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# PRINCIPLES AND TECHNIQUES OF ULTRASONIC INSPECTION

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## ABSTRACT

Ultrasonic inspection for subsurface flaws is widely used in American industry. This report reviews the general principles and specific techniques of ultrasonic testing. The information is based on a review of the technical literature plus the experience of the Quality Assurance Department at Sandia Corporation in applying this nondestructive testing technique to quality evaluation programs.

Case No. 403.0

July 2, 1953

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# PRINCIPLES AND TECHNIQUES OF ULTRASONIC INSPECTION

## INTRODUCTION

Since considerable interest has been shown in the techniques and applications of ultrasonic testing as utilized by the Quality Assurance Department in locating subsurface flaws, the Quality Engineering Division has gathered the pertinent material for interested Sandia groups. A Sperry Ultrasonic Reflectoscope, Model UR-50-C-028, is available in Room 111, Bldg. 892, for further study by anyone interested.

## PRINCIPLES OF ULTRASONIC TESTING

The term "ultrasonics," as used in acoustics, refers to frequencies which are beyond the herring limits of the human ear. These frequencies range upward from 20,000 cycles. The shortest ultrasonic waves are in the order of magnitude of visible light waves. The audible range sound laws, with the exception of certain phenomena peculiar to ultrasonics, are valid for the ultrasonic range.

Ultrasonic testing techniques employed at present utilize the extreme ranges of ultra-high frequency sound waves, generally in the order of a fraction to several megacycles. The primary purpose of ultrasonic testing is to detect internal flaws or foreign substances of different acoustic impedance in otherwise homogeneous masses. The piezoelectric effect derived from certain crystalline solids whose structures possess elements of symmetry of the trigonal group or lower, is, at present, the source of ultrasonic energy. Quartz, Tourmaline, Rochelle Salt, etc., are some of the more commonly used crystals for transmitting ultrasonic waves and are referred to as transducers.

The most convenient of several ways to transmit the ultrasonic waves produced by the crystal transducer is by coupling through a thin film of some substance such as oils, amalgams, etc. In some instances it is advantageous to immerse the specimen in a suitably chosen liquid. When the ultrasonic energy reaches the terminal boundary of the specimen, it is reflected to the same transducer and is reconverted to a voltage which may then pass into the mixer to be projected on a phosphorescent screen. A block diagram of the Ultrasonic Reflectoscope circuit is shown in Figure 1. In understanding the path of the sound waves, it is well to remember that the laws governing the reflection of light also govern the behavior of sound energy in a homogeneous mass.

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## INTRODUCTION OF THE SOUND WAVE

Because of the high frequency of ultrasonics used for the inspection of metals, the use of a piezoelectric transducer for sending purposes is necessary.

The introduction of a sound wave into a material is at present the most outstanding problem in practical testing. The source and the solid to be examined must be coupled together acoustically to effect a transfer of energy with minimum losses. This condition should be attainable when the source and the solid in question are of the same acoustic impedance. However, a good impedance match is very difficult to attain, for, regardless of the degree of smoothness achieved at the interface, an intervening layer of air is always present. This layer of air, having an extremely different acoustic impedance from the source and the material being tested, prevents adequate matching even though the layer is of only molecular thickness. An example of this situation is given in the early work of Sokolow, who discovered that the close fit between the surfaces of two Johansen blocks is not sufficient for good acoustic coupling.

It may be concluded, therefore, that the elimination of all gas at the interface between two solids is a prerequisite to good coupling.

## COUPLANT BETWEEN CRYSTAL AND TEST PIECE

Refraction and reflection may be appreciably decreased by the use of a medium interposed between the crystal source and the material under investigation that will exclude the air and effect a much better impedance match between the source and the material. This coupling medium may be a liquid such as an oil, soapy water, liquid soap, mercury, mercury amalgams, or a viscous solid such as plasticine. A most efficient and convenient coupling arrangement takes the form of a thin connecting film. A liquid which "wets" the surface involved is the most effective. This fact is the basis of the customary technique involving the use of a film of oil between the transducer and the specimen. The oil film is so important that many present day techniques would be impractical without it.

