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A REVIEW OF ULTRASONIC IMAGING METHODS,
WITH A SELECTED, ANNOTATED BIBLIOGRAPHY

by

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ABSTRACT

This review includes a discussion of many methods for detecting ultrasonic images with emphasis upon the problems involved in a nondestructive inspection system employing ultrasonic imaging techniques. The detection methods are compared from the standpoint of threshold sensitivity. It is concluded that a system which will respond to an ultrasonic intensity of 10^{-3} w/cm² or less will probably be necessary for a practical nondestructive inspection system. The detection methods which meet this requirement include those classified in this report as optical and mechanical, and as electronic. The annotated bibliography includes 74 entries, many of which contain more than one reference. Included in this bibliography are references to most of the known methods for ultrasonic imaging.

I. INTRODUCTION

Ultrasonic methods for nondestructive testing are widely used. These methods usually employ piezoelectric probes used basically in either a reflection or through-transmission inspection technique. The material being inspected is brought into an ultrasonic-radiation field, and a flaw is indicated either by a reflection of a portion of the ultrasonic radiation back to the transducer which was used as the transmitter, or by a reduced signal received by a second transducer opposite to the transmitter.

Although inspection methods such as these provide very useful information, there are a number of applications, both in the nondestructive testing and medical fields, for which an image presentation (explained in Section II) of the ultrasonic signal would be desirable. An improved system resolution capability is one advantage, and it also seems reasonable that the use of imaging methods would allow simpler interpretation of test results in many cases. It is further anticipated that the availability of such a system would appreciably broaden the usefulness of ultrasonic techniques for both industrial and medical applications.

In this report a review of a number of ultrasonic imaging methods will be given. The emphasis will be on those methods which appear to have characteristics most useful for an ultrasonic imaging inspection system for nondestructive testing.

II. DETECTORS FOR ULTRASONIC IMAGING SYSTEMS

The ultrasonic imaging systems to be discussed in this review are primarily through-transmission systems in which a uniform beam of ultrasonic radiation is allowed to pass through the object under study. The ultrasonic radiation which emerges from the other side of the object then contains an image which can be made visible by a number of methods.

A number of classification systems for these detection methods have been proposed in various reviews.^{(25,27,28,39)*} No particular distinction is claimed for the classification used in this review, other than convenience in grouping and the fact that this method appears to have some correlation with reported sensitivities.

The photographic and chemical methods described generally require cavitation intensities⁽²²⁾ in order to respond. The reported threshold ultrasonic sensitivities for these methods varied from about 0.5 to 5 w/cm². The thermal methods were somewhat more sensitive, on the average, requiring ultrasonic intensities of the order of 0.1 w/cm². Threshold sensitivities in the range of 10⁻³ to 10⁻⁷ w/cm² have been reported for the optical and mechanical techniques, while values as low as 10⁻⁹ w/cm² have been claimed for the electronic detection methods. A brief discussion of each of these general detection methods follows, and a listing of many of the detection methods with indications of sensitivity and references to publications is given in Table I.

A. Photographic and Chemical Methods

The fact that ultrasonic radiation influences a photographic emulsion was reported in 1933 by Marinesco.⁽¹⁾ Subsequent studies by many investigators have still not clearly revealed the exact mechanism involved. The analysis by Bennett,⁽²⁴⁾ in which he showed that luminescence and pressure effects did not appear to explain all the existing facts, remains a good discussion of this situation. Although Bennett showed rather conclusively that the softness⁽²⁴⁾ of the photographic emulsion was a very important factor in its response to ultrasound, he stated in his conclusion that "there is not sufficient evidence to delineate clearly the mechanism, whether thermal, mechanical or otherwise."

*Reference numbers refer to bibliography at the end of this report. References are listed chronologically.

Table I

ULTRASONIC IMAGING DETECTION METHODS

Technique	Approximate Threshold Sensitivity ^a (w/cm ²)	Bibliographic Reference for Sensitivity ^b	Other References to Technique ^c
Photographic and Chemical Methods			
Direct action on film	1 to 5	19	1, 18, 24, 72
Use of photographic paper in developer	1	d	34,43
Film in iodine solution	1	72	
Starch plate in iodine solution	1	22	72
Color changes caused by chemical action	0.5 to 1 ^e	9,28	
Thermal Effects			
Thermosensitive color changes	1	28	20, 33
Phosphor persistence changes	0.05 to 0.1	21	
Extinction of luminescence	~ 1	d	16, 20, 42
Stimulation of luminescence	-	-	4, 20, 42, 59
Change in photoemission	0.1	29	
Change in electrical conductivity	0.1 to 0.2	30	54
Thermocouple and thermistor detectors	0.1 ^f	57,9 60	
Optical and Mechanical Techniques			
Optical detection of density variations	3×10^{-4}	35	10, 15, 27, 32, 38, 51, 68
Optical detection of acoustic birefringence	10^{-1}	26, 28	64
Optical detection of liquid surface deformation	10^{-3}	28, 52	17
Mechanical alignment of flakes in liquid	2.8×10^{-7}	7	3
Electronic Methods			
Mechanical movement of transducer or object to form an image ^h	-	-	5, 37, 45, 46, 57, 58, 67, 69
Probe detection of potential on back of piezoelectric receiver	-	-	2, 31, 68
Electronic scanning of piezoelectric receiver	10^{-7} to 10^{-9}	35, 44, 50 74	28, 39, 49, 55, 61, 62, 66, 68, 71, 73
Electronic scanning of piezoresistive receiver	10^{-7}	i	70

^aThe minimum value of ultrasonic intensity required at the detector to obtain an ultrasonic image is given in w/cm².

^bThe number of the reference in the bibliography from which the sensitivity value was taken is given.

^cNumbers refer to bibliography at end of report.

^dApproximate threshold sensitivity as determined by unpublished Argonne work.

^eReference 9 indicates that a special color-change technique utilizing the addition of a compound such as CCl₄ to the color-change materials can respond to ultrasonic intensities as low as 0.07 w/cm².

^fA thermopile detector has been reported to respond to ultrasonic intensities as low as 0.01 w/cm². See O. E. Mattiat, Power Measurements in Ultrasonics, IRE Trans. on Ultrasonic Engineering, PGUE-3, 23 (May 1955).

^gThe average ultrasonic intensity given in the table was estimated from pulse values given in this reference; see text.

^hSimilarly, many sets of transducers can be used. See Ref. 56.

ⁱJ. E. Jacobs, Northwestern University, private communication.

