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Argonne National Laboratory

A TELEVISION SYSTEM
FOR ULTRASONIC IMAGING

by

Harold Berger

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

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ANL-7042
Engineering and
Equipment (TID-4500)
AEC Research and
Development Report

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

CFSTI PRICES

H.C. \$ 2.00; MN .50

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Harold Berger

Metallurgy Division

Program 12.1.6

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IN NUCLEAR SCIENCE ABSTRACTS

January 1966

Operated by The University of Chicago
under
Contract W-31-109-eng-38
with the
U. S. Atomic Energy Commission

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ABSTRACT

The capabilities of a continuous-wave, ultrasound, television imaging system as applied to several nondestructive testing problems are discussed. Application of the system to flaw detection is stressed, but some discussion and examples concerning the use of the system for other application areas, including liquid-level indication and fluid-flow studies, are also presented. It is concluded that, in the area of flaw detection, the television system offers particular promise for the ultrasonic inspection of thin, flat material. In inspections of objects of this nature, such as flat reactor fuel elements, the television system as normally used in these studies is capable of approximately one-mm resolution, of linear object inspection speeds of 120 cm/min, and of detecting such anomalies as bonding flaws, fuel inhomogeneities, and grain-size variations. The use of the television system in such inspection applications is recommended.

I. INTRODUCTION

Television systems for detecting and displaying ultrasonic images have been extensively described in the technical literature. Various review articles have summarized these efforts along with other methods for producing ultrasonic images.¹⁻³ More recent publications on the development of ultrasonic imaging systems employing television methods include the reports of Jacobs *et al.*,⁴⁻⁷ Smyth *et al.*,⁸ Sayers,⁹ Lawrie and Feith,¹⁰ Turner,¹¹ and Moseley.¹²

This report will be concerned with a study of a continuous-wave, ultrasonic television system⁴⁻⁷ for application to nondestructive testing problems. The inspection results obtained with this system are demonstrated in this report by prints of motion-picture recordings from the television monitor* during the inspection runs. These results are occasionally compared to more conventional, ultrasonic inspection results and, in some cases, to radiographic results on the same samples. Metallographic results are also given for several of the inspection samples.

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*A Bach-Auricon Pro-600, 16-mm camera with a TV-T shutter was used for the motion-picture recordings.

II. THE INSPECTION SYSTEM

The ultrasonic inspection system has been described previously.⁴⁻⁷ Briefly, the system, shown in Fig. 1, is a closed-circuit television system

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Fig. 1. A Diagram of a Television Ultrasonic-imaging System, as Arranged for Through-transmission Inspection

whose camera tube responds directly to ultrasonic energy. The kinescope provides a picture of the ultrasonic energy pattern at the camera tube. The transmitting transducer most used in these studies was a 5-cm-diam barium titanate transducer, whose resonant thickness was approximately 2 Mc. The transducer is operated at a great enough distance from the inspection object and receiver so that essentially plane waves are involved in the image production.^{3,9} The camera tube, continuously pumped, has a matching barium titanate transducer, which serves both as the target and vacuum

window of the camera tube. The tube is shown diagrammatically in Fig. 2. Sealed camera tubes equipped with quartz transducers are available^{5,6,7} and have shown good tube life.

Fig. 2

A Schematic Diagram of the Ultrasonic, Television Camera Tube

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A high-velocity electron beam is scanned across the tube target, and voltages induced in the target by the ultrasound modulate the secondary electron beam. Scanning is accomplished by electrostatic deflection in the demountable camera. The secondary electrons are collected through an

electron multiplier, thereby providing an amplified video output for the television circuitry.⁶ The presentation is made with the standard American television system of 525 lines, 30 frames/sec, interlaced. The bandwidth of the television system is 8 Mc. The image is displayed without demodulation of the ultrasound carrier. All images presented here were made by using continuous-wave ultrasound and direct-shadowing techniques as shown in Fig. 1, as contrasted to the use of lens systems.