## SURFACE PREPARATION

In previous sections of this memo, the assumption of a smooth surface on the piece to be tested has been made. Any surface having irregularities of the order of 1/20 or less of the wave length employed may be considered smooth. Conditions of roughness not overcome by the liquid or viscous solid media must, at present, be improved by grinding or other surface preparation prior to testing. Herein lies one of the greatest limitations of existing ultrasonic techniques.

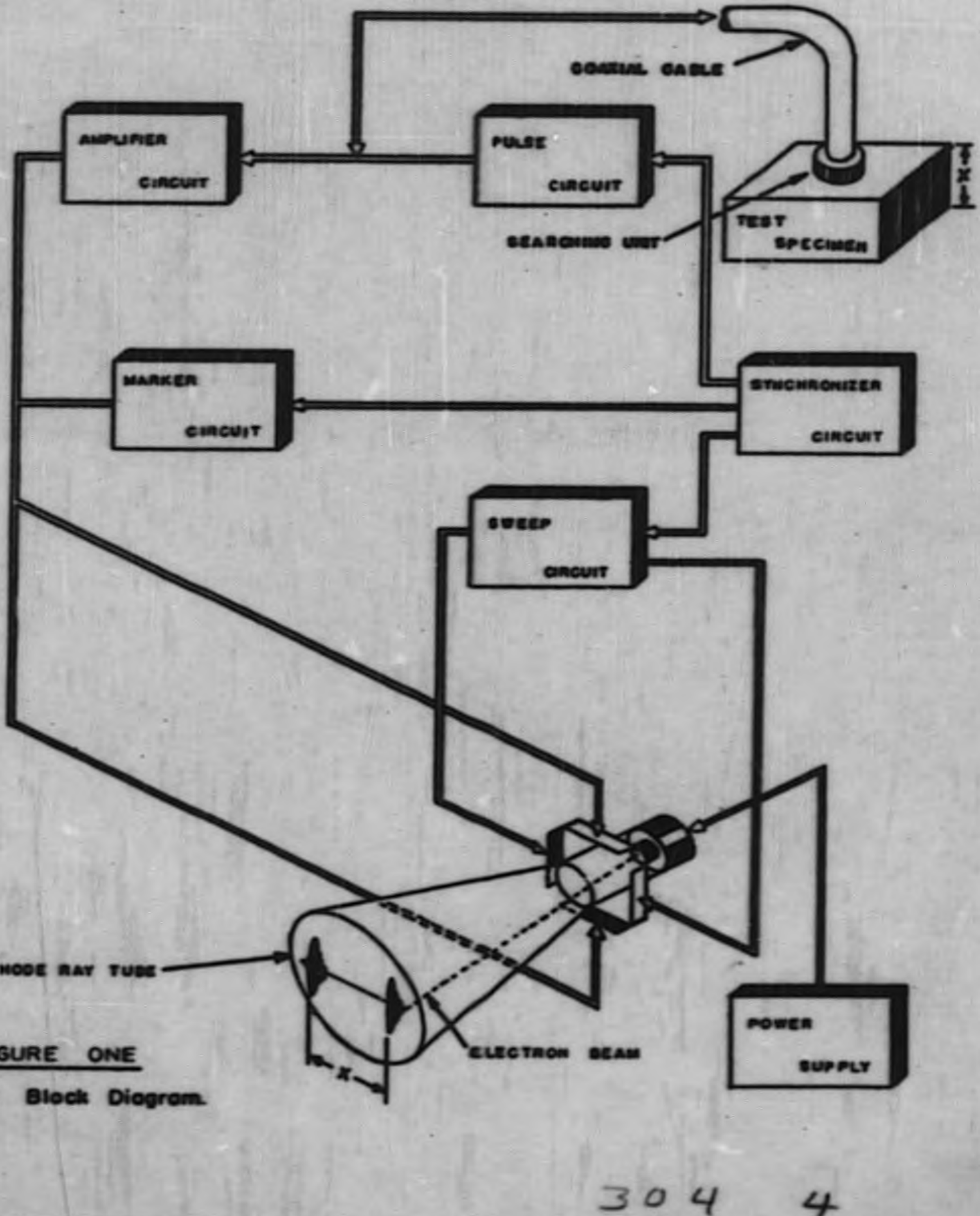


FIGURE ONE

Typical Block Diagram.