The mechanism involved in other detection methods employing photographic materials presents a somewhat simpler problem. For example, the action of ultrasound on photographic developer speeds the developing process in an effect similar to that produced by other means of agitation.* This fact can be used to detect ultrasonic images by using uniformly pre-exposed photographic paper exposed to an ultrasonic image in a developer solution.(34,43)

This detection technique employing photographic paper may be classified as much a chemical method as a photographic one. Another chemical method involves the releasing of iodine from KI solutions. This has been employed as an ultrasound detection method by making use of the

*See Film World, 16, 353 (Sept 1960) and U. S. Patent 2,945,760. The use of ultrasound in film development is claimed to increase film speed by factors of 2 to 10.

fact that iodine appears to inhibit the fixing of a photographic emulsion⁽⁷²⁾ and because the iodine can be used to cause color changes in materials.^(9,22) Other chemically induced color changes can also be used to detect ultrasound.⁽²⁰⁾

The sensitivities for these photographic and chemical techniques are generally of the order of one w/cm^2 , an intensity approximately that required for cavitation. It is generally agreed that such intensities are necessary for these detection methods.*

B. Thermal Effects

Color changes introduced by the heating effect of an ultrasonic radiation field have been used in a manner similar to the chemically induced color changes to detect ultrasonic images.^(20,33) In addition, the influence of ultrasound on luminescent materials has been explained as a thermal effect.^(16,21) Such methods have been used to detect ultrasonic images by visual observation or by photographing the phosphor image. The changes produced in the phosphors by ultrasound include persistence variations,⁽²¹⁾ extinction of luminescence excited by other radiation (for example, ultraviolet radiation),^(16,20,42) and stimulation of emission.^(20,42) Luminescence of various liquids is also stimulated by ultrasonic radiation.^(4,59)

Another thermal technique that has been used for ultrasonic imaging involves the use of a thermocouple detector. Dunn and Fry⁽⁵⁷⁾ have used a small thermocouple probe detector and have moved objects through the ultrasonic beam in order to make an image. It was reported that 1-microsecond ultrasonic pulses having peak intensities of $1000 \text{ w}/\text{cm}^2$ and working at 1000 pulses/sec would probably be required for this imaging system. This is equivalent to an average intensity of 0.1 to $1.0 \text{ w}/\text{cm}^2$, a range which is of the order of that required for most of the thermal techniques.

An interesting method proposed by von Ardenne⁽²⁹⁾ would make use of the photoemission from a cathode surface which would vary because of localized heating caused by an ultrasonic image pattern. This camera tube approach to the detection problem was estimated to require an ultrasonic intensity of $0.1 \text{ w}/\text{cm}^2$. Similarly, a camera tube might make use of electrical conductivity changes^(30,54) caused by the thermal effects of ultrasonic radiation.

C. Optical and Mechanical Techniques

The optical methods that have been used to detect ultrasound include the optical shadowing of a liquid surface deformed by the ultrasonic radiation

*See Ref. 22, page 471.

image and the detection of light variations caused by density changes or acoustic birefringence within the ultrasound transmitting medium. The first two of these techniques have been employed to produce ultrasonic images of objects.(17,28,68)

The technique developed by Pohlman^(3,7) has also been used to produce ultrasonic pictures of a variety of objects. This method makes use of a detector cell in which small aluminum flakes are suspended in xylene. In the presence of ultrasonic radiation, the flakes tend to become aligned so that they reflect light shining on the detector cell. The ultrasound areas therefore appear bright against a greyish background. With no ultrasound present, the flakes assume a random orientation and present a grey background by reflected light. The article by Rozenberg⁽²⁸⁾ cites a number of references to applications of this technique.

The theoretical threshold sensitivity of the Pohlman method has been reported⁽⁷⁾ to be $2.8 \times 10^{-7} \text{ w/cm}^2$. In a practical situation the useful threshold sensitivity of this detection system would probably be much closer to the average value for the overall class of optical and mechanical image detection methods. From the values given in Table I, an average value would be in the order of 10^{-4} w/cm^2 .

D. Electronic Methods

Conventional ultrasonic test methods normally make use of piezoelectric transducers in either a through-transmission or reflection method. The voltage produced on the receiving transducer by the reflected or transmitted ultrasound can be observed in a variety of ways. If the transducers are moved and the information is presented on an oscilloscope by a B-scan or C-scan technique, an ultrasonic image can be obtained. The B-scan method employs a reflection system and the transducer is moved in one direction across the object. A cross-section view, showing the depth of the flaws along the single-line scan, is then obtained. The C-scan method can be used either as a reflection or through-transmission technique. The transducer or transducers must be moved in two directions so they mechanically scan an area of the inspection object. The presentation yields an ultrasonic image of the test object by correlating the mechanical scan of the transducers with the presentation.* This technique has been applied to both medical^(45,46,67) and industrial^(37,69) inspection problems. A similar technique that uses many separate transducers has also been reported.⁽⁵⁶⁾

The necessity for mechanical movement of the transducer or the object in order to form the image is one of the major drawbacks of this technique. This problem can be eliminated by detecting the ultrasonic

*The B- and C-scan methods are described more fully in the Nondestructive Testing Handbook, Edited by R. C. McMaster, Ronald Press, New York (1959), Sec. 43, pp. 29-35.

image on a single piezoelectric transducer. The point-to-point voltage generated in the transducer will correspond with the ultrasonic intensity pattern striking the piezoelectric material. These voltage variations can be observed by using point probes on the back side of the transducer,^(31,68) or by scanning the transducer with an electron beam. Image detectors of this latter type, which yield a television presentation of the ultrasonic image have been described in the Russian,^(2,8,35,44,49,61,62) German,⁽⁵⁰⁾ English^(55,66) and American^(68,70,71,73,74) literature. When operated typically in the ultrasonic intensity range of 10^{-3} to 10^{-6} w/cm², these piezoelectric television camera tube imaging systems have been reported to have sensitivities as low as 10^{-9} w/cm².*

An ultrasound-sensitive material whose electrical conductivity varies with the ultrasonic intensity could also be used for an ultrasonic camera tube in a manner similar to the Vidicon** camera for light and X-ray image detection. Although most of the work in this area suggests that the conductivity changes produced by ultrasound are the result of heating effects,^(30,54) recent work† indicates that the speed of response for this detection system appears to be too fast to be explained on that basis.

Whether or not fast response for such a detection system could be obtained, it would probably offer the advantage of responding to a wide range of ultrasonic wavelengths. This is in contrast to the piezoelectric devices which work primarily at a frequency and harmonics determined by the thickness of the piezoelectric transducer. In addition, this detector would offer the advantage of storage†† in the detection system and would therefore present the possibility of appreciable sensitivity improvements.

III. DISCUSSION

The ultrasonic image detection methods discussed in the previous section differ widely in their characteristics. In addition to the obvious differences in threshold sensitivity, the time needed to form an image varies appreciably, for example from almost instantaneously for the television methods to several hours for the direct action of ultrasound on film. Other differences are encountered in considering image resolution and grey-scale capabilities.

*A recent publication by C. N. Smyth, F. Y. Poynton, and J. F. Sayers, Proc. IEE, 110, 16 (Jan 1963) indicated that the theoretical sensitivity limit of such tubes might be as low as 10^{-11} w/cm².

