DEVELOPMENT OF AN ULTRASONIC SURFACE WAVE TESTING STANDARD

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1962

Submitted to the Faculty of the Graduate School of
the Oklahoma State University of Agriculture and
Applied Science in partial fulfillment of the
requirements for the degree of
MASTER OF SCIENCE
May, 1963

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WAVE TESTING STANDARD

Thesis Approved:

Thesis Adviser

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PREFACE

Ultrasonic testing is rapidly becoming an important nondestructive testing method because of its high speed and sensitivity. Because of the need to test machine parts accurately and rapidly during overhaul, surface wave techniques, used in ultrasonic testing, are being developed.

Before surface wave techniques can be used to determine actual flaw size, a reference standard must be developed. By comparing a flaw indication to the indication received from a standard, it would be determined if the part should be rejected or not.

This study was undertaken to find if a surface wave testing standard could be developed to achieve the desired results. If the type of standard desired could be found theoretically, it was required that an experimental investigation be made to see if the theoretical and experimental values agreed.

Appreciation is expressed to Dr. R. L. Lowery for his suggestions and guidance of this study; to Phil Randles and Jim Simpson for their assistance in the development of the standard; and to the staff of the of the Mechanical Engineering Laboratory for their technical assistance.

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CHAPTER I

INTRODUCTION

Due to the ever-increasing demands for better quality control and the need for testing parts for flaws occuring during use, the role of nondestructive testing is one of utmost importance. In the past few years, nondestructive testing has progressed from the blacksmith's ring test to ultrasonic testing.

The sensitivity of the nondestructive testing methods used at the present time varies over a wide range. Often it is found that tests are either fast with low sensitivity or slow with high sensitivity. Because of the many specimens that usually have to be tested, speed is an important factor.

Because of the low factors of safety and high demands on critical aircraft parts, even microscopic flaws must be found during production and overhaul to prevent future failure in flight. Therefore, it is found that high sensitivity is another criteria that must be met for an acceptable nondestructive testing method. This presents the problem mentioned above of combining speed with sensitivity.

A method that is being developed to meet both requirements is the ultrasonic test method. This method uses a pulse-echo technique similar to the type used by radar. The transducers used for ultrasonic testing can be classified in the three general classes of longitudinal wave, shear wave, and surface wave.

The longitudinal transducer sends an ultrasonic wave straight through the material. The transducer face must make good contact with the material being tested. For this reason, longitudinal wave techniques are useful in testing parts of simple geometric shape.

The shear wave transducer sends the wave through the material at an angle so that it reflects between the bounding surfaces of the material. They must also be used on parts of simple geometric shape and usually of uniform thickness, such as flat plates or tubing.

Surface wave transducers send a wave along the surface of the material. This type of testing can be used on parts of almost any shape to find surface flaws and fatigue cracks, since the wave will follow the geometry of the surface.

The uses of the three types of waves are shown in Figure 1.

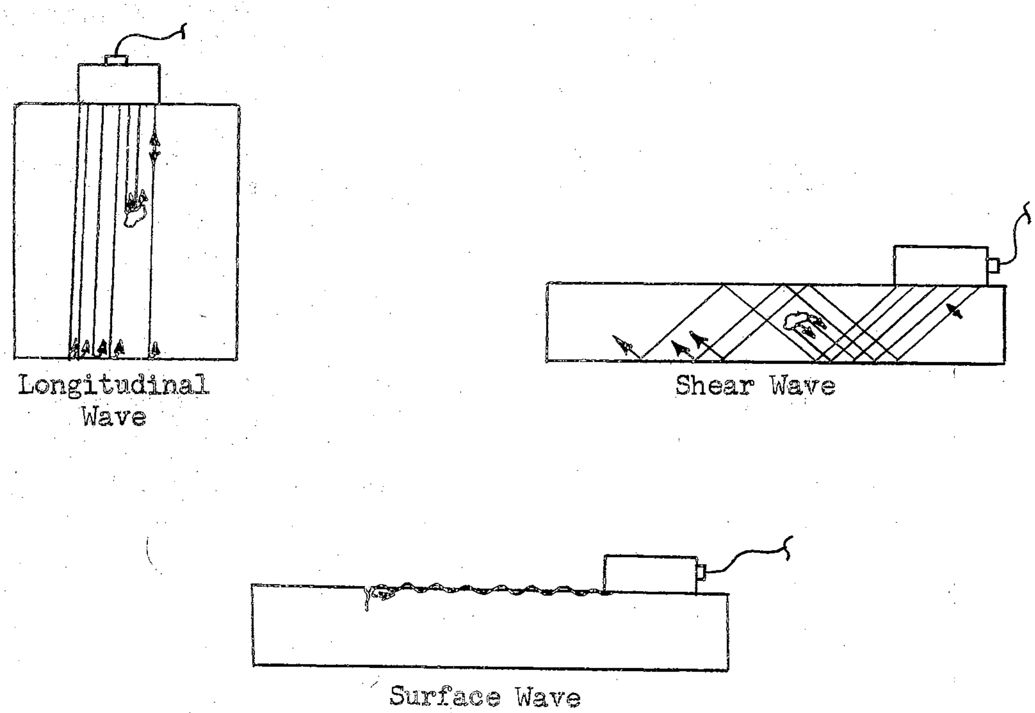

Figure 1. Types of Ultrasonic Transducers

During the past few years, the longitudinal and shear type transducers have been developed to a greater extent than have the surface wave type. This was because they are easy to use in quality control work. During this time, standards have been developed for longitudinal testing. These standards can be used for comparing transducers, testing machines, analyzing flaws, and specifying flaw tolerances.

With the advent of the use of ultrasonics to test machine parts during overhaul, the longitudinal and shear type transducers have run into several problems. Since many of these parts are not of uniform shape or thickness, they would be very difficult to test using longitudinal or shear wave techniques. Since failure due to variable stresses usually first occurs on the surface of the part, surface wave techniques can be easily applied in many cases. The ultrasonic testing group of the non-destructive testing research project at Oklahoma State University is presently developing surface wave techniques and applying them to the testing of jet engine components. The development of surface wave techniques has been greatly accelerated by this type of application.

At Oklahoma State University, the problem of surface wave standards has arisen. Five of the leading manufacturers of ultrasonic test equipment were contacted regarding this problem, and all of the manufacturers agreed that there were no such standards and that such standards are needed. Without a standard, it is difficult to specify surface flaw tolerances, to compare transducers and test machines, and to check wear or stability of transducers. It can easily be seen that there is a great need for a surface wave testing standard.

The purpose of this research is to attempt to develop a standard for surface wave testing. There are several problems associated with the development of such a standard. A few are as follows: What parameters of the surface wave should the standard measure? How can a standard be developed that will be simple to use, construct, and reproduce accurately? What type of construction will give linear results? How can a standard be made so it can be used for various frequencies and sizes of transducers?

Possible answers to these questions and others are developed in the following chapters.

CHAPTER II

BACKGROUND

Before a standard can be developed, a thorough understanding of the characteristics of the surface wave should be known. A few of the fundamental aspects which are of interest are as follows:

1. Production and use of surface waves for ultrasonic testing
2. Surface wave equations of motion
3. Characteristics of the surface wave

Once these parameters are understood, a surface wave standard can be developed from an engineering and mathematical point of view instead of by trial and error.

