees of freedom are needed for proper positioning of the transducers. Reference to Figure 5 should help clarify the following discussion. The transducer faces should be parallel to each other and to the faces of the test object; this is accomplished by the dual goniometer arrangement which has $\pm 30^\circ$ adjustment in two directions. Cross feeds behind the goniometers and vertical adjustments on the arms place the transducers opposite each other. With noncircular transducers like these, the transducers should be rotatable; this is accomplished by the worm gear in front of the goniometers. Finally, the distances of the transducers from each other and from the test piece can be independently adjusted to provide for different test objects and focal lengths.

FIGURE 4. Photograph of Multielectrode System

FIGURE 5. Close-up of Transducers and Mechanical Adjustments

ELECTRONIC SYSTEM

This section of the report describes the multiplexing and signal analysis portions of the multielectrode system. It also describes new amplifiers and readout techniques. Though the instrumentation was developed for the multielectrode system, one of the design philosophies was that to avoid duplication of equipment the units should be usable for single transducer ultrasonic testing as well. This has been carried out; the transmitter, signal analysis, and readout units are all in separate packages and may be used independently.

A study of Figure 6 may help to understand the relationships of the electronic system components. For ease of description and understanding, we can describe the system as three subsystems; signal generation, signal analysis, and readout.

FIGURE 6. Block Diagram of Electronic System for Implementation of Multielectrode Transducer

Signal Generation

This section describes in a general manner the SCR transmitter and its built-in clock and preamplifier. Schematics will be found in Appendix A.

The transmitter uses an SCR semiconductor as the main element. This was chosen because its rise time more closely approximates the resonant frequency of the transmitting transducers generally used than do faster semiconductors. This allows more nearly optimum energy transfer to the transducer. The peak voltage can be varied from either 0 to 75 or 0 to 300 V, depending upon the particular SCR used. The recommended conservative maximum for the lithium sulphate transducers that we used is about 75 V.

The transmitter fires each time a trigger pulse is applied to it; these can be generated internally or externally. The internal clock runs at 2000 pulses per second and supplies both a positive and negative synchronizing pulse for other units. The external synch requires a positive pulse 2 to 5 V in amplitude and about 0.1 μ sec in duration.

This unit also contains a limiter and preamplifier for single transducer work. The limiter restricts the transmit pulse to about ± 1 V so that the preamplifier is not damaged or saturated. The preamplifier is a wideband unit with a 3 dB point of 30 MHz with nominal gain of 200 at 5 MHz. Because the preamplifier has a low impedance output, it can drive relatively lengthy cables; this allows placing the transmitter unit inside a hot cell and leaving the other units outside.

Signal Analysis

The signal analysis unit performs several functions; it amplifies the received signal, gates out the portion of interest, peak-detects the maximum amplitude of the gated output (resetting for each pulse), multiplexes the signals from the receiving

transducer, and provides a staircase ramp output whose voltage at any time is proportional to the position of the electrode which is being sampled. Figure 7 shows representational waveforms at various points in the signal analysis unit.

The amplifier is a wideband amplifier with about 45 dB gain and a usable bandwidth of about 30 MHz. A ten-step attenuator on the input allows the optimum gain to be selected. The amplifier has a high input impedance so that it can be driven from many sources.

The gating circuits select the portion of the signal that is of interest and attenuate the rest; i.e., only a small part of the reflected signal is processed. The gating circuits are set up for operation in either a fixed delay or surface follower mode. In the fixed delay mode, the gate follows the transmit pulse by a set time. When used in the surface following mode, the reflection of pulse off the front surface of the part triggers the delay circuits and the gate is then at a certain time/distance behind the front surface. This compensates for irregularly shaped objects while allowing the gate to be very narrow and thus interrogate only a thin plane within the test object. To avoid ambiguous signals, the front surface reflection must be within the gate duration set by the fixed gate; this gate can generally be set fairly wide.

The peak amplitude detection circuitry converts the maximum amplitude of the gated pulse to a quasi-dc level. This dc level is reset for every transmit pulse, enabling the amplitude for each of the transducer elements to be dealt with independently (See Figure 8). (Most peak detectors average over many pulses and would not be suitable for this system.) Let us leave the peak-detected voltage for a moment since its next step is to the readout unit, and consider the multiplexing and digital to analog (D-A) functions of the signal analysis subsystem.

FIGURE 7. Typical Signal Processing Waveforms

THROUGH TRANSMISSION UNBOND OR CORE VOID TEST

FIGURE 8. Unbond and Resultant Peak Detected Amplitudes

The function of the multiplexing circuits is to sequentially sample the elements of the transducer array. The signal from a particular element is selected using straightforward diode gating circuits. The diodes are driven by a counting circuit which is stepped along by synch pulses from the transmitter or similar pulses from any other pulser. This circuit is set up for 32 elements; it is possible to use any number but this would require circuit modifications.