**For a description of this tube see P. K. Weimer, S. V. Forgue, and R. R. Goodrich, The Vidicon Photoconductive Camera Tube, Electronics, 23, 70 (May 1950) or RCA Review, 12, 306 (1951).

† J. E. Jacobs, Northwestern University, private communication.

†† The use of storage in a camera tube detector is discussed in a number of television texts. For example see, V. K. Zworykin and G. A. Morton, Television, 2nd Edition Wiley, New York (1954). In a storage system, the scanning electron beam would read all the signal information which a target element had collected since the last approach of the scanning beam. In a non-storage system, such as the piezoelectric image detector, the scanning beam can make use of the signal information being generated on a target element only while the particular element is actually being scanned by the beam. These information collection times can lead to great differences in detector sensitivity.

Looking at threshold sensitivity alone, however, it is not surprising to find that most of the ultrasonic imaging techniques which have involved inspection of actual objects, rather than visualization of ultrasonic transducer patterns, have been drawn from the two more sensitive categories of detection methods. One might conclude from that fact that detectors having threshold sensitivities of 10^{-3} w/cm² or better are needed for a practical ultrasonic image-inspection system. This appears to be a reasonable statement since reflection of the ultrasound from the various interfaces encountered in a practical system would reduce the ultrasonic intensity reaching the detector to a small percentage of that emitted from the ultrasonic transmitter.

If it is assumed that a practical ultrasonic image-inspection system implies an immersion technique, then it can be shown that the detector should respond to ultrasonic intensities of 10^{-3} w/cm² or lower. This requirement for an immersion technique, that is, one in which the ultrasonic energy would be transmitted from transmitter to object to detector by a surrounding liquid medium, would make the inspection system applicable to a variety of inspection problems. In a liquid system the ultrasonic intensity that could be transmitted into the liquid would be limited to approximately one w/cm². This limitation would be imposed by the necessity to eliminate cavitation* of the liquid, since the transmission of the ultrasonic beam through the cavitating liquid would introduce many nonuniformities in the ultrasonic beam.

This limit on the ultrasonic intensity which can be utilized, coupled with the losses due to attenuation and reflection,** would reduce the ultrasonic intensity reaching the detector to approximately 10^{-2} w/cm², even in a simple metal inspection system. The threshold sensitivity of 10^{-3} w/cm² or better for the detector therefore appears necessary, in order that some grey scale may be achieved and in order that complex objects may be inspected.

In tests made at this Laboratory it has been possible to detect images of transducer patterns and to prepare images of objects containing holes by the less sensitive imaging methods. The ultrasonic images shown in Figures 1 and 2 illustrate some typical results using such methods.

*Cavitation is discussed in many ultrasonic texts. For example, see Ref. 36, p. 225.

**For a further discussion of these and other ultrasonic losses, see Nondestructive Testing Handbook, edited by R. C. McMaster, Ronald Press, New York (1959), Vol. 2, Sec. 43, pp. 12-15 and 22-26. Typical reflection losses for a liquid-metal interface are such that only 10 to 20 per cent of the incident radiation is transmitted through the interface. At least two such interfaces would be encountered in a simple arrangement for metal inspection.

Figure 1

Photographic image of the near-field pattern 1/2 in. from a 2-1/2-in.-diameter barium titanate transducer. The frequency was 420 kc. The exposure was taken using Royal Ortho sheet film (emulsion toward the transducer) in an iodine-water solution. The exposure was 1 hr. The dark areas on this print represent areas in which the emulsion remained after fixing and therefore represent areas of ultrasonic exposure. See Ref. 72 for a further description of the method.

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2X

Figure 2

An ultrasonic image of a 16 mesh wire screen taken by a photographic paper in developer technique (see Refs. 34 and 43). The near-field pattern from the barium titanate transducer is readily observable. Exposure time was 30 sec.

When attempts were made to prepare ultrasonic images of solid objects, however, the reflections of the ultrasonic energy from the object-medium interfaces removed so much energy from the transmitted ultrasonic beam that the resultant images prepared by photographic and chemical methods were of poor quality. A typical test object used in these studies is shown schematically in Figure 3. This aluminum block had three shallow, oval-shaped volumes milled into one surface. A $\frac{1}{8}$ -in. aluminum cover was then bonded to that surface. The oval-shaped volume should not be bonded and should provide an aluminum-air interface to reflect ultrasonic energy. It was not possible to detect a useful image of this object by film techniques with an ultrasonic generator capable of a nominal 100-w output.

Figure 3

A diagram of an aluminum nonbond test object is shown. The object was 4 x 1-1/2 in. and 1-1/8 in. thick. The three oval-shaped volumes milled into the thicker section were 1/4 x 1/2 in. and 0.002, 0.005 and 0.010 in. thick. The thinner top plate was bonded to the thicker section with Eastman 910 Adhesive.

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Satisfactory ultrasonic images of these nonbond areas were prepared, however, by a mechanically scanned transducer method, and using the electronic, acoustic image-converter system. The images prepared by these two methods are shown in Figures 4 and 5.

Figure 4 is a photograph of the recording made by the mechanically scanned, transducer imaging system.⁽³⁷⁾ The method used employs two transducers, one on each side of the inspection object. The transducers are moved up and down while being moved across the object, thus making a sawtooth scan across the inspection object. After amplification, the output of the receiving transducer is recorded. The areas of nonbond, which would transmit little ultrasonic energy are shown as the white, oval shaped areas on the recording.

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Figure 4

The nonbond test piece of Figure 3 was inspected with a mechanically scanned, two-transducer system (see Ref. 37). This is a photograph of the electrosensitive paper recording of the image produced by that inspection system. The three white areas are the three oval nonbond areas of the test piece.

Figure 5 is a photograph of the televised ultrasonic image of one of the oval-shaped nonbond areas of the object illustrated in Figure 3. The method used to obtain that image is shown in Figure 6. The sensitive diameter₁ of the pickup tube used to detect the ultrasonic image is approximately $1\frac{1}{2}$ in., so only one nonbond area can be observed at a given setting of the object.

Note from Figure 6 that the transmitting crystal is shown quite a distance from the object and detector. The distance used was about $2\frac{1}{2}$ ft. A large distance is required in this configuration in order to eliminate near-field effects or nonuniformities in the ultrasonic emission from the transducer. Some of these near-field nonuniformities are illustrated in Figures 1 and 2.

Nonuniformities in the ultrasonic field do present problems, even beyond the so-called near-field region.* In fact, the discussion by Suckling⁽³¹⁾ describes the difficulty of obtaining a uniform ultrasonic field as one of the basic limitations to ultrasonic imaging systems.

*Descriptions of near-field effects can be found in a number of texts on ultrasonic transducers. For example, see Ref. 36, pp. 66-72.