The minimum amount of surface preparation recommended on the samples for ultrasonic testing is as follows:

1. A surface roughness of not more than 125 microinches (nms) of the contact surface should be maintained. The use of a portable disk grinder has proved to be the most advantageous and economical method for preparing a surface.

2. Loose scale is detrimental and must be removed before inspection. Areas where scale has been indiscriminately chipped due to handling are not satisfactory for ultrasonic testing. The area should be either all tight scale or clean metal.

3. Foreign material, such as dirt, grit, grease, slag, etc., must be removed before the coupling fluid is applied.

DETECTION OF FLAWS

Where the reflection method of detection is used, the inspector looks for an echo from a discontinuity. Where no discontinuity exists in the homogeneous mass, there is no echo signal.

The single transducer technique is made possible by pulsing the sound wave. That is, a wave pulse is transmitted, after which the transducer is free to "listen" for echoes from discontinuities. However, there is enough of the initial pulse of sound energy picked up by the receiving circuit to obscure the reflections from flaws in the first 1/2 to 3/4 inch of the material under investigation. Therefore, discontinuities close to the sending transducer are generally not detected unless the testing is accomplished from both of the two opposing faces.

Particularly in the case of metallic media, variations in acoustic impedance may be encountered in the form of structural variations and voids which give rise to reflection and scattering of the sound beam. When the size of the grains of a metallic material is sufficiently large in relation to the wave length of the sound, it is difficult, if not impossible, to pass the wave energy through the metal. In general, materials having a worked or otherwise refined grain structure can be more readily penetrated than as-cast material.

INTERPRETATION OF FINDINGS

The interpretation of test results is primarily based upon a knowledge of the basic theory regarding ultrasonics and some actual experience.

With regard to the effect of voids on the propagation of ultrasonic energy through a medium, the size, shape, and orientation of these voids with respect to the beam must be considered. Larger voids intercept more sound energy and therefore will reflect more energy.

Figure 3 illustrates a typical cathode ray tube pattern as obtained in modern reflection methods using the single crystal technique. The significant parts of the pattern are the calibrated sweep axis, appearing as a notched horizontal line, the initial pulse deflection at A, the flaw echo deflection at B, and the back surface echo deflection at C. The notches in the sweep line at D represent units of time, which may be correlated with the velocity of sound through the material tested to indicate distance in that material. Figure 4 illustrates the stretching of the pattern that results from nonparallelism of the two opposing faces of the test piece.

The lack of a deflection of the cathode ray trace between A and C, as shown in Figure 2, may indicate the absence of any discontinuity of sufficient size to be detectable at the wave length used. The absence of all deflections except that at A (see Figure 5) may be due to any one of several causes. The material may be too coarse-grained, too porous, or may have a back surface that is either too rough or not sufficiently parallel to cause an echo at the crystal.

If a second deflection appears to the left of the proper position for a back surface echo and the latter is virtually absent, a discontinuity similar to a lamination and large enough to reflect the entire beam is probably present. Figure 6 illustrates this point. If the crystal is placed upon, but not acoustically coupled to, the material being tested to effect a transfer of energy, the A pulse will be long (see Figure 7). This long pulse is caused by a reverberation of the sound energy within the crystal, called "ringing." The amount of "ringing" or widening of this pulse is indicative, therefore, of the degree or efficiency of the acoustic coupling to the material being tested.

In addition to conditions described above, there may be numerous higher order reflections as shown in Figure 8. The number of these reflections gives a rough indication of the transparency of the material with respect to sound energy, or, again, an indication of coupling efficiency.

COMPLEX REFLECTION METHODS

It is often necessary to inspect pieces having curved surfaces or otherwise presenting no flat surface upon which the crystal may be placed. If the contact area between the crystal face and the surface of the work is large enough to pass sufficient energy into the work, no particular problem exists. However, if it is evident through trial that inadequate coupling is being attained, further modifications

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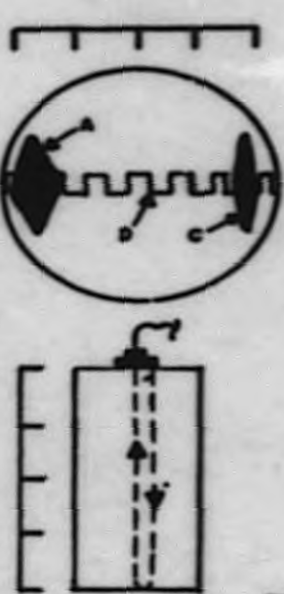


