CLASSROOM TRAINING HANDBOOK - ULTRASONIC TESTING

Prepared under Contract NAS 8-20185 by

Convair Division
General Dynamics Corporation
San Diego, Calif.

for George C. Marshall Space Flight Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GPO PRICE $ _____

CFSTI PRICE(S) $ _____

Hard copy (HC) ___*3,00*___

Microfiche (MF) ___*.65*___

ff 653 July 65

CLASSROOM TRAINING HANDBOOK - ULTRASONIC TESTING

PREFACE

Classroom Training Handbook - Ultrasonic Testing (5330.18) is one of a series of training handbooks designed for use in the classroom and practical exercise portions of Nondestructive Testing. It is intended that this handbook be used in the instruction of those persons who have successfully completed Programmed Instruction Handbook - Ultrasonic Testing (5330.13, Vols. I-III).

Although formal classroom training is not scheduled at the present time, this handbook contains material that is beneficial to personnel engaged in Nondestructive Testing.

NASA's programs involve tightly scheduled procurement of only small quantities of space vehicles and ground support equipment, requiring the extreme in reliability for the first as well as later models. The failure of one article could result in mission failure. This requirement for complete reliability necessitates a thoroughly disciplined approach to Nondestructive Testing.

A major share of the responsibility for assuring such high levels of reliability lies with NASA, other Government agencies, and contractor Nondestructive Testing personnel. These are the people who conduct or monitor the tests that ultimately confirm or reject each piece of hardware before it is committed to its mission. There is no room for error -- no chance for reexamination. The decision must be right -- unquestionably -- the first time.

General technical questions concerning this publication should be referred to the George C. Marshall Space Flight Center, Quality and Reliability Assurance Laboratory, Huntsville, Alabama 35812.

The recipient of this handbook is encouraged to submit recommendations for updating and comments for correction of errors in this initial compilation to George C. Marshall Space Flight Center, Quality and Reliability Assurance Laboratory (R-QUAL-OT), Huntsville, Alabama 35812.

ACKNOWLEDGMENTS

CLASSROOM TRAINING MANUAL
ULTRASONIC TESTING

CHAPTER 1: INTRODUCTION
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CHAPTER 1: INTRODUCTION

100 GENERAL

The complexity and expense of space programs dictate fabrication and testing procedures that ensure reliability of space vehicles and associated ground support equipment. Nondestructive testing (testing without destroying) provides many of these procedures. Of the number of nondestructive test procedures available, ultrasonic testing, with which this handbook is concerned, is widely used.

101 PURPOSE

The purpose of this handbook is to provide the fundamental knowledge of ultrasonic testing required by quality assurance and test personnel to enable them to: ascertain that the proper test technique, or combination of techniques, is used to assure the quality of the finished product; interpret, evaluate, and make a sound decision as to the results of the test; and recognize those areas of doubtful test results that require either retest or assistance in interpretation and evaluation.

102 DESCRIPTION OF CONTENTS

1. ARRANGEMENT

The material contained in this handbook is presented in a logical sequence and consists of:

a.	Chapter 1:	Introduction and testing philosophy
b.	Chapter 2:	Ultrasonic testing principles with description of procedures, applications and capabilities
c.	Chapter 3:	Equipment
d.	Chapter 4:	Testing techniques
e.	Chapter 5:	Calibrating testing units
f.	Chapter 6:	Calibrating transducers
g.	Chapter 7:	Comparison and selection of NDT processes

2. LOCATORS

The first page of each chapter consists of a table of contents for the chapter. Major paragraphs, figures, and tables are listed in each table of contents.

103 INDUSTRIAL APPLICATIONS OF ULTRASONIC TESTING

Because of the basic characteristics of ultrasonic testing, it is used to test a variety of both metallic and nonmetallic products such as welds, forgings, castings, sheet, tubing, plastics, and ceramics, etc. Since ultrasonic testing is capable of economically revealing subsurface discontinuities (variations in material composition) in a variety of dissimilar materials, it is one of the most effective tools available to quality assurance personnel.

104 TESTING PHILOSOPHY

The basic reason for use of nondestructive testing is to assure maximum reliability of space and associated ground support hardware, fabricated of many materials. To accomplish such reliability, standards have been set and test results must meet these NASA standards.

105 PERSONNEL

It is imperative that personnel responsible for ultrasonic testing be trained and highly qualified with a technical understanding of the test equipment and materials, the item under test (specimen), and the test procedures. Quality assurance personnel must be equally qualified. To make optimum use of ultrasonic testing, personnel conducting tests must continually keep abreast of new developments. There is no substitute for knowledge.