Figure 5

This print shows three frames of a motion picture recording of a kinescope presentation of the ultrasonic image of one of the oval nonbond areas of the test piece shown in Figure 3. The detection system used for the inspection is shown in Figure 6. The oval nonbond area can be seen in the central portion of each frame. The active diameter of the pickup tube piezoelectric target used for this picture was 1-1/2 in. The outline of this target is shown by the circular shape immediately surrounding the oval nonbond image. The images outside that circle are of other objects (mesh, glass, etc.) inside the pickup tube. The ultrasonic beam used to obtain this image was 2-Mc continuous wave.

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Figure 6

A diagram of a television ultrasonic inspection system is shown. The object shown in the tank in the inspection position is the nonbond test object shown in the preceding figures. This experimental ultrasonic imaging system, developed by J. E. Jacobs at Northwestern University, is being evaluated concerning its application to medical diagnosis and nondestructive testing problems.

The optics problem is indeed a difficult one, involving not only uniformity problems, but also those which may be termed depth-of-field problems. Note in Figure 6 that the flaws in the nonbond test plate were placed close to the detector. The flaws could still be imaged if the plate were moved somewhat away from the detector, or were turned around, but the sharpness of the image would decrease rapidly with increasing object-detector distance because of diffraction effects. Some improvement in this situation can be gained through the use of apertures and lenses, but the object thickness region which will remain in good focus at the detector is still usually rather small. This can be an advantage because it allows one to look at slices through the inspection object by changing lens-detector or lens-object distances. The speed of the inspection with an ultrasonic imaging system, therefore, might depend on the thickness of the inspection object and the defect size which should be detectable.

Further optical studies may improve some of these features of the imaging system, and the bibliographic references to focusing systems,^(12,13) lenses^(6,14,23) and transmission plates⁽⁶⁾ may be of some help in this regard.

As a final comment, some mention of ultrasonic frequency should be made. Much of the work with the less sensitive ultrasonic image detectors was done at frequencies of the order of $\frac{1}{2}$ to 1 megacycle, possibly because cavitation intensities are required and these can be conveniently obtained in the low-frequency range with ultrasonic cleaning equipment. Most of the imaging work reported in which the more sensitive detection methods were used has been in the frequency range of 1 to 7 Mc.

From the standpoint of resolution it would be desirable to operate at the higher frequencies. For example, the wavelength of a 1-Mc ultrasonic field in water is about 0.060 in., while at 10 Mc it is one tenth that value. However, as the ultrasonic frequency is increased, attenuation problems become more significant. Some compromise must usually be made between these two factors. For general inspection purposes, the frequency range between 2 and 7 Mc appears very useful, although for application work having very high-resolution requirements, a higher frequency might be needed.

IV. CONCLUSIONS

A number of ultrasonic imaging systems have been briefly described in this review. Further information can be obtained from the extensive bibliography in the following section. Although the bibliography is by no means complete, it is hoped that at least one reference to each of the many known methods of ultrasonic imaging detectors can be found therein. In addition, the bibliography contains references to other aspects of the imaging problem and to reports which may be of value in future imaging developments.

From the information presented in this report it may be concluded that a detector should be capable of responding to ultrasonic intensities of as small as 10^{-3} w/cm², if it is to be generally useful in a practical inspection system employing ultrasonic imaging methods. This limitation on sensitivity presently appears to limit the possible detectors for such an inspection system to those classified in this report as optical and mechanical, or electronic.

The actual choice of detector may depend on the application. However, the electronic methods, many of which are in a high state of development at the present time, seem to meet most of the requirements that would be imposed by a normal nondestructive testing inspection application.

V. ACKNOWLEDGMENTS

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2. S. Sokoloff, Means for Indicating Flaws in Materials, U. S. Patent 2,164,125 (June 27, 1939).

This patent describes the use of television pick-up methods employed with piezoelectric transducer materials, for the detection of ultrasonic images.

3. R. Pohlman, On the Possibility of an Acoustic Image in Analogy to an Optical One, Z. Physik, 113, 697 (1939) (In German).

An ultrasonic image detector consisting of a suspension of small aluminum flakes in xylene is described. The mechanical action of the sound pressure aligns the flakes so that light reflected from the flakes forms a visible picture of the ultrasonic image. Resolution of the order of a mm is claimed.

4. P. Paounoff, The Luminescence of Water under the Action of Ultrasound, Compt. rend., 209, 33 (1939) (In French).

The emission of light, primarily in the range from 4450 to 5580 Å, from water in an ultrasonic field is described.

5. O. Barbier, Optics of Ultrasonic and Ultra-acoustic Images, Alta Frequency, 11, 383 (1942) (In Italian).

A mechanical scanning system which employs a visual signal presentation is described. A quartz transducer was used in a frequency range from 2 to 3 Mc. The resolving power obtained was about a mm.

6. P. J. Ernst, Ultrasonic Lenses and Transmission Plates, J. Sci. Instr., 22, 238 (1945).

Solid lenses of high efficiency are described. Transmission plates which permit low-loss transmission of ultrasonic radiation from one medium to another are also discussed.

7. R. Pohlman, Internal Examination of Material by Ultrasonic Optical Pictures, Z. angew. Physik, 1, 181 (1948) (In German).

A discussion of the aluminum-flake suspension in xylene method for detecting ultrasonic images is given. The theoretical sensitivity threshold of this method is said to be 2.8×10^{-7} w/cm², although at that intensity the time to align the flakes to form the image would be fairly long.

8. S. Ia. Sokolov, An Ultrasonic Microscope, C. R. Acad. Sci. USSR, 64, 333 (1949) (In Russian).

An ultrasonic imaging system employing a TV pick-up tube sensitive to ultrasonic radiation is described. See also J. Tech. Phys. (USSR), 19, 271 (1949) and translation by G. B. Devey, Radio Electronic Engr. (Feb 1953), pp. 8-9. The system proposes the use of very high frequencies (3000 Mc) in order to obtain sound wavelengths and therefore a resolution capability in the order of those encountered in light microscopy. A description of this device is also given in Wireless World, 60, 448 (1954).

9. H. Rust, R. Haul, and H. Studt, Employment of Chemical Reactions to Obtain Pictures of Acoustic Phenomena, Naturwissenschaften, 36, 374 (1949) (In German).

Potassium iodide-starch solutions are contained in small Plexiglas squares. The action of the ultrasound accelerates oxidation and results in a visible color change. The intensities required are in the order of those needed for cavitation, although some improvement in sensitivity can be gained by adding small amounts of aliphatic chlorides such as CCl₄ or chloroform to the solution. See also Angew. Chemie, 62, 186 (1950) and 64, 308 (1952). The later work of P. Renaud, J. Chimie Physique, 52, 339 (1955) is also of interest concerning this detection method. The threshold sensitivity of this method was reported to be 0.07 w/cm² in the 1950 reference.

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Ultrasonic waves are visualized in a liquid medium by means of a Schlieren optical system. Many other references to Schlieren techniques are given in Ref. 27.