Fig. 2

SOUND MATERIAL


Fig. 3

UNSOUND MATERIAL

A - INITIAL PULSE DEFLECTION
B - FLAW ECHO DEFLECTION
C - BACK ECHO DEFLECTION
D - TIME-DISTANCE MARKERS

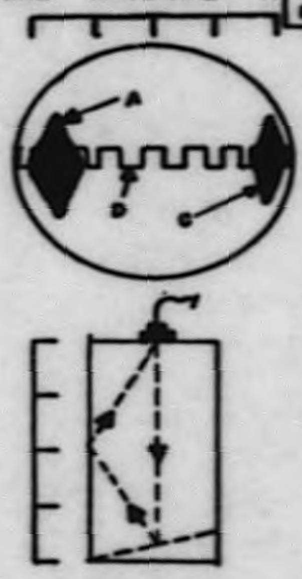


Fig. 4

NON-PARALLEL BACK SURFACE


Fig. 5

IMPENETRABLE MATERIAL

TYPICAL CATHODE RAY TUBE PATTERNS

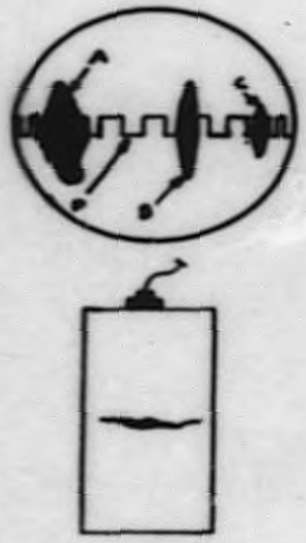

FIG. 6

LARGE FLAW

FIG. 7

POOR CRYSTAL-SPECIMEN CONTACT

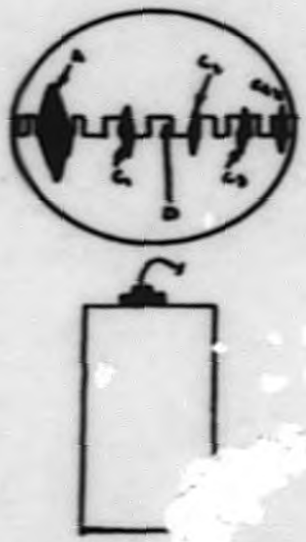

FIG. 8

HIGHER ORDER REFLECTIONS

A- INITIAL PULSE DEFLECTION

B- FLAW ECHO DEFLECTION

C- BACK ECHO DEFLECTION

D- TIME-DISTANCE MARKERS

TYPICAL CATHODE RAY TUBE PATTERNS

of technique must be employed.

it is possible to refract ultrasonic waves by means of specially constructed curved crystals and/or metallic "lenses." This method utilizes the refraction principle to advantage in the transmission of ultrasonics from a flat crystal into curved surface of a test specimen. Two aluminum compensating pieces are used to correct the curvature of the specimen surface and present a surface to which a flat crystal may be applied. Such a technique would be practical for inspection when a large number of like parts are to be tested. Figure 9 illustrates a lense of this nature.

Figure 10 illustrates the use of a V wedge to introduce sound through couplants at a particular angle parallel to a side face. This type of angle or "carom" testing is especially useful in working with thin cross-section (less than one inch).

PENETRATION CHARACTERISTICS

The ability of ultrasonic waves to penetrate large sections (up to 50 feet in depth) has been the major feature of the method since no other means of doing this is available at present. This by no means limits the use of ultrasonics to large areas, however. By scanning an area, the inspector can gain a reasonable idea of the size and shape of the discontinuity and venture a fairly accurate opinion regarding its proper classification. Areas containing segregation, fine porosity or clusters of small inclusions, prove more difficult to identify. Such areas will often reflect no signal because of internal scattering. However, they will give rise to a greatly attenuated boundary reflection. In extreme cases, the bottom echo may be entirely missing. This latter fact implies that some discontinuity is present. The nature of such a discontinuity can sometimes be deduced if the inspector has some idea regarding its extent or location. An accurate picture as to its location and extent may be gained by testing from two or more surfaces of the material.