The Production and Uses of Surface Waves

The most common way of producing ultrasonic waves for ultrasonic testing is with a piezoelectric crystal. This crystal is mounted in a case and is usually placed on a plastic wedge. The angle at which the crystal is mounted on the wedge, with respect to the horizontal, can be varied depending on the type of transducer being made. If the face of the crystal is placed parallel to the horizontal, the wave produced will be longitudinal and the wave transmitted into the test specimen will remain longitudinal. It seems logical that when the crystal is tilted at an angle from the horizontal that the longitudinal wave produced by the crystal will be refracted into the test material as a longitudinal wave obeying Snell's law. Although this is true, it is found that this is not the complete case. The refracted wave obeys Snell's law, but in order to satisfy all continuity equations, it is required that both a longitudinal and shear wave be produced (1).[1] Since these two waves have different velocities, they will be refracted into the material at different angles. Because the shear wave has the slower velocity, it will be refracted at the lesser angle. As the crystal is rotated further, the longitudinal wave will approach the surface. When the crystal is at an angle called the first critical angle, the longitudinal wave just grazes the surface and a surface wave is produced. As the crystal is rotated still further, the second critical angle is reached when the shear wave makes the surface wave while the longitudinal wave is totally reflected. Most surface wave transducers use the shear wave to produce the surface wave, since in this case there will be only one wave traveling through the test material.

Basically, a pulse-echo test unit consists of a pulser, receiver, cathode ray tube (CRT), and transducer. The pulser sends a voltage pulse to the faces of the piezoelectric crystal. This impulse causes the crystal to vibrate at all frequencies, the amplitude of the fundamental frequency producing the predominant vibration. This produces a longitudinal wave that travels through the transducer and down the surface of the test material as described above. This surface wave travels down the surface until it is reflected, either totally or partially, from a flaw or boundary of the material. This reflected wave travels back toward the transducer. Meanwhile, back at the transducer the crystal is not in use. When the reflected wave reaches the transducer, it is refracted back to the crystal.

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[1] Numbers in parentheses refer to sources listed in the selected bibliography.

When the wave strikes the crystal, it vibrates at its natural frequency since the frequency of the reflected wave is the same as the wave emitted from the transducer. The vibration causes a charge to be developed on the faces of the crystal. This charge is picked up by the receiver and amplified to drive the CRT. The height of the indication seen on the CRT indicates the pressure of the reflected wave on the face of the crystal. The CRT will display indications at the initial pulse, the flaw reflection, and the back reflection. By adjusting the time delay controls, these indications can be separated for observation. (See Figure 2.)

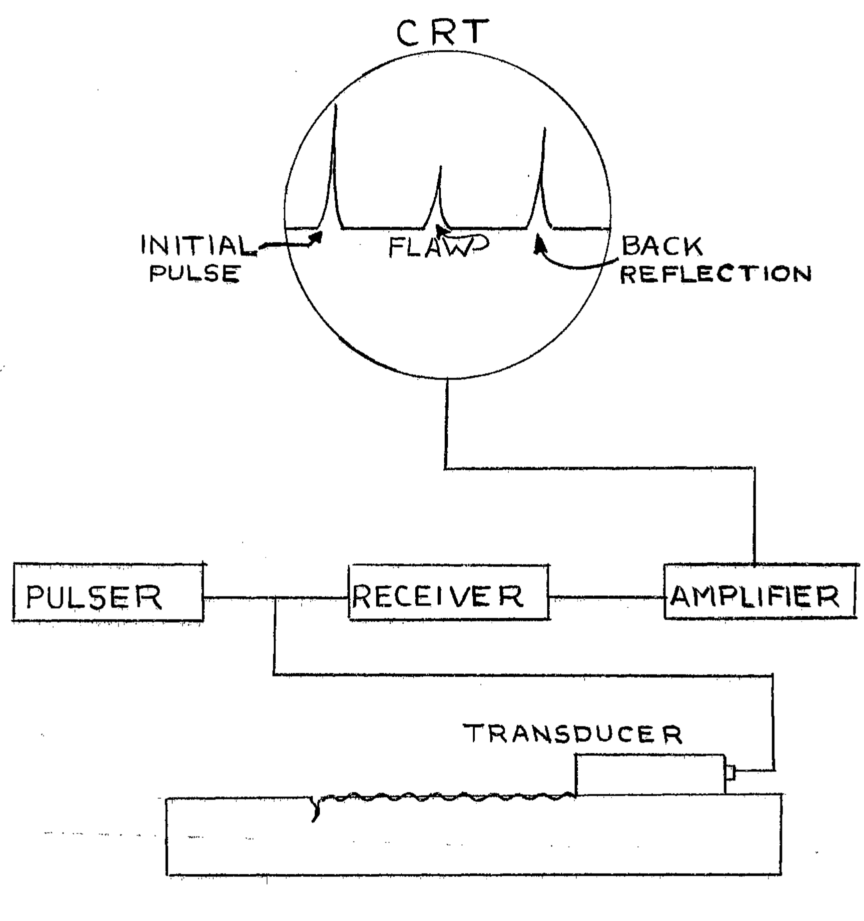


Figure 2. Schematic of Pulse-Echo Ultrasonic Testing Unit

Surface Wave Motion and Characteristics

The equation of motion and its characteristics must be known in order that the critical parameters of the motion be singled out. To understand the characteristics that are unique with surface waves, one must be familiar with the surface wave equation and the assumptions used in deriving the equation.

The general wave equation as derived by Lindsay (2) is

$$\rho \ddot{\Delta} = (B + \frac{4\mu}{3}) \nabla \nabla \cdot \Delta - \mu \nabla \times \nabla \times \Delta \tag{2-1}$$

where ρ = density,

B = bulk modulus,

μ = shear modulus,

Δ = total displacement vector, and

∇ = differential operator.

Figure 3 shows the coordinate system used.

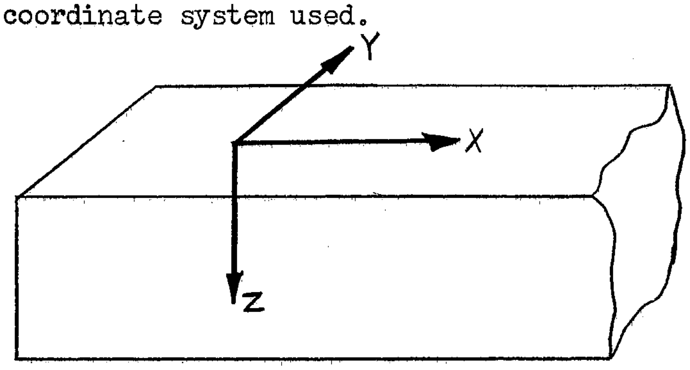


Figure 3. Coordinate System for Derivation of Surface Wave Equation

Lindsay solves the wave equation with the boundary condition that all shear stresses vanish at the surface. He also assumes that the wave travels sinusoidally in the X direction and is unvarying in the Y direction.

The resulting equation is

$$4\mu\left[\left(1-\frac{V_r^2}{V_i^2}\right)\left(1-\frac{V_r^2}{V_s^2}\right)\right]^{\frac{1}{2}} = \left[\frac{4\mu}{3}-\left(B+\frac{2\mu}{3}\right)\frac{V_r^2}{V_i^2}\right]\left[2-\frac{V_r^2}{V_s^2}\right] \quad (2\text{-}2)$$

where V_r = phase velocity of the surface wave,

$V_i = \left(\frac{B+\frac{4\mu}{3}}{\rho}\right)^{1/2}$ = velocity of a longitudinal wave, and

$V_s = \left(\frac{\mu}{\rho}\right)^{1/2}$ = velocity of a shear wave.