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12. F. E. Fox and V. Griffing, Experimental Investigation of Ultrasonic Intensity Gain in Water due to Concave Reflectors, J. Acoust. Soc. Am., 21, 352 (1949).

An ordinary watch glass was used to focus an ultrasonic radiation beam, producing an intensity increase of about 70. This reference and the two immediately following, from the same volume of the J. Acoust. Soc. Am., deal with methods for focusing ultrasonic radiation.

13. G. W. Willard, Focusing Ultrasonic Radiators, J. Acoust. Soc. Am., 21, 360 (1949).

Other references to work concerned with shaped piezoelectric transducers include A. Goubanov, J. Tech. Phys. USSR, 19, 30 (1949); L. Fein, J. Acoust. Soc. Am., 21, 511 (1949), and H. O'Neil, ibid., 21, 516 (1949).

14. D. Sette, Ultrasonic Lenses of Plastic Materials, J. Acoust. Soc. Am., 21, 375 (1949).

A number of plastic lens configurations are discussed and illustrated. Intensity gains of 100 to 1 can be gained through use of plano-spherical lenses.

15. B. Carlin, Ultrasonics, McGraw-Hill Book Co., New York (1949), 270 pages.

This book on the field of ultrasonics "leans to the practical and engineering sides." Some discussion of imaging methods is included with the discussions of optical techniques; the method proposed by Sokoloff (Ref. 2) is particularly useful. A second edition of this book, containing more information on imaging methods, was published in 1960.

16. H. Schreiber and W. Degner, Methods of Making Ultrasonic Waves Visible, Naturwissenschaften, 37, 358 (1950) (In German).

A technique for imaging ultrasonic fields by use of an excited ZnCdS phosphor screen whose luminescence is decreased by exposure to ultrasonic radiation is described. The action of the ultrasonic radiation in extinguishing the luminescence is said to correspond to that produced by infrared radiation. See also A. Eckardt and O. Lindig, Ann. Physik, 7, 410 (1950), and H. Chomse, W. Hoffman and P. Seidel, Naturwissenschaften, 40, 288 (1953).

17. K. Schuster, Ultrasonic-Optical Imaging by Means of Surface Relief, Jenaer Jahrbuch, 1951, 217.

Ultrasonic images were produced by passing light through the surface of a liquid distorted by the ultrasonic field.

18. P. J. Ernst, Ultrasonography, J. Acoust. Soc. Am., 23, 80 (1951).

The action of ultrasonic radiation on photosensitive emulsions is discussed. Other papers on photographic methods for detecting ultrasound are given in the next few references. Others include H. W. Kolle, Exper. Tech. der Phys., 1, 97 (1953) and F. Hauer and G. Keck, Naturwissenschaften, 42, 601 (1955).

19. G. S. Bennett, A Note on the Activation of Photographic Emulsions by Ultrasonic Waves, J. Acoust. Soc. Am., 23, 478 (1951).

It is reported that ultrasonic intensities of 1 to 5 w/cm² require exposure times of 1 to 4 hr to detect an image on photographic film.

20. P. J. Ernst and C. W. Hoffman, New Methods of Ultrasonoscopy and Ultrasonography, J. Acoust. Soc. Am., 24, 207 (1952).

This paper discusses several techniques for detecting ultrasonic images. These include the use of temperature-sensitive chromotropic compounds, leucobases of dyes, thermostimulable phosphors, and detonation methods using labile compounds. It is concluded that a quenching method with a temperature-sensitive phosphor was the best of these techniques at the time the article was published. See also J. Acoust. Soc. Am., 24, 87 (1952).

21. L. Petermann, New Photographic Method of Detecting Ultrasonic Radiation, J. Acoust. Soc. Am., 24, 416 (1952).

A Ca-SrS phosphor screen is stimulated and then exposed to ultrasonic radiation. The ultrasound increases the persistence of the phosphor so that ultrasound irradiated areas appear brighter. The final image can then be photographed. It is reported that an ultrasonic exposure of about 1 min at an intensity of 0.1 w/cm² yields good results when used with a photographic film exposure of 20 sec. This work is also reported in Helv. Phys. Acta, 24, 596 (1951), Proc. N.E.C., 11, 481 (1955), J. Acoust. Soc. Am., 27, 1005 (1955), and IRE Trans. Ultrasound Eng., PGUE-4, 42 (1956). This latter paper indicated the technique was sensitive to ultrasonic intensities of 0.05 w/cm² and provided a resolution of 0.2 mm.

22. G. S. Bennett, A New Method for the Visualization and Measurement of Ultrasonic Fields, J. Acoust. Soc. Am., 24, 470 (1952).

This paper describes the use of a starch plate exposed to ultrasound in a dilute iodine solution as an image detector for ultrasonic radiation. Exposure times were a few minutes in an ultrasonic intensity sufficient to produce cavitation (about 1 w/cm² or higher). In addition to speed, the starch-plate technique has the advantage of being insensitive to light.

23. J. A. Bronzo and J. M. Anderson, The Effectiveness of Plastic Focusing Lenses with High Intensity Ultrasonic Radiators, J. Acoust. Soc. Am., 24, 718 (1952).

Plexiglas and polystyrene lenses were compared at ultrasonic intensities up to 6.6 w/cm^2 . Polystyrene showed no sign of damage up to that point, while the Plexiglas lenses showed signs of physical breakdown above about 2 w/cm^2 .

24. G. S. Bennett, On the Mechanism of the Photographic Effect of Ultrasonic Waves, J. Acoust. Soc. Am., 25, 1149 (1953).

It is shown that the softness of the photographic emulsion has a large effect on the response of a photographic material to ultrasonic radiation.

25. G. Spengler, Problem of Acoustic-Optical Image Conversion, Nachrichtentechnik, 3, 399 (1953) (In German).

This paper reviews several methods for detecting ultrasonic images.

26. F. L. McNamara and T. F. Rogers, Direct Viewing of an Ultrasonic Beam in a Transparent Solid, J. Acoust. Soc. Am., 25, 338 (1953).

Temporary birefringence induced by ultrasonic stress causes depolarization in a plane-polarized light beam traversing a transparent quartz plate. Detection of this depolarization allows the complete sound field to be made visible. (Authors abstract). Similar work for shear waves was reported later by V. G. Averianova, V. I. Markarov, and S. N. Rzhavkin, Soviet Physics - Acoustics, 2, 237 (1956).

27. L. Bergmann, Der Ultraschall, S. Hirzel, Stuttgart, 6th edition (1954) 1114 pages (In German).

This book covers the entire field of ultrasonics and contains a good review of ultrasonic imaging methods. The book, with the supplement published in 1957, has an excellent list of references covering all aspects of ultrasonics.

28. L. D. Rozenberg, Survey of Methods Used for the Visualization of Ultrasonic Fields, Soviet Physics-Acoustics, 1, 105 (1955).

A very good review of visualization methods is presented. The bibliography includes 45 items, many of them references to earlier Russian work in this field.