Laminations and such flaws lying parallel to the direction of rolling cannot be conclusively detected from the end surfaces. This is obvious from the fact that their surface, normal to the direction of energy propagation, is comparatively small.

ACCURACY

Tests run by the Quality Assurance Organization in conjunction with Los Alamos Scientific Laboratory indicated that the accuracy of the Sperry Ultrasonic Reflectoscope compares favorably with the Betatron instrument in locating subsurface

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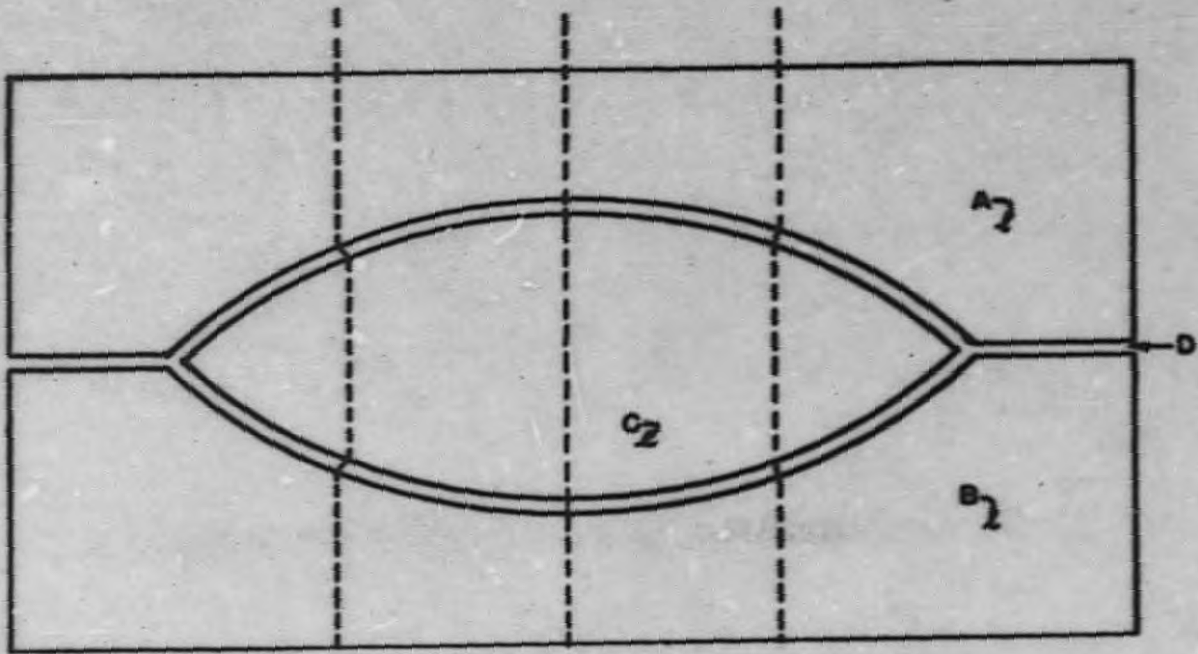


FIGURE NINE

CURVED SPECIMEN WITH COMPENSATING PLATES

A - FRONT COMPENSATOR

B - REAR COMPENSATOR

C - SPECIMEN

D - COUPLING MEDIUM AT INTERFACE

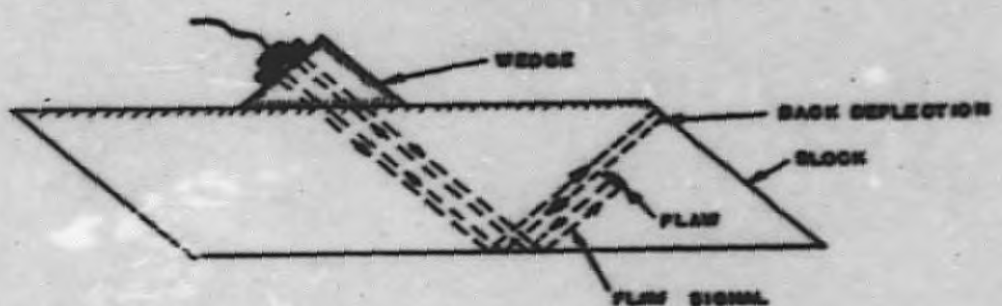


FIGURE TEN

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flaws. Results of testing the same pieces on both instruments under identical conditions revealed that the Reflectoscope will pick up any flaws indicated by the Betatron. Consequently, the ultrasonic tester may be considered of comparparable accuracy as the Betatron for inspection purposes.