106 TESTING CRITERIA

When required by appropriate documentation, every vehicle and support article must be tested using applicable Nondestructive Testing techniques. The criteria is part of a building block test philosophy which dictates that each item must be tested individually before they are required to perform in assemblies, and sub-assemblies are tested individually before they are required to perform in assemblies. Using this approach, unsatisfactory and faulty articles are discovered at the earliest possible time, resulting in higher system reliability and reduced cost.

107 TEST PROCEDURES

Approved procedures for ultrasonic testing are formulated from analysis of the test specimen, review of past history, experience on like or similar specimens, and information available concerning similar specimen discontinuities. It is the responsibility of personnel conducting or checking tests to ensure that test procedures are adequately performed, and that the test objective is accomplished. Procedures found to be incorrect or inadequate must be brought to the attention of responsible supervision for correction and incorporation into revised procedure.

108   TEST OBJECTIVE

1.   The objective of ultrasonic testing is to ensure product reliability by providing a means of:

   a.   Obtaining a visual recorded image related to a discontinuity in the specimen under test.

   b.   Disclosing the nature of the discontinuity without impairing the material.

   c.   Separating acceptable and unacceptable material in accordance with predetermined standards.

2.   No test is successfully completed until an evaluation of the test results is made. Evaluation of test procedures and results requires understanding of the test objective.

CHAPTER 2: PRINCIPLES
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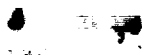# TABLE OF CONTENTS (CONT)

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CHAPTER 2: PRINCIPLES

200 GENERAL

Ultrasonics may be defined as sound with a pitch too high to be detected by the human ear. Normal adults may hear notes of frequencies higher than 16,000 cycles per second (16 Kc), which is about six octaves above middle C, up to about 20,000 cycles per second (20 Kc). The term supersonic is used to describe speeds greater than the speed of sound in air, and is never used as a synonym for ultrasonic. In ultrasonic testing, frequencies of 200 thousand to 25 million cycles per second are commonly used.

201 ENERGY MOTION

Sound is produced by a vibrating body. The pitch of the resultant note is determined by its frequency (F) or the number of complete vibrations or cycles completed in one second. Particles, making up the medium, oscillate about their fixed mean positions when sound travels through a medium. The actual particles do not travel in a direction away from the source. It is the energy, which moves the particles slightly in each wave, that is moving progressively.

202 WAVEFORMS

If sound waves are measured from trough to trough or from crest to crest, the distance is always the same and it is known as the wavelength (λ). The time taken for the wave to travel a distance of one complete wavelength, λ, is the same amount of time for the source to execute one complete vibration. The velocity of sound (V) is given by the equation:

$$V = \lambda F$$

Several types of waves are possible with sound energy traveling through solid matter. These are longitudinal, or compression, waves where the particle vibrations are in the same direction as the motion of the sound; and shear, or transverse, waves where the particle vibrations are in a direction at right angles to the motion of the sound. It is possible, within certain limits, to produce shear waves along the free boundary or surface of a solid so that it ripples across the surface to a depth of only a few particles. These are known as surface or Rayleigh (pronounced "ray'lee") waves. The shortest ultrasonic wavelengths are of the order of magnitude of the wavelength of visible light. For this reason, ultrasonic wave vibrations possess properties very similar to those of light waves, i.e., they may be reflected, focused, or refracted. High-frequency particle vibrations or sound waves are propagated in homogeneous solid objects in the same manner as directed, bundled light beams, with very little absorption. At any surface acting as a boundary between the object and an interface with a gas, liquid, or another type of solid, these soundbeams are almost completely

reflected. As with echo-sounding in sonar applications, the ultrasonic pulses echo from discontinuities, enabling detection of their presence and location. Ultrasonic vibrations, in liquids or gases, are propagated in the longitudinal mode only because of the absence of shear rigidity. Longitudinal, shear, and surface wave modes are possible in solids.

203 EARLY SONIC TESTS

For centuries, men tested parts by hitting them with a mallet and listening for a tonal quality difference. Around the turn of this century, railroad men inspected parts by applying kerosene to the part and covering it with a second coat of whiting. Then they struck the part with a mallet. In areas where the whiting looked wet, the part was assumed to be cracked. In the early 1940's, Dr. F. A. Firestone developed the first pulse-echo instrument for detecting deep-seated flaws. The establishment of basic standards and the first practical immersion testing system is credited to W. C. Hitt and D. C. Erdman.