An overscanned television presentation was normally used in these tests. Therefore, the useful target diameter of the camera tube appeared totally on the 40.2-cm (17-in.) kinescope; electron images of parts of the side walls were also obtained. In the demountable system used for the test results given in this report, the active diameter of the camera-tube target was about 4.4 cm, unless otherwise indicated. The total diameter of the barium titanate was 5 cm, the difference being taken up by the rubber gasket used for the vacuum seal. The electron image of the camera tube, as normally presented, is shown in Fig. 3. The active diameter of the target was normally presented as about a 17.5-cm-diam image on the kinescope. For comparison with Fig. 3, the image of the 1.9-Mc* ultrasonic beam is shown in Fig. 4. In this case, no object is shadowing the beam; note the uniformity of the far-field ultrasonic pattern.

41447

Fig. 3. The Overscanned Television Image of the Ultrasonic, Camera-tube Target as Normally Presented on the Kinescope. Three frames of the 16-mm motion-picture film recording are shown in this case, and in all the motion-picture records to follow.

41446

Fig. 4. A Television Image as in Fig. 3, but with the Ultrasound Imaging Beam Turned on. No object is shadowing the ultrasound reaching the detector.

*The imaging frequency used with the ultrasonic television system was 1.9 Mc, unless otherwise indicated. A particular camera-tube transducer has its best imaging response at one particular frequency or harmonic thereof.

III. THE INSPECTION METHOD

For nonlens ultrasonic imaging systems, one is essentially limited to the inspection of relatively thin materials. It would be difficult, for example, to obtain a meaningful inspection of a metallic object having a thickness of 8 cm or more, without employing an ultrasonic lens. This is the case because the large flaw-detector distances encountered when thick objects are inspected permit diffraction effects and other variations to complicate the continuous-wave image presentation.¹³ It has been found experimentally with the direct-shadowing system¹⁴ that the image correlates well with object flaw size for flaw-detector distances up to about 4 cm.

Some lens studies have been conducted on this program, particularly in regard to reflection inspection methods.⁷ These initial lens studies, made with simple, single-element plastic lenses, did provide reasonably satisfactory results. Much superior results have been obtained more recently by using a two-element polystyrene lens described by Suckling and Ben-Zvi.¹⁵ A typical arrangement for a reflection test is shown in Fig. 5. By varying lens-object distance, one can focus on different depths within the test object. The lens arrangement for through-transmission testing of a thick object would be similar to that shown in Fig. 5, except for the changed location of the transmitting transducer.

37110

Fig. 5. A Partial, Top View of the Television Ultrasonic-imaging System Arranged for Reflection Testing

The major emphasis in this investigation, however, has been concerned with tests of relatively thin samples. That being the case, nonlens systems have been most employed. The inspection technique utilized for

41487

Fig. 6. Partial Views of the Television Imaging System (side view, upper; top view, lower), Showing Angulation of Flat Inspection Objects

the image area by placing the object at a suitably large angle. Secondly, in the case of relatively thin, metallic inspection objects, placement of the sample at the proper angle for the generation of a first-order Lamb-wave mode can improve the result by the increased ultrasonic transmission and the improved sensitivity to internal flaws.^{16,17}

The Lamb-wave technique for ultrasonic imaging has been investigated and reported.¹⁸ First-order Lamb-wave modes presented better results than higher-order modes, undoubtedly because of improved ultrasonic transmission intensity. The choice between a first-order symmetrical or asymmetrical mode for best imaging purposes usually had to be determined experimentally. The only rule that seemed to apply in this choice was that the asymmetrical mode should be avoided when the phase velocity approached that of Rayleigh waves. This seemed to be true in that case because of the increased tendency for the generation of surface waves. A test result showing ultrasonic images at normal incidence and at the proper angles of incidence for the generation of several Lamb-wave modes is shown in Fig. 7.