Also, the real displacement terms in the X and Z directions are

$$\xi_r = B_1 K\left(e^{-\alpha z} - \frac{2\alpha\alpha'}{\alpha'^2+K^2}e^{-\alpha' z}\right)\sin(\omega t - Kx) \quad (2\text{-}3)$$

$$\zeta_r = B_1 \alpha\left(e^{-\alpha z} - \frac{2K^2}{\alpha'^2+K^2}e^{-\alpha' z}\right)\cos(\omega t - Kx) \quad (2\text{-}4)$$

where ξ_r = displacement in the X direction,

ζ_r = displacement in the Z direction, and

B_1, K, α, And α' are constants.

From equation (2-2), it is seen that the phase velocity of the surface wave (V_r) can be solved in terms of the elastic constants and density. It is also seen that the velocity is independent of the frequency since frequency has disappeared from the equation. Therefore, there is no dispersion of surface waves.

The dissipation factors in parentheses in equations (2-3) and (2-4) are important in determining the depth to which a surface wave will penetrate. From equation (2-3), it is found that the displacement in the X direction decreases with an increase in the value of kZ and actually passes through zero displacement. From equation (2-4), it is found that the displacement in the Z direction decreases with increasing values of kZ, but its value never passes through zero. The decay depends on frequency since k is proportional to ω. (See Figure 4.) (3)

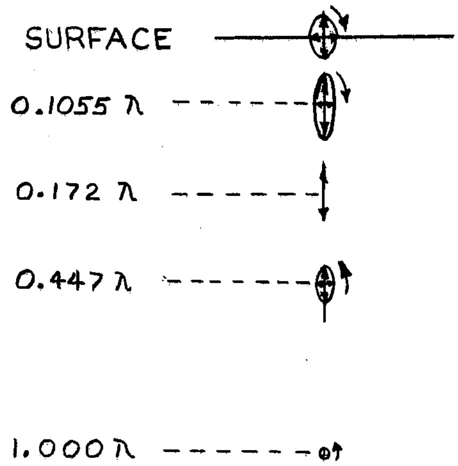


Figure 4. Decay of the Amplitude of a Surface Wave With Depth

Several problems associated with the development of a standard have been encountered, but they can best be understood when discussing an actual design or when analyzing data taken from a tentative standard. These problems will be discussed in Chapters 3 and 4.

Present Ultrasonic Standards

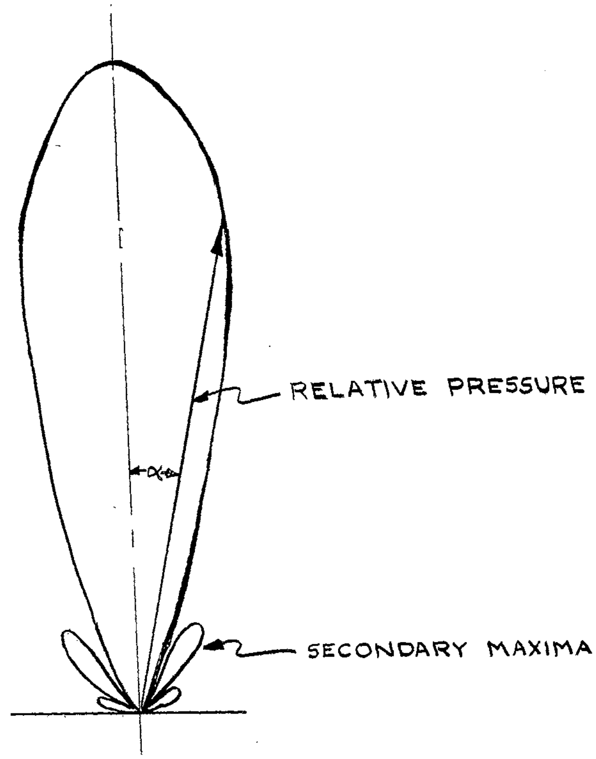
As mentioned before, ultrasonic standards have been developed for longitudinal wave testing. These standards have been accepted by the American Society for Testing Materials (ASTM). The standards set up by the ASTM include the procedures for fabrication of test blocks, for calibrating the test instrument and transducer, and for checking the test blocks.

The standards developed are aluminum blocks containing flat bottom holes. The reflections obtained from these holes are the standard indications. The purpose of these standards, as stated by the ASTM, is to use them for checking performance of ultrasonic testing equipment and for standardization and control of ultrasonic tests of aluminum alloy products using pulsed longitudinal waves.(4)

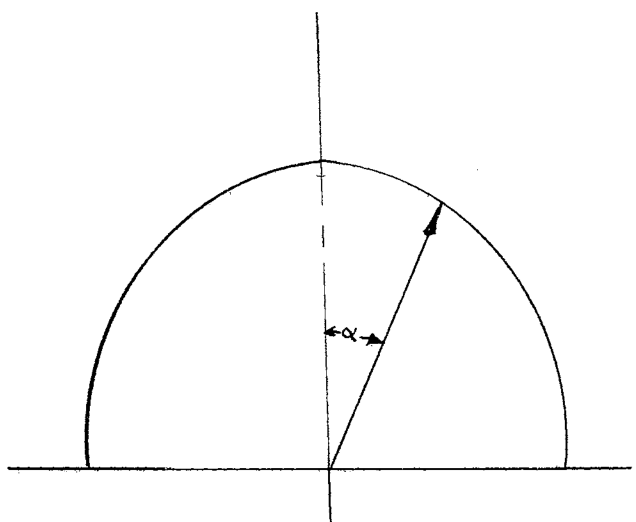
This type of standard is known as a secondary standard. Since a standard flaw would be very difficult to produce, the reflections from the flat bottom holes serve as the secondary standard with which an actual flaw indication can be compared. The flaw will probably not resemble the hole bottom in size or shape; only the indications can be compared.

The present longitudinal standard has a possible disadvantage. This is the problem of reflection characteristics. Reflecting areas of different sizes will have different reflecting characteristics known as radiation patterns. The amount of incident energy reflected in different directions from a certain size and shape interface will vary as a function of the shape and size of the interface compared to the wave length of the frequency being used. For large interfaces as compared with the wavelength (4 times as large), the radiation pattern is very directional in most cases; whereas, for a small size as compared to a wavelength (.5 times as large), the radiation pattern changes radically. An example of this is shown in Figure 5. Since ultrasonic tests are carried on with several sizes of transducers and several test frequencies, the radiation pattern effect could cause serious difficulties in that a reflection curve for one size and frequency transducer with a set of holes would give a different curve for another size and frequency transducer.

The standard developed by the ASTM can not be used for surface wave testing. A similar theory of reflection from an interface can be applied to surface wave standardization, but there are many more problems than encountered using longitudinal waves. This method will be discussed in the next chapter.



$\frac{d}{\lambda} = 4.0$



$\frac{d}{\lambda} = 0.5$

Figure 5. Radiation Patterns

CHAPTER III

POSSIBLE SURFACE WAVE STANDARDS

After a considerable amount of study on the theory of surface waves and after actually using surface wave techniques for testing parts, certain requirements that a standard must meet to actually be of benefit can be specified.