The reflection method will locate internal discontinuities which present a reflecting surface to the sound beam as it passes through the material. The minimum size discontinuity which can be detected is roughly one having a projected lateral dimension equal to about 0.1% of the distance from the crystal to the defect. For example, at 6 inches, the smallest detectable defect would be .006 inch; while at 10 feet, it is possible to locate a 1/8 inch defect, with an accuracy of upwards of 1/8 inch. By moving the crystal on the surface, the extent of the discontinuity can be outlined.

CALIBRATION OF THE TESTER

As the speed of transmission and wave length varies in different materials, calibration of the ultrasonic tester to the condition of the material in question is necessary. A test block made of the same material as the test specimen and drilled with different sizes of holes is necessary to calibrate the ultrasonic instrument.

LIMITATIONS

It should be realized that even careful calibration will not ensure that discontinuities within a part can be accurately measured as to shape and size. Approximations must be made depending upon the distance of the discontinuity from the transducer, the location with respect to edges of the part, and the type of defect as judged by the appearance of its indication on the oscilloscope. However, with proper attention to all of the calibration details, flaw sizes can be determined to an accuracy of 25 per cent.

NEED FOR STANDARDIZATION

So far, attempts to establish industry-wide ultrasonic standards have not been successful. The E-7 Committee of ASTM is thoroughly reviewing tentative standards, and it is merely a matter of time until national standards are available. A copy of these tentative standards is attached as Appendix A to this memorandum. One complete set of standard reference blocks is being fabricated by the Quality Assurance Department for use at Sandia. No inspection engineer or metallurgist can set up acceptable standards for any specific product unless he can state the type and size of discontinuities that shall be considered to be defects. The need is markedly present that some form of standardization, whether company-wide or industry-wide, should be attempted to determine what should be considered acceptable and what is substandard. These should be determined in sufficient classes according to need and function to be clear and useful to the inspectors following them.

## ADDITIONAL TECHNICAL INFORMATION

The material covered in this report was obtained from experience of the Quality Assurance Department, plus technical information obtained from the following sources:

1. Symposium on Ultrasonic Testing, Special Technical Publication No. 101, ASTM.

2. Ultrasonics and Their Scientific and Technical Applications, Dr. Ludwig Bergmann, John Wiley and Sons, Inc., 1948.

3. Manual for the Calibration of the Sperry Ultrasonic Reflectoscope, GMX-1-Q1, Los Alamos Scientific Laboratory.

4. Glossary of Words & Expressions used in Ultrasonic Testing, Sperry Products, Inc., Danbury, Conn.

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# APPENDIX A

## - PROPOSED -
## TENTATIVE RECOMMENDED SPECIFICATIONS FOR STANDARD A.S.T.M. REFERENCE BLOCKS FOR ULTRASONIC TESTING

### SCOPE

1. In ultrasonic testing there are many variable factors such as pulse amplitude, pulse strength, amplifier gain, variations in transducers, surface conditions, etc., which are balanced to a definite testing condition. As these factors cannot be adequately recorded to enable duplication of test conditions, it is necessary to record the indications from reflections obtained on known reference blocks containing artificial discontinuities.

   These standards are recommended so that duplicate testing conditions can be determined for ultrasonic testing. Inasmuch as these standards do not simulate actual material or testing conditions, reference blocks should not be used to determine actual size of nonhomogeneities in production samples.

   Standard reference blocks may be used to set up specified ultrasonic tests and may be so specified in testing specifications.

### DESCRIPTION

2. The standard reference blocks consist of two sets of aluminum blocks provided with artificial discontinuities. To cover the wide range of ultrasonic testing it is necessary to have available one set of reference blocks with different sizes of artificial discontinuities as well as another set with the same range of sizes at a different distance from the test surface.