29. M. von Ardenne, On Making (Ultra-) Sound Visible Using an Electron-Optical Image Converter, *Nachrichtentechnik*, 5, 49 (1955) (In German).

This paper summarizes many known methods for visualizing ultrasound and shows the need for better methods for medical use. A system employing an electron image converter tube using a signal cathode which emits electrons due to localized heating caused by ultrasound is proposed. It is estimated that this system could be used to detect ultrasonic intensities of about 0.1 w/cm^2 at a frequency of 5 Mc.

30. L. Herforth and J. Krumbiegel, Effect of Ultrasound on the Conductivity and Fluorescence of Zinc Sulfide and Cadmium Sulfide Crystals, *Naturwissenschaften*, 42, 39 (1955) (In German).

The photoconductivity of excited crystals falls to a value dependent on the ultrasound intensity for intensities up to 0.8 w/cm^2 . The fluorescence is not effected.

31. E. E. Suckling and W. R. MacLean, Method of Transducing Ultrasonic Shadowgraph or Image for Display on Oscilloscope, *J. Acoust. Soc. Am.*, 27, 297 (1955).

A capacity probe mechanically scanning the back surface of a piezoelectric detector is used to modulate the scanning beam in a cathode ray tube to yield an ultrasonic image. This work is further described in a number of subsequent papers, including: *J. Acoust. Soc. Am.*, 28, 502 (1956); *J. Acoust. Soc. Am.*, 29, 146 (1957); *J. Acoust. Soc. Am.*, 31, 678 (1959); and *J. Acoust. Soc. Am.*, 34, 1277 (1962). The 1959 reference deals with the difficulty of obtaining uniform ultrasonic fields to use for imaging purposes.

32. M. F. Canac, Visual Display of Ultrasonic Waves and Applications, *J. Phys. Radium*, 16(3) 3S (1955) (In French).

A stroboscopic optical method for viewing standing waves is described.

33. H. Tielsch and A. Boczek, A Contribution to the Visual Detection of Ultrasound by the Thermal Method, *Z. angew. Physik*, 7, 213 (1955) (In German).

This paper briefly reviews a number of detection methods, but is primarily concerned with the use of materials which change color due to thermal effects as a method for detecting ultrasound images. The bibliography includes 29 references.

34. Y. Torikai and K. Negishi, A Simple Method for the Visualization of Ultrasonic Fields, J. Phys. Soc. Japan, 10, 1110 (1955).

The detection method described uses photographic paper which has been uniformly pre-exposed to light. It is then placed in a developer solution and exposed to the ultrasonic field. The ultrasound accelerates the development and therefore produces a print in which the areas of higher ultrasound intensity are darker.

35. P. K. Oshchepkov, L. D. Rozenberg, and Iu. B. Semennikov, An Electronic-Acoustical Transducer for the Visualization of Sound Images, Soviet Physics-Acoustics, 1, 362 (1955).

An imaging device employing a piezoelectric transducer electronically scanned on the side opposite to the ultrasonic field is described. The image is observed by conventional television methods. The system is said to have a linear response from the operational threshold of $3 \times 10^{-9} \text{ w/cm}^2$ up to $3 \times 10^{-3} \text{ w/cm}^2$. The system operated in the low megacycle range, and the sealed-off pickup tube employed barium titanate piezoelectric elements, 120 mm in diameter.

36. T. F. Hueter and R. H. Bolt, Sonics, J. Wiley and Sons, Inc., New York (1955), 456 pages.

This book was prepared to present the subject of sonics to people of varying technical backgrounds and is therefore very useful to engineers and scientists who do not have extensive experience in this field. A brief section on ultrasonic image converters is included and the use of such a technique for nondestructive testing is compared with more conventional methods (Table 8.8, pp. 369-7).

37. W. J. McGonnagle and W. N. Beck, An Ultrasonic Scanning and Recording System, Proc. ASTM, 56, 1415 (1956).

A through-transmission system in which a mechanical scan of the test object is made is described. The image is made visible by recording the signal from the detector transducer on electrosensitive paper. The possible use of such a technique for medical applications is discussed in J. Acoust. Soc. Am., 29, 865 (1957), and the use of the system for nondestructive testing applications is further described in Nondestructive Testing, 15, 42 (1957), as well as in several Argonne National Laboratory reports. For example, see ANL-5653 (1957).

38. E. Hiedemann, Ultrasonic Stroboscope, IRE Convention Record, 4, Part 9, 38 (1956).

A brief review of ultrasonic stroboscopes is given. One such technique is described in detail.

39. W. R. Turner, An Evaluation of Image Techniques in the Ultrasonic Inspection of Material, NAVORD-4090 (July 2, 1956).

A piezoelectric pickup tube for yielding a television presentation of ultrasonic images is described. Other methods for obtaining ultrasonic images are reviewed and evaluated from a sensitivity standpoint. Further details of this work are discussed in NAVORD-3967 (1955).

40. T. Schilb, C. Bennett, and C. E. Adams, Ultrasonography by a Bleach-out Method, J. Acoust. Soc. Am., 29, 145 (1957).

Gelatine-coated plates are soaked in dye, then exposed to an ultrasonic image in an aqueous solution of bleach. The bleaching action is higher in areas of higher ultrasonic intensity, and images can therefore be made.

41. H. Gobrecht, H. Hamish, and A. Tausend, Piezoelectric Effect in Selenium, Z. Physik, 148, 209 (1957) (In German).

42. M. Leistner and L. Herforth, Changes in the Luminescence of Continuously Excited Zinc Sulfide Screens under Ultrasonic Action, Naturwissenschaften, 44, 59 (1957) (In German).

Screens made of ZnS:Cu showed an increase in ultraviolet-excited emission when also excited by 800-kc ultrasonic radiation. ZnS:Ag screens quenched with ultrasound.

43. M. E. Arkhangel'skii and V. Ia. Afanasev, Investigation of the Photo-diffusion Method of Visualizing Ultrasonic Fields, Soviet Physics-Acoustics, 3, 230 (1957).

Photographic paper is exposed to ultrasonic radiation in a developer solution in a technique such as that reported by Torikai and Negishi (Ref. 34).

44. V. G. Prokhorov, The Problem of Converting an Ultrasonic Image into a Visible One, Soviet Physics-Acoustics, 3, 272 (1957).

An electronic image converter tube for ultrasonic image detection by television methods is described. An equivalent circuit is developed and the limiting sensitivity is calculated to be of the order of 10^{-9} w/cm². Semennikov challenged the sensitivity calculation method in his 1958 paper (Ref. 49), and the two exchanged further remarks in Soviet Physics-Acoustics, 5, pp. 389 and 390 (1959).

45. D. H. Howry, "Techniques Used in Ultrasound Visualization of Soft Tissues," in Ultrasound in Biology and Medicine, edited by E. Kelly, American Institute of Biological Sciences, Washington (1957), p. 49.