It is found that there are two general parameters in ultrasonic testing - those controlled by the operator and those controlled by the specific inspection problem. These parameters are listed below:

A. Operator Controlled Parameters

  1. Equipment selection
     a. Instrument type
     b. Transducer type (crystal, case, and wedge)
  2. Operation of Equipment
     a. Technique
        (1) Coupling method
        (2) Scanning procedure
        (3) Maximum indication procedure
     b. Control settings
        (1) Reject level
        (2) Sensitivity
        (3) Delay time
        (4) Pulse rate

B. Inspection Controlled Parameters

1. Specimen Properties

    a. Wave velocity

    b. Attenuation

    c. Geometry

        (1) Transducer size and shape

        (2) Transducer type (longitudinal, shear, or surface)

    d. Transducer frequency

    e. Surface condition

    f. Noise level

2. Flaw Properties

    a. Transducer type (longitudinal, shear, or surface)

    b. Depth

    c. Width

    d. Shape

    e. Impedance

    f. Orientation

A standard should be designed so as to assist the operator in adjusting his control parameters to measure the Inspection Controlled Parameters. It should also serve as a means by which the operator can select the proper equipment for the inspection problem at hand. For an example of the first case, if a certain size flaw could be tolerated, then the maximum indication of any flaw would be the standards indication corresponding to the flaw specified. In the second case, the standard must be used as the means by which the response of instruments and transducers can be compared.

The logical type of standard would be one which gives different indication amplitudes for different size standard reflectors. As explained before, a standard must by necessity be a secondary standard since it would be very difficult to produce a standard flaw. On the other hand, standards which are made up of reflectors of different sizes could be thought of as a perfect flaw. A slot machined in a steel plate could be considered the perfect flaw. Since the interface would be air, the reflection would be essentially one hundred per cent. The reflecting surface would be perpendicular to the direction of wave travel so there would be no loss of energy from energy being incident at an angle to the reflector. A flaw, say a fatigue crack, of the same size as a slot would probably give a lower indication than the corresponding slot because the fatigue crack would have a combination of air steel interface which would allow more energy to pass through than if it had been air alone. Also, the interface of the fatigue crack would probably be jagged, thus allowing more energy to be deflected away from the transducer. These effects are demonstrated in Figure 6.

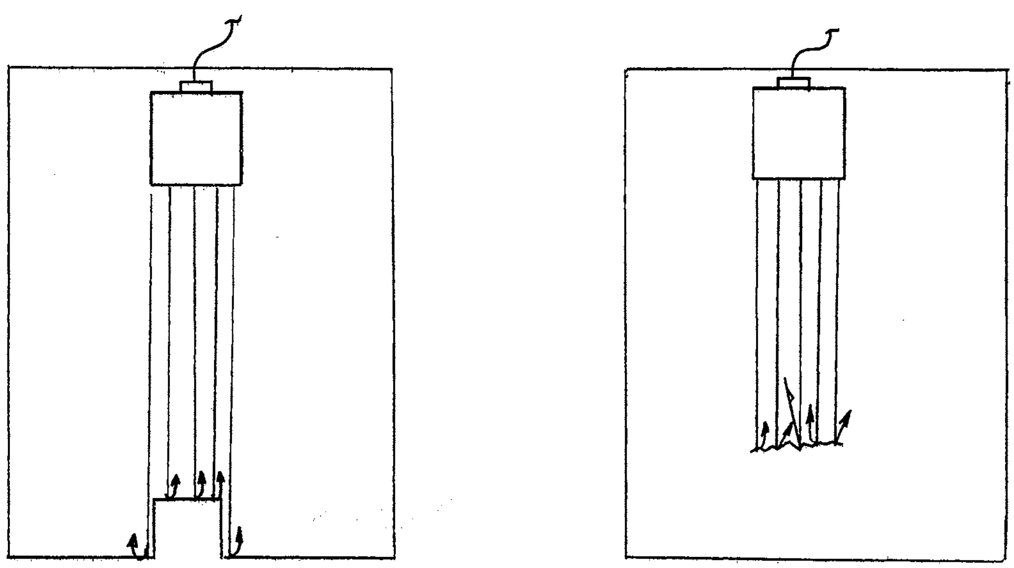


Figure 6. Reflection from Regular and Irregular Surfaces

Two possible standards of this type were designed and tested. One consisted of a circular steel plate with holes of varying sizes drilled at a radius from the center. The other was a circular steel plate with varying width slots machined along the edge. These plates are shown in Figures 7 and 8.

By varying the diameter of the holes or the width of the slots, it was believed that a linear variation in the ultrasonic indication could be obtained.

The holes were used because: (1) Holes can be drilled easily and accurately, and (2) Since the reflecting surface is curved convex to the transducer, energy would be spread over a large area, which would reduce the reflected energy to the transducer; therefore, a large hole could be used to get a small indication. The circular plate was used to reduce the amount of necessary movement of the transducer. To predict the results of the reflections obtained from the varying size holes, a theoretical study of ultrasonic reflections from holes is now being made.

The slots were used because: (1) It was believed that the theoretical considerations would be simple since the reflectors would consist of a rectangular piston source, and (2) It was believed that the indication would be directional proportional to the width of the slots. To determine the amounts of energy returned to the transducer from a slot, a theoretical investigation of the ultrasonic reflections from a slot must be made.

If the radiation patterns from the rectangular piston source, or for simplification a line source, were independent of length and frequency, the energy reflected to the transducer should be proportional to the length of the line source. Since the radiation patterns depend upon the length

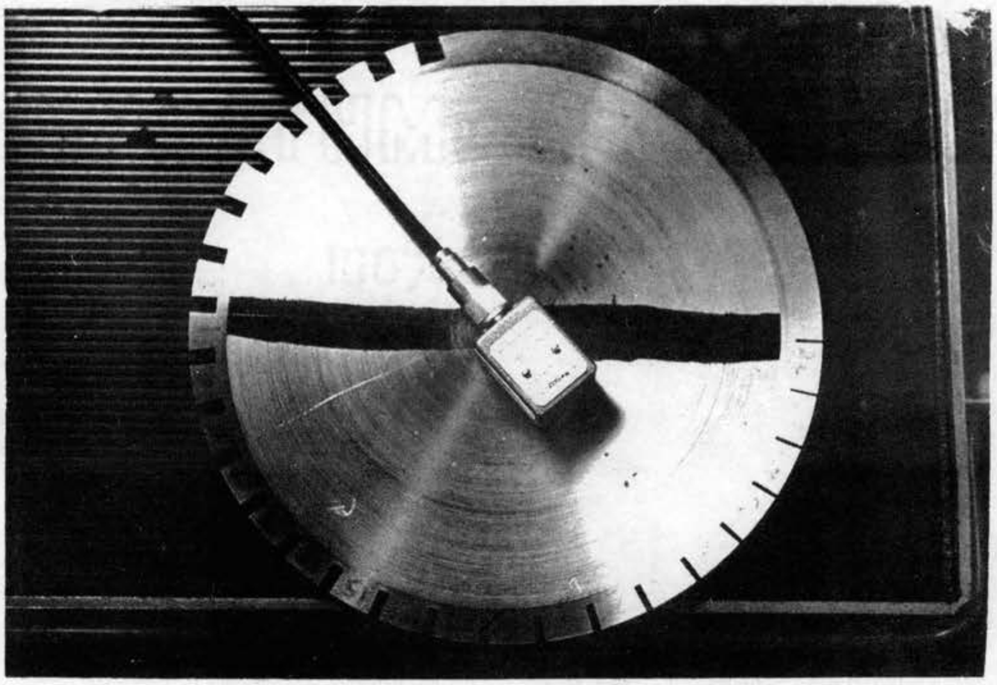


Figure 7. Circular Plate with Slots.