### SPECIFICATIONS

3. (a) Material - aluminum 14S-F-rolled square bar stock. Each bar should be checked ultrasonically to assure uniformity of internal structure. Scattering or reflection indications from the internal structure of the block shall not have an amplitude of more than 10 per cent of the amplitude of the reflection from the 1/32" hole in block No. 4-31. Direction of rolling to be lengthwise, which is normal.

   (b) The blocks are to be made in two sizes: two inches (2") square by five inches (5") long; and two and one-half inches (2 1/2") square by seventeen inches (17") long. Overall dimensions of the block are to be plus or minus one sixty-fourth inch.

(c) The artificial defect is to be made by drilling a flat-bottomed hole one inch deep at the center of one end face of each block so that the plane of the flat bottom is parallel to the ends. To assure that the hole is true and flat, the bottom may be peened with a tool having a ground flat the size of the hole. The hole is to be cleaned and plugged, but not filled to the bottom, to keep it clean. The depth of the hole is to be one inch plus or minus one thirty-second inch.

(d) Testing surface of block (end opposite hole) is to be finished to 90 to 110 microinches RMS. Sides and other end of block are to be equal to a rolled finish and free of nicks.

(e) Blocks are to be stamped with 1/4 inch high figures on one side within 3/4 inch of the top testing surface. The first part of number to represent the distance from the testing surface to the bottom of the hole; 4 for the 5" long blocks, and 16 for the 17" long blocks. The second part of the number, separated by a dash, will represent the diameter of the hole in thousandths of an inch. Example - See Table I.

(f) The size of the flat-bottomed holes and the identification numbers for each block are as follows:

TABLE I
REFERENCE BLOCK SPECIFICATIONS

| Identification Numbers | | Hole Dimensions. | | All 1" Deep |
|---|---|---|---|---|
| 2" by 2" by 5" long | 2 1/2 by 2 1/2 by 17" long | Dia. in inches | Area in Sq. inches | Drill Size |
| 4-31 | | 0.0313 | 0.00076 | 1/32 |
| 4-43 | 16-43 | 0.043 | 0.00145 | No. 57 |
| 4-62 | 16-62 | 0.0625 | 0.00307 | 1/16 |
| 4-89 | 16-89 | 0.089 | 0.00622 | No. 43 |
| 4-125 | 16-125 | 0.125 | 0.01227 | 1/8 |
| 4-177 | 16-177 | 0.177 | 0.02460 | No. 16 |
| | 16-250 | 0.250 | 0.04909 | 1/4 |

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## USE OF STANDARD REFERENCE BLOCKS

4. (a) Ultrasonic testing depends to a large extent on the skill of the operator to interpret the indications on the oscilloscope screen or any other indicating or recording device used. These indications vary widely with the equipment used and the adjustments on similar pieces of equipment. Because of the nature of the equipment and the test, it is necessary to have standard blocks on which readings may be made as a reference for all tests so that the test can be repeated under similar conditions. It is recommended to record readings on both long and short blocks to adequately bracket the testing conditions.

(b) The great variety of ultrasonic testing being done requires that a number of reference blocks be available. Actually for any general application only about four to six blocks may be necessary. The reference blocks probably most useful for various frequencies of testing are as follows:

| | |
|---|---|
| 1/2 megacycle | 4-125 to 4-177 and 16-177 to 16-250 |
| 1 megacycle | 4-62 to 4-125 and 16-89 to 16-250 |
| 2-1/4 megacycles | 4-31 to 4-89 and 16-62 to 16-177 |
| 5 megacycles | 4-31 to 4-62 and 16-43 to 16-125 |

## REPORTING DATA ON STANDARD REFERENCE BLOCKS

5. Because of the many variables in ultrasonic testing, it is necessary that a complete standard reference block report include the following information. This data is to be taken without changing any instrument settings after test is completed.

(a) Type of pulse generator and receiver.
(b) Type of searching unit.
(c) Size and shape of transducer.
(d) Frequency.
(e) Couplant.
(f) Type number of reference block (at least two).
(g) Peak-to-peak amplitude of reflection indications on each block.
(h) Temperature of test piece if other than normal.
(i) Other unusual conditions.

END

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