The ultrasonic television system, therefore, lends itself to several inspection arrangements. Lens systems can be employed for either through-transmission or reflection techniques. Direct shadowing methods can be used with a normal or slightly angled object orientation to reduce standing-wave effects and, in the case of thinner inspection objects, the direct method can be used in the Lamb-wave orientation. Since one of the more promising areas of application for the system is the inspection of relatively thin, flat reactor fuel plates, most of the inspection examples to be presented will involve the Lamb-wave orientation technique.

thin metallic samples has generally used a Lamb-wave approach in which the samples were placed in the inspection position at other than the normal angle of incidence. If one places the inspection object at an angle of incidence, θ_i , as shown in Fig. 6, a two-fold advantage results. First, angling the flat inspection object at any angle larger than a few degrees tends to eliminate the interference of standing waves in the ultrasonic image. Ultrasound, which would otherwise reflect back and forth between the object and the detector, is essentially removed from

38995

Fig. 7. Photographs of the Television Presentation of a Continuous-wave Ultrasonic Inspection of a Stainless-steel Sample. (Frequency was 1.9 Mc/sec, thickness was 0.124 cm, fd product was 2.36×10^5 cm/sec.) The sample contained a simulated flaw. Pictures were taken at θ_i values, left to right of 0, 12.4, 21.7, and 32.5°, illustrating normal incidence and the second asymmetrical, first symmetrical, and first asymmetrical Lamb-wave mode images, respectively. Improved imaging at the 21.7° angle, the first symmetrical mode, is apparent. A slight image of the flaw can be observed through the standing-wave pattern at normal incidence. Only a small portion of the tube target area is shown in each photograph. In contrast to all the other ultrasonic television-system results shown in this report, these were still photographs instead of motion-picture recordings

IV. EXPERIMENTAL RESULTS

Although some results with the television system were shown in Fig. 7, it might be advantageous to demonstrate test results obtained with simple objects before proceeding into more complex test situations. Figure 8 shows the television image obtained for 1.9-Mc ultrasound transmitted through a rubber sheet (approximately 0.6 cm thick) containing several through-holes of various sizes. Holes as small as 1 mm in diam have been observed in this sample. This limiting value is essentially imposed by the wavelength of the ultrasonic energy (the wavelength of 1.9-Mc ultrasound in water is 0.78 mm). Shadowing the ultrasound beam with small wires placed in front of the receiving transducer, wire sizes as small as 0.2 mm in diam have been imaged at 1.9 Mc. In this case, as in the case of small holes, the image of such small objects appears as though the object is larger. Resolution studies on such systems at Northwestern University indicate that objects smaller than the ultrasonic wavelength or the receiving-transducer thickness can be imaged, but that they appear to be as large as the larger of these two values.¹⁹

An object commonly observed through imaging systems of this type is the tip of a human finger. For comparison purposes, an image of this type obtained with this equipment is shown in Fig. 9.

Some nondestructive-testing results for the ultrasonic television system are demonstrated for BORAX-V superheater fuel plates^{20,21} as inspection objects. These plates contain a dispersion of UO₂ in Type 304-B austenitic stainless steel and are clad with Type 304-L stainless-steel

material. The plate dimensions are approximately $64 \times 9.3 \times 0.075$ cm. The fuel-core dimensions are approximately $61 \times 8.86 \times 0.0356$ cm. One such plate was used as a test standard during the actual inspections of these fuel plates;²⁰ this test plate contained two artificially produced jacket-jacket defects. Radiographs of the sections of the plate containing these defects are shown in Fig. 10. Figure 11 shows the television ultrasonic image of the larger of these edge defects. Figure 12 shows the television presentation of the smaller edge defect. The inspection object in each of these cases was angled to generate a first-order Lamb-wave mode. For comparison, ultrasonic through-transmission images of these same two defects obtained with a mechanical-scan system^{22,23} are shown in Figs. 13 and 14. The mechanical-scan system used 5-Mc lead metaniobate transducers (Branson, Z-K) with a 1.59-mm (1/16-in.) collimator on the transmitting transducer. The receiver output was amplified and recorded on a two-dimensional plot. The larger edge defect is shown with the recording system for the mechanical-scan system printing both in the jacket and fuel regions of the fuel plate. The smaller edge-defect indication was not detectable when that approach was used; the mechanical-scan recording is shown with the recording system set to print only in the nonfuel region of the plate.