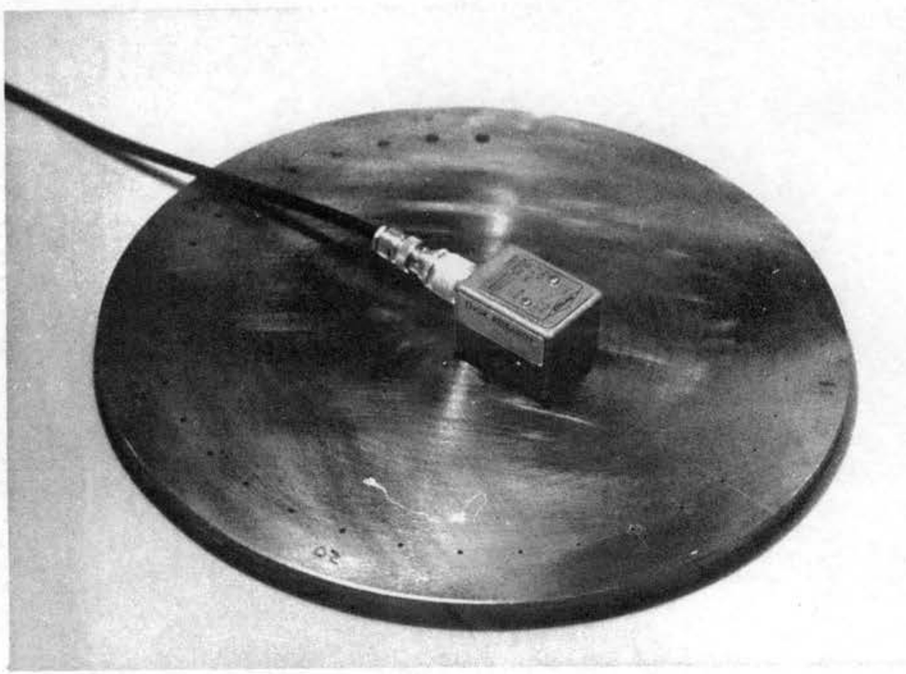


Figure 8. Circular Plate with Holes.

of the reflector and frequency (which determines wave length in a particular medium), one of the main factors which determines the pressure received by the transducer is the radiation pattern effect.

Suppose the width of the piezoelectric crystal is one inch and the width of a slot is one-half inch. The maximum radiation that the slot could possibly reflect would be one-half of the total energy sent out by the transducer. Due to the varying radiation patterns formed by different width slots at a given frequency, the energy received by the transducer will be less than the ideal case.

The radiation patterns from any source can be approximated by a number of point sources aligned in the same geometrical shape and of the same phase relationship as the actual radiator. The radiation pattern can then be obtained by summing the contributions of each point source at any angle to an arbitrary axis of radiation. This process is sufficient for the main beam of the reflection pattern but is not sufficient for the secondary maxima since the relative intensity of the secondary maxima rises to unity which is the same as for the main beam. For this reason, the source must be analyzed as a continuous line source. As a line source, secondary maxima of the pattern become progressively smaller instead of rising to unity. This is due to the fact that for directions other than the normal to the line, all the radiation from all points can never be in phase; whereas, in the source consisting of point sources, secondary maxima equal in intensity to the radiation straight ahead appear at angles inclined to the normal when radiation from all points are in phase. In the case of the continuous line source, the secondary maxima are much smaller, although not necessarily so small as to exercise a disturbing influence.

The equation for the relative pressure of the straight line source is derived by Irving Wolff and Louis Malter (5) by taking the equation for (n) point sources a distance (d) apart and allowing (n) to approach infinity and (d) to approach zero in such a way that nd=L. Therefore, the line source is the limiting case. The equation so derived is

$$R_\alpha = \frac{\sin\left(\frac{\pi \ell}{\lambda} \sin\alpha\right)}{\frac{\pi \ell}{\lambda} \sin\alpha} \qquad (3\text{-}1)$$

where R_α = relative pressure,

α = angle between the normal (to the line source),

L = length of the line source, and

λ = wave length

The amount of energy intercepted by a slot will be proportional to its width compared to the width of the beam sent out by the transducer. The slot widths which would be of any value, therefore, would be those of width equal to and less than the width of the transducer beam. For the ideal case, all the energy intercepted by a slot would be reflected to the transducer. Because of the radiation patterns as described by equation (3-1), all the energy reflected from the slots will not be picked up by the transducer. Since the maximum voltage output of the transducer will be proportional to the amplitude of the pressure reflected to the crystal, the effect of the energy being spread over a large area will reduce the indication.

The average pressure on the face of the crystal must be found to accurately predict the indication returning from a slot. The intensity of the reflected wave is proportional to the square of the pressure. The area under the intensity curve divided into the area that intercepts a slot gives the portion of the total intensity that was incident on the transducer. The square root of this value is the average pressure incident on the crystal. To find these values, equation (3-1) must be solved for various values of L. To predict the indications, the following values must be computed:

1. Area under R_α^2 curve for different values of L.
2. Area of R_α^2 curve that intersects the transducer.
3. Ratio of total R_α^2 curve to the part that returns to the transducer.
4. Portion of total energy from the transducer that intersects the slot.

The area of the R_α^2 curve represents the total intensity reflected by the slot. The area of the R_α^2 curve inside the angle that intersects the transducer represents the intensity received by the transducer. This is shown in Figure 9.

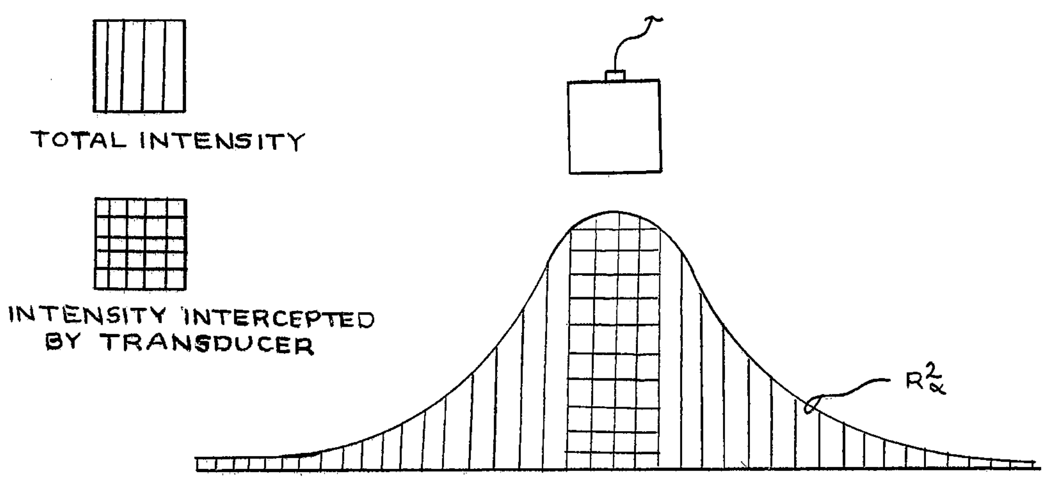


Figure 9. Portion of Intensity Intercepted by Transducer

The value obtained from dividing the total area into the intercepted area gives the portion of the total that is received by the transducer. Since the computations would be long and tedious, a digital computer was used to compute the needed quantities. The results are shown in Chapter 4.