A transducer detector was mechanically scanned through the image area. The frequency used was 2 Mc, yielding a resolution of 20 lines/in. horizontally and 32 lines/in. in the range direction. A frequency of 6 Mc was suggested as being useful for medical work because of the improved resolution capability.

46. Y. Kikuchi, K. Tanaka, and T. Wagai, Early Cancer Diagnosis through Ultrasonics, J. Acoust. Soc. Am., 29, 824 (1957).

A number of ultrasonic methods are discussed, one of which employs a mechanically scanned transducer coupled to a cathode ray tube (CRT). The reflection signals received by the transducer are presented in a visual display on the CRT. Ultrasonic reflection pictures of several portions of the human body are shown.

47. W. Welkowitz, Ultrasonics in Medicine and Dentistry, Proc. IRE, 45, 1059 (1957).

Ultrasonic imaging methods are included in this review article.

48. L. K. Zarembo and V. V. Shklovskaya-Kordi, A Method for Visualizing Acoustic Streaming at the Boundary of Two Immiscible Liquids, Soviet Physics-Acoustics, 3, 401 (1957).

Colored tracers are photographed after a time lapse.

49. Iu. B. Semennikov, A Study of Acoustic Image Converters, Soviet Physics-Acoustics, 4, 72 (1958).

The paper describes the mechanism of acoustic image conversion. Derivations are given for the basic relationships used in determining the output signal of acoustic image converters as a function of the applied sound pressure for specified image contrast. A method is given for experimental determination of the equivalent electrical parameters of acoustic image converters. The design sensitivity is compared with the experimental results. (Author's abstract).

50. W. Freitag, Investigations of an Electronic Ultrasonic Image Converter, Jenaer Jahrbuch, Part I, 228 (1958) (In German).

An electronic pickup tube for yielding a signal suitable to display an ultrasonic image in a television presentation is described, as is the entire ultrasonic imaging system. A quartz piezoelectric target is used. The theoretical threshold sensitivity of the system is shown to be about 10^{-9} w/cm², and operation at ultrasonic intensities of the order of 10^{-8} w/cm² is claimed. This work is further described

in the following publications: W. Freitag and H. J. Martin, *Acoustica*, 8, 197 (1958) and W. Freitag, H. J. Martin, and G. Schellbach in *Medical Electronics - Proceedings of the Second International Conference on Medical Electronics*, C. C. Thomas, Springfield, Ill. (1960), pp. 373-9.

51. J. M. Barnes, W. G. Mayer, and E. A. Heidemann, Multiple Diffraction of Light by Ultrasonic Vibrations in Transparent Solids, *J. Opt. Soc. Am.*, 48, 663 (1958).

52. E. D. Pigulevskii, The Sensitivity and Resolution of Acoustic-Optical Image Conversion at a Liquid Surface, *Soviet Physics-Acoustics*, 4, 359 (1958).

Basic relations governing the sensitivity and resolution of an image system based on the deformation of a free liquid surface are given. It is shown that, for practical conditions, the ultrasonic intensity must be at least 10^{-3} w/cm^2 and that the resolution varies as the square root of the product of the wavelength of the ultrasound and the distance from the object to the converter.

53. I. E. El'piner, On the Chemical Action of Ultrasonic Waves, *Soviet Physics-Acoustics*, 5, 135 (1959).

A survey is given of the chemical action of ultrasonic waves. The bibliography includes 90 references. The author's survey article Ultrasonic Luminescence: A Survey, *Soviet Physics-Acoustics*, 6, 1 (1960), is also a valuable contribution.

54. V. A. Zhuravlev and M. I. Kozak, The Conductivity of Semi-conductors in an Ultrasonic Field, *Soviet Physics-JETP*, 36, 236 (1959).

The conductivity changes measured in an ultrasonic intensity of 10 w/cm^2 and a frequency of 600 kilocycles are explained as heating effects.

55. C. N. Smyth and J. F. Sayers, Ultrasonic Image Camera, *Engineer*, 207, 348 (1959).

An ultrasonic pickup tube having a quartz piezoelectric target is described. The quartz faceplate was 2.5 cm in diameter and 0.7 cm thick. It was cemented to the glass frame by an Araldite epoxy. For an incident ultrasonic intensity of 10^{-6} w/cm^2 at a frequency of 4 Mc, a camera face voltage of 150 mv was achieved. The presentation of the ultrasonic image by television methods is briefly described. Further descriptions of this work were reported in *Electrical Manufacturing*, 64, 10 (Aug 1959) and *Electronics*, 32, 124 (Sept 11, 1959). The sealing method used to prepare the quartz-glass seal was described by J. F. Sayers, *J. Sci. Instr.*, 37, 203 (1960). A more recent description of this ultrasonic imaging study is given in *Proc. IEE*, 110, 16 (Jan 1963).

56. V. M. Verekin, N. A. Evdokimov, K. V. Zharkov, and L. G. Merkulov, Ultrasonic Assembly for Recording Images of Flaws in Sheet Metal, Soviet Physics-Acoustics, 5, 372 (1959).

A through-transmission system using many sets of transmitting and receiving transducers whose output is connected to a recording system is described.

57. F. Dunn and W. J. Fry, Ultrasonic Absorption Microscope, J. Acoust. Soc. Am., 31, 632 (1959).

A stationary ultrasonic source and a small thermocouple probe detector make up the microscope described. The object to be inspected is moved slowly across the ultrasonic beam to generate the image. A more recent description of this work was given by Fry and Dunn in "Ultrasonic Absorption Microscopy and Spectroscopy," Proceedings Symposium on Physics and Nondestructive Testing, Southwest Research Institute, San Antonio, Texas (1962), pp. 33-57.

58. A. M. Voutas, Ultrasonic Matterscope, J. Acoust. Soc. Am., 32, 282 (1960).

A through-transmission technique is described in which the transmission of ultrasonic energy is used to determine microstructure and predict failure of the specimen.

59. P. Jarman, Sonoluminescence: A Discussion, J. Acoust. Soc. Am., 32, 1459 (1960).

A summary of existing knowledge of sonoluminescence is given. It is concluded that this phenomenon is basically thermal in origin.

60. E. K. Labartkava, A Thermoelectric Ultrasonic Pickup with Semi-conducting Thermistor, Soviet Physics-Acoustics, 6, 468 (1960).

A thermistor probe covered by a thin Plexiglas layer is shown to be a small (about 1 mm in diameter), sensitive probe for detecting ultrasonic intensities in the range from 0.1 to 2 w/cm².

61. Yu. B. Semennikov, Certain Aspects of the Operation of an Electron-Acoustic Image Converter, Soviet Physics-Acoustics, 7, 56 (1961).

It is shown that the best electromechanical parameters for a piezoelectric target material for a piezoelectric ultrasonic camera tube are found in barium titanate and Y-cut lithium sulfate.