Examples of natural defects detected in these plates are shown in Figs. 15-19. Figure 15 is a print of a motion-picture recording of the ultrasonic television image of a blistered section of BORAX-V plate HCD-104.

41445

Fig. 8. The Television Presentation of an Ultrasound Image Obtained When the Beam Is Shadowed by a Rubber Sheet Containing Several Through-holes. Hole sizes as small as 1 mm in diam have been observed at 1.9 Mc.

41443

Fig. 9. The Television Ultrasonic Image of the Tip of a Human Finger

Fig. 10. Positive Prints of Portions of an X-radiograph of a BORAX-V Test Plate Showing Two Artificially Produced Jacket-Jacket Defects. View 1A presents an image of a defect $1.59 \times 3.18 \times 0.127$ mm; view 1B shows the larger defect, $3.18 \times 3.18 \times 0.254$ mm. The latter defect is deep enough to reach the core.

Fig. 11. A Television Ultrasonic Image of the Larger Jacket-Jacket Defect Shown in Fig. 10. The edge of the fuel plate, running vertically, is centered in the picture. The fuel plate is on the right side of the view shown. Unattenuated ultrasound produced the white signal on the left.

Fig. 12. The Television Ultrasonic Image of the Smaller Jacket-Jacket Defect Shown in Fig. 10. The arrangement is similar to that shown in Fig. 11.

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Fig. 13. Ultrasonic, Through-transmission, Recorder Trace Showing Image of the Larger Jacket-Jacket Defect Shown in Fig. 10. Compare to Fig. 11. The small white area near the top of the recording is the flaw indication.

41486

Fig. 14. Ultrasonic, Through-transmission Image of the Smaller Jacket-Jacket Defect Shown in Fig. 10. The inspection unit was set to print only in the clad region. Compare to Fig. 12.

41448

Fig. 15. A Television Ultrasonic Image of a Blistered Portion of a BORAX-V Fuel Plate

The mechanical-scan, ultrasonic, through-transmission image of this area of the same object is shown in Fig. 16. Similar ultrasonic-test results on the same fuel plate, indicating a jacket-core separation at the end of the plate are shown in Figs. 17 and 18, respectively. Metallographic confirmation of this last indication is shown in Fig. 19.

41484

Fig. 16

An Ultrasonic, Through-transmission Recording of the Fuel Plate Shown in Fig. 15. The recording shows a greater area of the plate than the television image.

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Fig. 17. A Television Ultrasonic Image of a BORAX-V Fuel Plate Showing a Jacket-Core Separation. The finger points out the dark, long, narrow defect.

41485

Fig. 18. An Ultrasonic, Through-transmission Recording of the Fuel-plate Area Shown in Fig. 17

39306

14X

Fig. 19. Metallographic Indications of Jacket-Core Defect Shown Ultrasonically in Figs. 17 and 18. The fuel plate was cut to show more of the length of the defect area in this 14X magnification photograph.

The television ultrasonic-imaging-system technique used in the preceding illustrations was the Lamb-wave method. The first-order asymmetrical mode was used in each case. A mechanical translation system used in conjunction with these tests permitted the fuel-plate inspection object to travel through the useful inspection area at various linear speeds. Defects such as those discussed above could be detected at object speeds from 0 to 120 cm/min. In most cases, detection of the ultrasonic indication was easier if there was some regular object movement, since the eye was easily attracted to the moving variation indication.

The Lamb-wave orientation technique is sensitive to the angle of incidence. The relatively crude translation system used in these tests maintained a reasonably constant angular orientation of the inspection object. Changes in this orientation were immediately apparent because of the change in ultrasonic transmission. If the plates were not flat, broad areas of the plate would show such changes. Such plates could be inspected by means of slower scan methods; the angle of incidence was manually changed when necessary. Localized changes, such as indentations in the plate, were also readily detectable by this technique. Figure 20 shows the television ultrasonic-system indication obtained for a small indented area on one of the BORAX-V plates.