Once the four values have been computed, the theoretical percentage of the total energy that leaves the transducer that is reflected back to the transducer can be found as follows:

A = size of slot compared to size of crystal

B = portion of area of R^2_α that returns to transducer

C = percentage of total indication

by knowing A and B

$$C = AB \times 100 \qquad (3-2)$$

From the values computed, a theoretical curve can be drawn for any set of slot widths. To determine if the radiation patterns are the main controlling factors in the indications as seen by the transducer, the theoretical curve should be compared with an experimental curve. These results are found in Chapter 4.

CHAPTER IV

DATA AND RESULTS

To test the feasibility of using machined slots as a surface wave testing standard, a theoretical curve for transducer indication for various size slots is needed. The usual size of transducers ranges between one-fourth inch and one inch. For the reflections to be of value, they must be smaller than the beam width of the crystal. The range selected to analyze was from 0.03125 to 0.5 of an inch.

For the theoretical consideration, the sizes of the slots started at 0.03125 inch and went to 0.5 inch in 0.015625-inch increments. To obtain values for the transducer indications, equations (3-1) and (3-2) must be solved for each slot width. Equation (3-1) was solved for the area of R_α^2 for each slot width and for various frequency transducers with a digital computer. To compute the value of (A) in equation (3-2), the transducer beam width was divided into the slot width. The value (B) in equation (3-2) was found by dividing the total area of the R_α^2 curve into the area of R_α^2 that intercepts the receiver crystal and taking the square root of this value. The value of (C) in equation (3-2) was found by multiplying (A) times (B). This gives the portion of the total pressure response that is returned to the transducer. The following is a sample calculation.

Slot width = .3125 in.
Transducer frequency = 2.25 mc Transducer width = 1 inch
Portion of R_α intercepted by transducer = 12°
A = .3125 ÷ 1 = .3125 B (by computer) = $(.89608937)^{1/2}$ = .9475
C = AB = .3125 x .9475 = .296 = 29.6%

The results of these computations are shown in Table I and Figure 10. Also shown in the figure is the curve that would be obtained neglecting the radiation pattern.

It can be seen from the figure that the curves become more linear for higher crystal frequencies. Also the reflection becomes more directional for high frequencies. The reflection from a .265625-inch slot at 5 mc should give the same indication as a .28125-inch slot at 2.25 mc, or the same indication as a .375-inch slot at 1.0 mc. If the transducer were located closer to the slots, the curves would lie closer to the linear curve which is independent of frequency. If it were located further from the slots, it would intercept a smaller portion of the intensity curve and the curves would lie further from the linear curve.

From these curves, it is evident that slots could be used as a testing standard. To see if experimental values are the same as the theoretical values, slots of different widths were machined in a steel plate.

The transducer used to test the plate was a 2.25 mc 1-inch by 0.5-inch transducer. The crystal width was one inch, but the beam width was measured and was found to be 0.6 inch. The transducer was placed so it would intercept a twelve degree arc of the radiation pattern. A Magniflux ultrasonic testing instrument (shown in Figure 11) was used to take the data. Indications were read in centimeters. The actual portion of the total energy sent out by the transducer that was reflected to the transducer was found by dividing the indication of the total reflection from a boundary into the indication received from the slots. The theoretical percentage was computed as mentioned before. The data obtained is Found in Table II. This data is plotted in Figure 12. It is seen that the theoretical values and the experimental values agree with a few per cent.

TABLE I

THEORETICAL REFLECTIONS FROM SLOTS

(Transducer Width = 1 inch)

Slot Width (in.)	Percent of Total Reflection		
	Transducer Frequency		
	1 mc	2.25 mc	5 mc
.031250	.921	1.17	1.79
.046875	1.492	2.25	3.255
.062500	2.21	3.44	4.82
.078125	3.20	4.69	6.50
.093750	4.18	6.16	8.27
.109375	5.39	7.71	10.00
.125000	6.60	9.23	11.69
.140625	7.78	10.91	13.30
.156250	8.97	12.65	14.94
.171875	10.41	14.25	16.44
.187500	11.60	16.01	17.95
.203125	13.10	17.80	19.45
.218750	14.70	19.83	20.95
.234375	16.29	21.20	22.50
.250000	17.79	22.95	24.1
.265625	19.25	24.60	25.7
.281250	20.75	26.25	27.3
.296875	22.4	28.00	28.9
.312500	24.1	29.62	30.6
.328125	25.9	31.15	32.1
.343750	27.6	32.60	33.5
.359375	29.5	34.30	35.3
.375000	30.9	35.80	36.8
.390625	32.6	37.50	38.3
.406250	34.3	39.00	39.8
.421875	36.1	40.40	41.4
.437500	38.0	41.90	43.0
.453125	39.7	43.40	44.5
.468750	41.4	44.75	46.1
.484375	43.0	46.40	47.6
.500000	44.6	48.00	49.2