62. P. K. Oshchepkov, L. D. Rozenberg, and Yu. B. Semennikov, Note on the Electro-acoustic Converter for Visualizing Acoustic Images, Soviet Physics-Acoustics, 7, 213 (1961).

The method for sealing either quartz or barium titanate piezoelectric targets in sealed-off ultrasonic camera tubes is described. Lifetime

of tubes sealed by this method is 2 to 3 yr. The vacuum seal was made with a low-melting solder (about 100°C).

63. I. N. Kanevskii, A Simple Method for the Visualization of Ultrasonic Fields and Streams, Soviet Physics-Acoustics, 7, 352 (1961).

Standing waves are made visible by bubbles in the transmitting liquid and can be photographed for a permanent record. The ultrasonic intensities used varied from 0.5 to 20 w/cm².

64. R. F. Weeks, Optical Measurement of Ultrasonic Fields, J. Acoust. Soc. Am., 33, 741 (1961).

An apparatus is described which facilitates the measurement of ultrasonic fields within transparent solids. The optical system makes use of the birefringence produced within the solid by the passage of the ultrasonic wave.

65. H. D. Nine and R. Truell, Photosensitive-Ultrasonic Properties of Cadmium Sulfide, Phys. Rev., 123, 799 (1961).

Ultrasonic attenuation and electrical conductivity of CdS single crystals were studied. Amplification rather than attenuation of ultrasonic radiation has been reported in semiconducting materials by E. Tucker, Phys. Rev. Letters, 6, 547 (1961) and A. R. Hutson, J. H. McFee, and D. L. White, Phys. Rev. Letters, 7, 237 (1961). See also A. R. Hutson and D. L. White, J. Appl. Phys. 33, 40 (1962).

66. R. S. Sharpe, Future Development in Nondestructive Testing, Brit. J. Nondestructive Testing, 3, 111 (1961).

This review includes some discussion of ultrasonic imaging methods for nondestructive testing by the quartz target pickup tube developed by Smyth and Sayers (Ref. 55).

67. Y. Kikuchi, "Recent Results of Research and Development in the Field of Ultrasonics in Japan," Proc. of the Third International Congress in Acoustics, Elsevier Publishing Co., Amsterdam (1961), p. 1193.

This review discusses medical applications of ultrasonics. The paper includes some discussion of imaging methods and shows an ultrasonomograph (B Scan) of a normal breast and of one containing cancer. There is an extensive bibliography (31 references).

68. W. E. Lawrie and K. E. Feith, Ultrasonic Methods for Nondestructive Evaluation of Ceramic Coatings, WADD Tech. Report 61-91, Part I (March 1961) (Armour Research Foundation Report series 6043).

This report includes a discussion of an imaging method in which the back surface of a quartz piezoelectric receiver is mechanically scanned to yield a voltage picture of the ultrasonic image. A later

report (April to June, 1961) discusses the refinement of this method by putting the quartz target in an electron scanning tube and presenting the image by a television method. The sixth quarterly report (Oct to Dec 1961) discusses the use of Schlieren methods for visualizing ultrasonic images. The electro-acoustic pickup tube technique was reported at the 63rd Meeting of the Acoustical Society of America in May, 1962 (abstract F-7). That report indicated that the resolution of the imaging system was sufficient to observe a 0.5-mm wire. A 0.75-mm-diameter defect, 0.01 mm deep, in a steel plate could also be observed at a frequency of 7 Mc. The system was also reported by W. N. Redstreak, *Iron Age*, 190, 171 (Sept 13, 1962). Many of the characteristics of the imaging systems studied in this program are summarized in WADD-TR-61-91 Part II (April 1962).

69. L. J. Anderson and G. J. Posakony, Investigation of Methods for Determining Actual Flaw Size in Materials by Nondestructive Ultrasonic Means, ASD Technical Report 61-205, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio (1961).

A single transducer system, utilizing a mechanical manipulator to scan the inspection object is described. The output signal is presented on a cathode ray tube whose sweep configurations are synchronized with the mechanical movement of the transducer. The screen can be photographed for a permanent record. The images of a number of different shapes of internal defects are presented. Another report on this system was presented by W. C. Hitt, "New Parameters in Ultrasonic Testing," at the Pacific Northwest Metals Conference, Seattle, June, 1962.

70. Nghiem Ung Phan, The Application of Television Scanning Techniques to the Problem of Visualizing Ultrasound Images, unpublished M.S. Thesis, Northwestern University, 1961.

Several semiconducting materials were investigated to determine their suitability for use in an ultrasound sensitive camera tube, in which the resistivity change of the target material was used to convert the acoustical image into an electrical charge pattern. Of the materials studied, CdS:Cu yielded the best result.

71. R. G. Goldman, Electronic Acoustic Image Converter, *J. Acoust. Soc. Am.*, 34, 514 (1962).

This paper discusses some characteristics of quartz target ultrasonic pickup tubes developed by the General Electric Company. Further descriptions and a general discussion of ultrasonic imaging are contained in Goldman, Ultrasonic Technology, Reinhold, New York (1962), pp. 211-222.

72. H. Berger and I. R. Kraska, Photographic Film Detection Methods for Ultrasonic Field Visualization, J. Acoust. Soc. Am., 34, 518 (1962).

Evidence is presented to support the idea that the direct action of ultrasound on a photographic emulsion is influenced to a great extent by the softness of the emulsion. A technique for obtaining ultrasonic images by exposing film in an iodine solution is also discussed.

73. J. E. Jacobs, "Ultrasonic Image Converters and Cinesonography in Nondestructive Testing," Proceedings Symposium on Physics and Nondestructive Testing, Southwest Research Institute, San Antonio, Texas, 1962, pp. 59-74.

This paper described an ultrasonic imaging system employing a high-velocity electron scanning pickup tube having either a quartz or barium titanate piezoelectric target. Applications of the system to nondestructive testing were stressed. The medical applications of the system were reported by J. E. Jacobs, D. W. Cugell, J. R. Wennemark, and W. J. Collis, "Cinesonography As Applied to Biological Problems," at the 15th Annual Conference on Engineering in Medicine and Biology, Chicago, Nov., 1962.

74. J. E. Jacobs, H. Berger, and W. J. Collis, An Investigation of the Limitations to the Maximum Attainable Sensitivity in Acoustical Image Converters, 1962 Ultrasonics Symposium (IRE Professional Group on Ultrasonic Engineering), New York, (Nov 1962). To be published, IEEE Trans. Ultrasonic Eng.

The sensitivity limitation of electronic-acoustic image converter systems has been reported by many investigators to be the noise voltage produced by the load impedance of the input circuit. This limitation has been eliminated in the tube described here by using an electron multiplier within the tube. It is suggested that the sensitivity threshold (10^{-9} w/cm²) determined by the previous method was not actually achievable, since the threshold sensitivity of the tube with the multiplier is of the order of 10^{-7} w/cm². The sensitivity is limited by the voltage variation on the piezoelectric target which can be detected by the scanning beam.