For thicker inspection objects, the Lamb-wave technique loses much of its potential advantage.¹⁸ Examples of natural defects detected by the television system in thicker objects are shown in Figs. 21-24. Figures 21 and 22 are prints from motion-picture recordings of the

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Fig. 20. A Television Ultrasonic Image Showing Indication Caused by a Slight Indentation on a Flat BORAX-V Fuel Plate. A Lamb-wave orientation technique was used. The finger points out the indentation indication.

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Fig. 21. A Television Ultrasonic Image of a Defect Detected in an X-8001 Aluminum-alloy sheet material inspection (the dark spot in the middle of the image). The metallographic indication is shown in Fig. 23.

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Fig 22

A Television Ultrasonic Image of a Defect Detected in an X-8001 Aluminum-alloy Sheet-material Inspection, at Larger Magnification. The scanning pattern in the ultrasonic camera tube was decreased making the television presentation in this case appear larger. The same information is available, but the larger presentation (compare to Fig. 21) makes it appear less sharp. The metallographic confirmation of this defect indication is shown in Fig. 24.

Fig. 23

Lamination in 0.47-mm-thick X-8001 Aluminum-alloy Sheet Material as Disclosed by Metallography. Ultrasonic defect indication is shown in Fig. 21.

41438

25X

41439

25X

Fig. 24

Another Lamination Indication Detected by Ultrasonic Television-imaging Inspection; Material Is as in Fig. 23. Ultrasonic defect indication is shown in Fig. 22.

television ultrasonic system showing through-transmission defect indications in X-8001 aluminum-alloy sheet material. This material, used as cladding for ALPR fuel, was 0.47 cm thick. The inspection was accomplished by a through-transmission technique, the material being angled only enough to eliminate standing-wave problems. The defects found by the indications in Figs. 21 and 22 were laminations, as shown by the metallographic indications in Figs. 23 and 24. Previous studies with similar material indicated that the television system used in a reflection test method was capable of detecting inclusions.⁷ That reference⁷ also showed the capability of the system for inspecting much thicker material; nonbond areas in an aluminum test object having a thickness of 3.17 cm were detected by the television system, and comparisons with a mechanical-scan ultrasonic system and with X-radiography were made.

The potential usefulness of the television inspection system in a different area is illustrated in Fig. 25. A glass tube is shown in a small portion of the ultrasonic field; the image produced when warm water flows past the imaging transducer is shown. This image is the result of the change in velocity of ultrasound between the incoming warm water and the water in the ultrasonic tank. Similar tests in which water at the same temperature as that in the tank was introduced did not yield this indication. Water-temperature differences as little as 5°C have been observed in this manner.⁶

By means of this approach, an indication of the temperature of a liquid flowing in a tube could be obtained. An abrupt change in the liquid temperature could easily be observed. The absence or presence of the liquid can also be determined, as shown in Fig. 26. The level of oil in a closed plastic bottle is shown.

Fig. 25

Ultrasonic Indication of Temperature Difference as Detected by Flowing Warm Water Past the Ultrasonic Television Camera Tube. The image of a glass tube appears in the lower left area of each frame. The dark streak upward from the glass tube is the image of the warm water flowing within the cooler water of the ultrasonic tank.

Fig. 26

Oil Level in a Plastic Bottle as Indicated by the Television Ultrasonic System. The dark area at the top of the image indicates attenuation of the ultrasonic beam by the air over the oil level.

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V. DISCUSSION

Potentially useful areas of application for the ultrasonic television system have been indicated in the preceding section. Flaw detection, liquid level, fluid-flow studies,²⁴ and biological applications²⁵ are suggested by the examples shown. Another area, which has been suggested previously, is in regard to underwater problems, particularly the identification of objects in coastal waters.^{19,26} However, for this discussion, we shall be concerned only with the first item, flaw detection.

For the inspection of thicker objects by means of lens systems, it should be recognized that the speed of such an inspection method would probably be relatively low. For best inspection results, one would have to scan the object through the inspection zone in the area plane perpendicular to the ultrasound beam direction, and, in addition, one would have to scan the object in the direction of the ultrasonic beam, essentially focusing on different planes throughout the thickness of the material. This could be a time-consuming method, but it would yield a useful inspection.