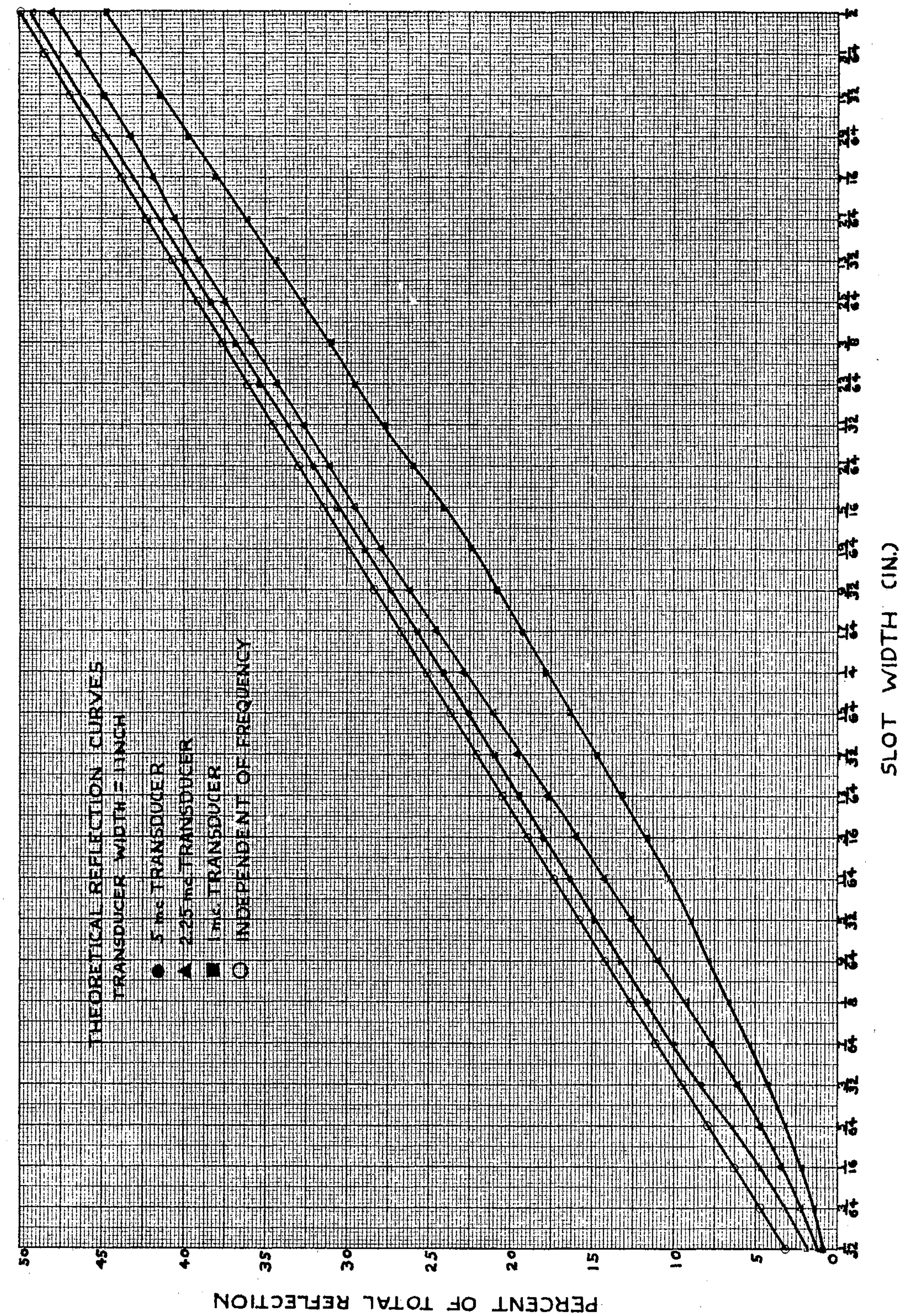


Figure 10. Theoretical Reflection Curves.

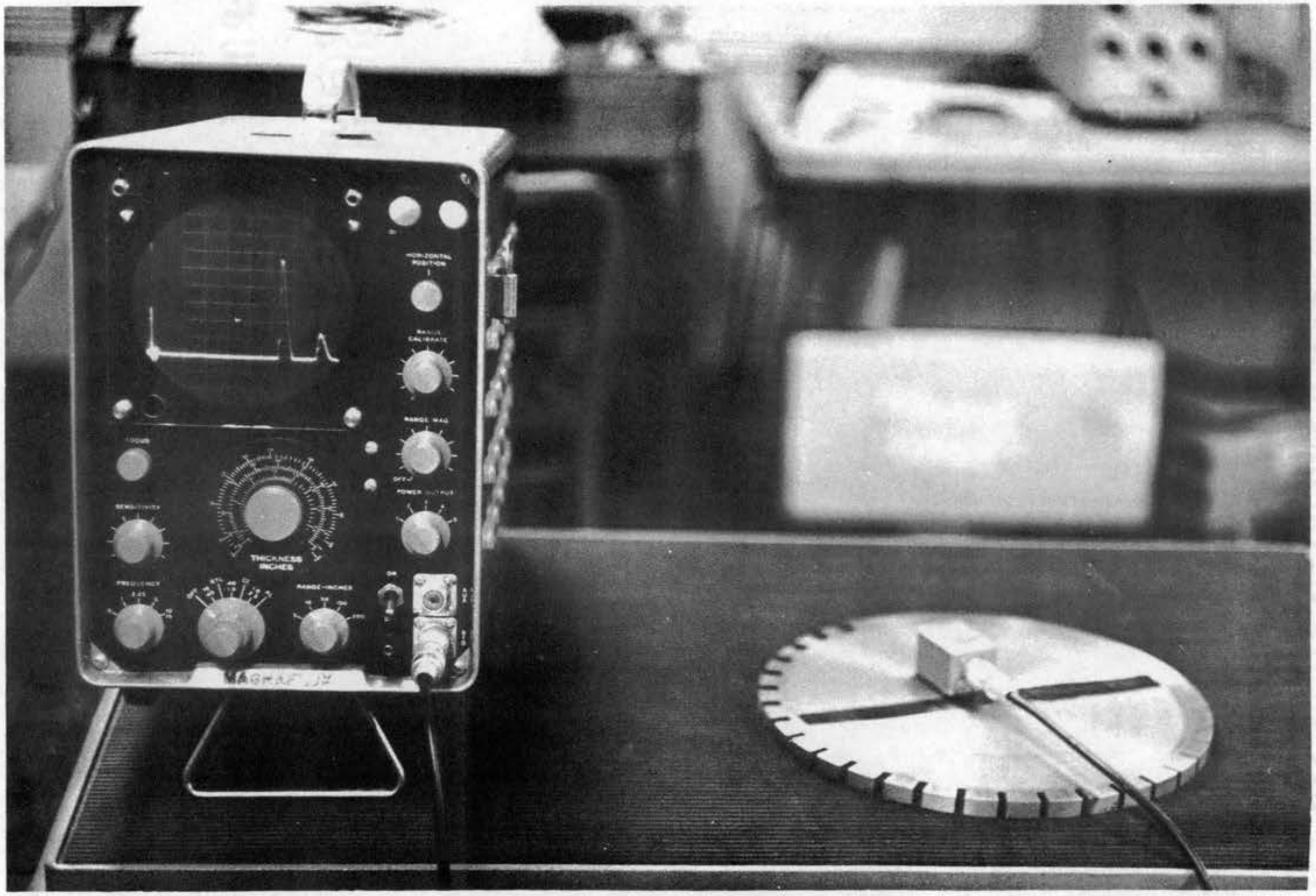


Figure 11. Ultrasonic Testing Instrument Used

TABLE II

THEORETICAL AND EXPERIMENTAL REFLECTIONS FROM SLOTS

(Transducer Width = 0.6 inch)

(Transducer Frequency = 2.25 mc)

Slot Width (in.)	Percent of Total Reflection	
	Theoretical	Experimental
.031250	1.95	3.64
.046875	3.75	4.55
.062500	5.74	5.06
.081250	7.80	6.57
.093750	10.27	9.1
.109375	12.85	11.4
.125000	15.38	14.0
.140625	18.20	17.1
.15625	21.05	19.5
.171875	23.75	20.4
.187500	26.70	25.7
.203125	29.7	30.6
.218750	33.1	33.7
.234375	35.4	33.7
.250000	38.3	37.8
.265625	41.0	41.9
.281250	43.8	44.5
.296875	46.7	45.3
.312500	49.4	48.2
.328125	51.9	50.0
.343750	54.4	54.2
.359375	57.2	56.8
.375000	59.7	58.6
.437500	69.7	65.4
.468750	74.5	66.5
.500000	80.0	63.5