The readout of the system is typically a two-dimensional image of the part under test. Linear potentiometers provide a signal proportional to the axis which is being mechanically scanned; the staircase ramp provides the other axis. This ramp is generated by converting the digital counter output in the multiplexing circuit to an analog voltage, thus supplying a "step" for each element. Since this is electronically scanned very rapidly compared to the horizontal mechanical scanning, it essentially provides a vertical axis for the readout.

Readout

The function of the readout unit is to modify the output signal when a defect is present. Depending on the output device and desired mode of operation, when the defect signal exceeds a predetermined value it can: 1) blank or intensify an oscilloscope signal, 2) raise or lower the pen on an X-Y recorder or 3) actuate the pen or pens on a facsimile recorder.

The discriminator circuits detect when the peak-detected voltage exceeds a certain limit. This limit can be set by the test operator. The advantage of this is a positive go-no-go action. The oscilloscope presentation could be in shades of gray, if desired.

Output

Several types of recording instruments have been used or considered for the final readout of the multielectrode system.

The oscilloscope presentation has been favored because of its ability to match the scanning speed that the multielectrode transducer makes possible. The image is recorded by photographing the CRT image as the transducer is mechanically scanned.

A fast recorder that has 100 separate writing elements has also been used with this system. Thirty-two of the writing elements are individually actuated, allowing permanent, fast, dry paper recording.

RESULTS

The first application studied was the detection of small simulated voids or unbonds. These were simulated by drilling flat bottomed holes in a strip 1.8 x 0.18 x 32 cm (0.75 x 0.075 x 12.5 in.) fabricated by coextruding a stainless cladding and a nonactive cobalt core. The holes were 0.3 cm (0.125 in.) in diameter and had depths of 0.025, 0.075, and 0.16 cm (0.010, 0.030, 0.065 in.). Since this is a through-transmission system, the effect of the holes was not exactly like that of an unbond since the holes tended to both time-shift and attenuate the received signal (because of scattering by the rough bottom). The net effect, however, was to diminish the signal within the gate period, the same as an unbond or void would. The results of detecting these holes were shown in Figure 1.

Several development strips such as the one just mentioned were tested for bond between the clad and core. Figure 9 shows the results from testing the upper edge of three of these strips. Strip A has a complete unbond; sound passes only to the electrodes which are above the edge of the strip. (Only the top edge was tested since this particular transducer was only 1.5 cm wide and the strip was 1.8 cm wide.) Strip B had

FIGURE 9. Multielectrode System Examination of Bond Integrity on ^{60}Co Coextruded Sources

PARTIAL BOND
(b)

GOOD BOND
(c)

COMPLETE UNBOND
(a)

a partial unbond along the top edge, while strip C was completely bonded. The dimensions are roughly actual size in these photographs. The scan was made as fast as the lathe would allow; about 1 in./min. The transducer system is capable of much faster translation; it would interrogate every 0.15 mm if the translation speed were 1 cm/sec.

Figure 10 shows a photograph and radiograph print of a 10 cm long nonradioactive sample source with a 0.25 mm stainless steel cladding and a strontium-silicate, aluminum matrix core. Also shown is a scan taken with the multielectrode system of the right end of the sample. A portion of the cladding on the left end has been removed to show the Sr-SiO₃ minispheres in the aluminum matrix. The radiograph of the sample shows where the cladding has been removed, and also shows a triangular area of low density at the right end. The ultrasonic scan shows an area of unbond or void that has a triangular shape but is larger than the low density area on the radiograph. This is probably due to the apparent small voids in that area or to unbonds.

ACKNOWLEDGEMENTS

The design and construction of a complete ultrasonic testing system must be based on previous work and comments of many contributors. Special thanks to C. L. Kinney for constructing the electronic system and to J. C. Harris for construction of the transducers. The constructions of good high frequency pulse circuits and special ultrasonic transducers are still as much art as science and an excellent job has been done.

PHOTOGRAPH

RADIOGRAPH PRINT

MULTIELECTRODE SCAN

FIGURE 10. Multielectrode Readout of Possible Void or Unbond
in Sr-SiO₃-Al Matrix Source

APPENDIX A

CIRCUITRY DIAGRAMS OF SIGNAL GENERATION
FOR THE MULTIELECTRODE ULTRASONIC TRANSDUCER TECHNIQUE

TI SN7440

FSC. 9601

Neg. 710700-2

FIGURE A.1. Transmitter and Synchronizing Clock Schematic

FIGURE A.4.

Neg. 710700-5
 FIGURE A.5. Sequential Period Gating Schematic

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