Thinner objects, on the other hand, could be inspected with reasonable speed because the entire thickness could be inspected at once. For nonlens systems, with either the direct shadowing or Lamb-wave technique, the 1.9-Mc inspection system described is capable of inspecting an object having a width of about 4.4 cm, and a length of 120 cm in one minute. The resolution capability of the system is of the order of a millimeter.

The resolution of the system and the object area that can be inspected in a given time are both dependent on the ultrasonic frequency at which one operates. Transducers having a resonant frequency of the order of 5 Mc and diameters as large as 2.5 cm have been used with these systems. A

system of this type would provide a useful inspection area of about 2 cm, as opposed to the 4.4 cm for the 1.9-Mc system described, and would probably provide a resolution capability of a few tenths of a millimeter.

On the other hand, one can go to larger inspection areas if the inspection requirements can accept the decreased resolution that results from the thicker camera-tube target needed to provide a useful vacuum window. As indicated in Fig. 2, the sensitive target of the camera tube is also used as the vacuum window. As the resonant frequency is increased, the transducer material must be thinner, thereby requiring that a smaller area be used to provide the mechanical strength. Two devices have been suggested and used to modify these requirements. Jacobs¹⁹ has used a coarse mesh behind a large-area, high-frequency transducer to provide additional mechanical strength for the vacuum window. A 5-Mc transducer having an overall diameter of 3.8 cm has been used successfully.¹⁹ Lawrie and Feith¹⁰ (see also Ref. 3, pp. 30 and 31) have approached this problem by cementing the receiving transducer inside the tube on the back side of a window was to provide the required mechanical strength. Transducer size and frequency problems then are replaced by the need for a uniform bond between the transducer and the window. Receiving transducers 5 x 5 cm in area, and having resonant frequencies in the 7- to 10-Mc range, have been used.

With the receiving transducer used directly as the vacuum window, however, a reasonable choice of frequencies and image areas is available. Among those which have been successfully used are 5 Mc, 2.5-cm diam; 2 Mc, 5-cm diam; and 1 Mc, 10-cm diam. An image presented on a 1-Mc, 10-cm-diam transducer is shown in Fig. 27. The difficulties of obtaining a large-area ultrasonic beam of relatively uniform-intensity cross section for imaging work do impose an upper limit on areas that can be considered. It was difficult, for example, to provide an even ultrasonic-intensity distribution over more than about the central 7.5-cm diam when the 1-Mc, 10-cm-diam transducers were used.

Fig. 27

A Television Ultrasonic Image of a Blistered BORAX-V Fuel Plate (as shown in Fig. 15). In this case, the detecting target of the camera tube was a 10-cm-diam barium titanate transducer, operating at about 1 Mc. The blister image is readily observed (centered dark area), as is the reduced image sharpness resulting from the larger image presentation and the use of the lower frequency.

For most applications, systems operating at about 2 Mc provide a reasonable compromise between resolution capability and useful image area. Considering the inspection of thin, flat objects, the capabilities of the 1.9-Mc system would provide an image area of about 4.4-cm diam, a linear object-movement inspection speed of at least 120 cm/min, and a resolution of about 1 mm. This system, capable of detecting the same types of flaws and inhomogeneities as the mechanical-scan, through-transmission, ultrasonic system, offers advantages in both resolution and inspection speed.