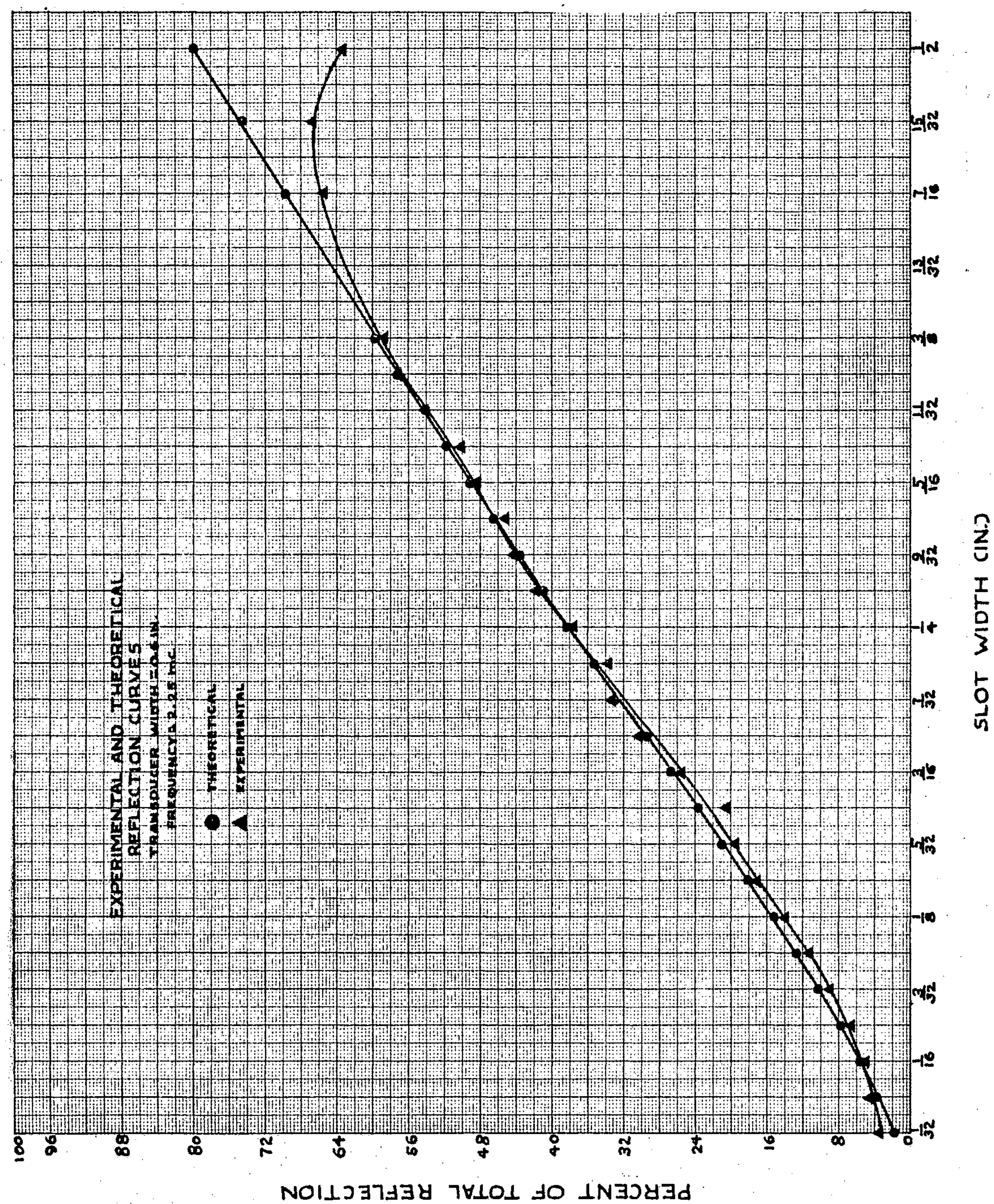


Figure 12. Experimental and Theoretical Reflection Curves.

The main difficulty in obtaining data from these slots was in getting the maximum indication possible. One of the factors that contributed to this problem was the fact that the transducer had to be placed so that the maximum intensity portion of the beam had to be incident on the slot while at the same time the crystal had to be perfectly parallel to the slot. Another main factor in this problem was the different indications that could be obtained with different oil film thicknesses under the transducer. If any air was between the transducer and the plots, that portion of the surface wave would not reach the crystal. If too much oil was used, the oil would damp out a portion of the surface wave before it would reach the crystal, or it would reflect a portion of the returning wave. The first plate tried was a square steel plate with slots machined along the edges. It was very difficult to obtain data from this plate because the transducer was difficult to position. The circular plate proved to be better than the square one because positioning was achieved by varying only one coordinate. The best results were obtained when the portion of the plate where the transducer would be moved over was coated with a thin film of oil. The transducer was then placed on the plate and a weight was set on the transducer to keep a constant pressure applied to it. The transducer was moved by sliding it a small distance around the small radius of the center hole.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

In Chapter 1, several questions which were related to the problem encountered in developing a surface wave testing standard were asked. These questions can now be answered in part. These questions are now repeated. How can a standard be developed that will be simple to use, construct, and reproduce accurately? What type of construction will give linear results? How can a standard be made so it can be used for various frequencies and sizes of transducers?

The construction of a circular steel plate with slots machined along the edges is simple to construct and reproduce accurately. The only variation that could occur using the same type of material would be in the machining tolerances. It can not be said that this standard is easy to use. A wide variation of indications can be obtained by using slightly different methods of peaking procedure.

After working with surface wave techniques, it has been found that they are very sensitive to many variables. For this reason, it would be expected that a surface wave standard would be more difficult to use than a longitudinal wave standard.

From the theoretical results and the experimental results, it is evident that it is possible to achieve a fairly linear variation of ultrasonic indication with a linear variation of slot widths. It was found that both curves began to level off at small slot widths. If it is found that indications in this region are important, which is likely, this will be an undesirable feature of using slots as a standard.

Because of the varying slot widths, a standard can be made for any size transducer. If the width of the slots goes above the width of the transducer crystal, the standard could be used to measure the beam spread of a transducer.

From the theoretical curve, it was noticed that the curve became more non-linear as the frequency of the transducer decreased. If the slots were to be used as a standard, a standard curve would have to be drawn for each frequency. Although the curves were all constantly decreasing with the slot width, the decrease was not the same for each frequency.

It has been stated that a standard should be used for specifying flaw tolerances, for comparing transducers and test machines, and to check wear or stability of transducers. The question is how the standard developed can be used to perform these tasks.

Probably the main use of the standard would be to set the reject level on the instrument. Once the maximum size flaw permissible is stated, the standard slot corresponding to this size flaw would be found and, with the instrument receiving the indication from that slot, the reject level could be set. Any part, in which a flaw gave an indication equal to the standards indication, would be rejected. If at any time the operator wanted to check his instrument it would be a simple matter to check the instrument on the standard slot.

The slots can be used to compare transducers by measuring the beam width, by measuring the sensitivity and resolution, and by testing the signal to noise ratio. For comparing test instruments, they could be used to test the linearity of the receiver amplifier, to test the linearity of the controls, and to check the signal to noise ratio using the same transducer on different instruments.

To check the wear or stability of a transducer, the new transducer would be tested on a specific instrument and a standard slot. The control settings of the instrument and the test slot would be recorded. If at any time the transducer was suspected of being defective because of wear or loss of resolution power, it would be checked using the data previously taken on it. The same type of test could be done on a testing instrument. In general it seems that a standard of varying size slots is promising. There are a few problems, however, that need to be solved.

Recommendations

It is felt that several of the problems not solved by this research should be analyzed and solved in the future. These problems are as follows: (1) How can the maximum indication procedure be improved? (2) How can the standard be applied for very small flaw sizes? (3) Can another type of standard be developed that will be superior to the theory behind the slots?

In solving the maximum indication procedure, the actual causes of the problem must be found. Perhaps a jig could be made to clamp the transducer at the correct angle and would also provide a control for moving from slot to slot. Also, the dependence of the indication on the oil film thickness under the transducer should be studied.

For very small flaws, the slots may prove to be unsatisfactory. An experimental and theoretical study should be made on slots of very small widths. Perhaps the use of very small holes as the reflectors will prove to be satisfactory for small flaws.

Since it seems that the radiation pattern effect is a main factor in analyzing a standard, it would be advantageous to develop a standard which would give the same indication independent of frequency. This would be very useful for transducers of different frequencies. It would also be advantageous to develop a standard which would not depend on different size reflectors. This would greatly reduce the maximum indication problem. One way of doing this would be to change the impedance match at the interface instead of changing the size of the reflector. By using a plane interface of greater widths than the transducer beam width being used, and by changing the interface from steel to air, which causes one hundred percent reflection, to something between the air and steel, the indications received would be independent of frequency and reflector width. By using several materials at the reflecting boundary, the desired type of curve could be achieved.

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