The overall sensitivity of the system to internal defects is good, as is shown by the numerous illustrations in the preceding section. Another indication of the sensitivity of the system concerns its use in choosing fuel-element samples for thermal-conductivity tests. A recently completed study made to compare thermal conductivity and ultrasonic transmission on various samples included tests on samples of BORAX-V fuel plates. These test plates were scanned by means of the television system, and areas of good and questionable ultrasonic transmission were therewith determined. The test samples were cut from the plate on the basis of these tests. All the areas shown as questionable showed a lower thermal conductivity than the good areas; the ultrasonic tests made later by conventional through-transmission tests were inconclusive.²⁷

A disadvantageous property of the television system is that there is, in the system as used here, little or no grey scale. The television presentation of a complete nonbond area in an inspection object is difficult to differentiate from some other inhomogeneity. For example, a television ultrasonic image of a prototype fuel plate for the Argonne Advanced Research Reactor (AARR) is shown in Fig. 28. On the photograph, a finger points out the location of a simulated flaw made by a small tape area containing an air bubble. The flaw area is difficult to distinguish from other indications in the inspection sample, apparently the result of inhomogeneities in the distribution of the fuel.²⁸ The television image of a more homogeneous sample²⁸ of the same type is shown in Fig. 29. A mechanical-scan system could be set to eliminate indications from such inhomogeneities and yet record the location of gross flaws such as nonbond areas.

Recording of inspection data is another potentially difficult area for the television system as compared to the recorder read-out systems commonly used with mechanical scanning systems. However, motion-picture or video-tape recordings can be made for permanent inspection records. Motion-picture cameras for recording television images are available in the \$2000 and up price range. Video-tape recorders normally cost about \$15,000, although newer models have recently become available at less than \$5000. Motion-picture film costs (16 mm) would be about \$40 per hour of recording (plus development costs). Video-tape costs are in the same range. Either film or video tape can provide a satisfactory solution to the data-recording problem.

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Fig. 28. A Television Ultrasonic Image of a Portion of a Prototype AARR Fuel Plate. The finger points to the image of a simulated flaw (tape, with a bubble left in it). The non-uniform ultrasonic image, resulting from inhomogeneities in the fuel distribution, make it difficult to locate flaw indications.

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Fig. 29. A Television Ultrasonic Image of a More Homogeneous AARR Fuel Plate (as compared to that shown in Fig. 28).

Finally, since we are considering television ultrasonic inspection systems, pulsed systems should be mentioned as opposed to the continuous-wave system discussed in this report. Pulsed systems are being considered in several laboratories.^{3,9,10,29,30} Such systems should eliminate or reduce some of the problems encountered with continuous-wave techniques, such as those associated with standing waves. At least one pulsed imaging system is actually in operation.¹⁰ At the present stage of development, one can choose between the conventional television presentation used with the continuous-wave system, or a slower presentation (about one second for a complete frame) as presented by the available pulsed system. The enhanced ability of an observer to detect a flaw indication if it is moving, tends to favor the faster, continuous-wave method. The fact that standing-wave effects can be eliminated or lessened by the Lamb-wave technique, by slight angular orientation of the object, or, as more recently indicated, by placing a thin, ultrasonic absorber between the object and detector,³¹ also favors the continuous-wave system at present. Future developments, however, may change this situation. A camera tube having storage, for example, would present a useful component for a pulsed, ultrasonic, imaging system.^{3,19}

VI. CONCLUSIONS

The continuous-wave, ultrasonic, television-imaging system described appears to be potentially useful for flaw detection, liquid-level investigations, fluid-flow studies, and other application areas. Flaw detection, the primary area of application considered in this report, is shown to be promising, particularly with regard to flat metallic objects and for the detection of flaws normally of interest for ultrasonic inspection. For the specific task of inspecting flat reactor fuel elements for such anomalies as bonding flaws, fuel inhomogeneities, and grain-size variations, the television system described appears very useful and is highly recommended. It offers the prospect of increased inspection speed and improved resolution as compared to other ultrasonic inspection methods.³²

ACKNOWLEDGMENTS

The cooperation of Prof. John E. Jacobs of Northwestern University throughout this study, particularly in the earlier stages, is sincerely appreciated. Helpful discussions with G. W. Plice of James Electronics, Inc., and R. A. di Novi, R. G. Peterson, and R. H. Selner of Argonne, are also acknowledged. The assistance of I. R. Kraska throughout this study, in both the experimental work and in the discussion of fruitful ideas, is gratefully acknowledged. The comparison ultrasonic tests made by R. H. Selner and radiographic assistance from N. P. Lapinski have been very helpful.

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