204 WAVE GENERATION

When a tuning fork is struck with a mallet, it vibrates and produces sound waves by compressing the air. These waves travel through air to the ear of the listener as shown in Figure 2-1. The tuning fork vibrations soon die out and no longer produce

MALLET

STRONGER
WAVE

WEAKER
WAVE

LISTENER
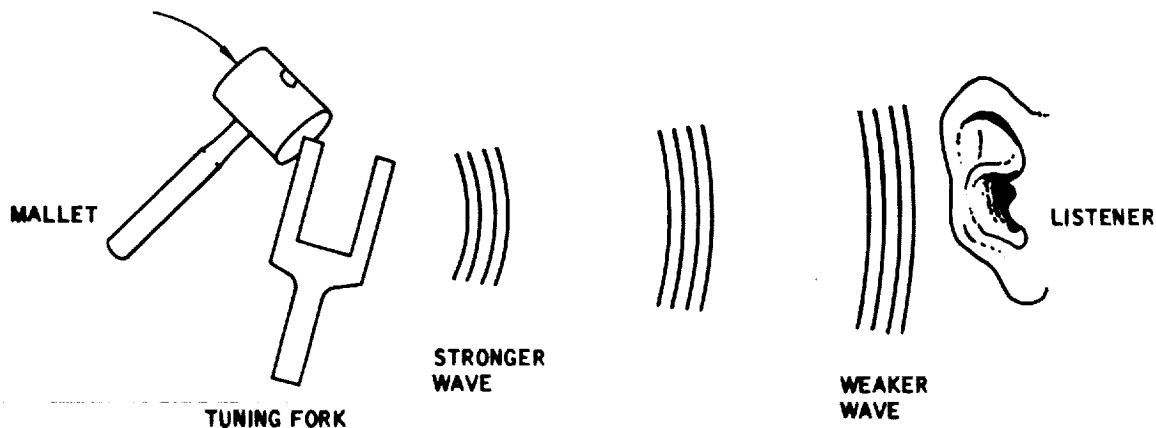
TUNING FORK

Figure 2-1. Sound Wave Generation

waves. Similarily, in ultrasonic testing, a short pulse of electrical current hits or excites a transducer (crystal) which vibrates as did the tuning fork. The soundbeam from the transducer then travels through a couplant, which may be water, oil, etc., to the front surface of the test piece. Figure 2-2 shows the transducer, in contact with the test piece, with the soundbeam pulses traveling through the piece.
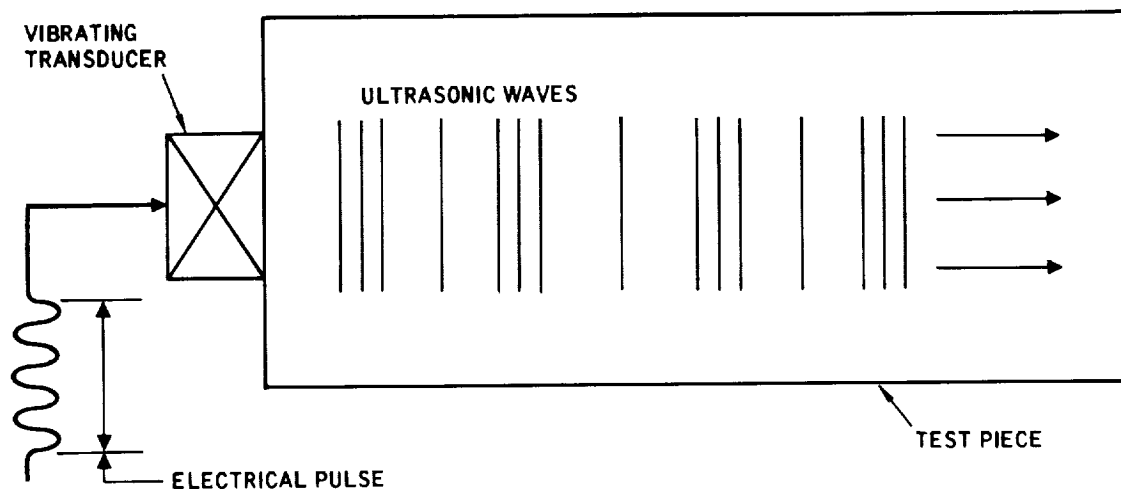
Figure 2-2. Ultrasonic Wave Generation

205 PIEZOELECTRICITY

In actual practice, a high-frequency transmitter applies electrical pulses to a "piezo-electric" crystal. The prefix "piezo" is derived from a Greek word meaning "to press." The first two syllables should be pronounced like the words "pie" and "ease." Piezoelectricity refers to a reversible phenomenon whereby a crystal, when vibrated, produces an electric current, or conversely, when an electric current is applied to the crystal, the crystal vibrates. This crystal then transforms the electric energy into mechanical vibrations and transmits them through a coupling medium, such as water or oil, into the test material. These pulsed vibrations propagate through the object with a speed depending on, among other factors, the density and elasticity of the test material.

206 SOUNDBEAM REFLECTION

In many ways, high-frequency vibrations react in the same way as light. For example, when they strike an interrupting object, they reflect most of the soundbeam energy. These reflections may then be picked up by a second, or, in most cases, by the same crystal or transducer. Within the crystal, they are transformed into electrical energy again, amplified, and presented as a vertical deflection of a horizontal trace or base line on a cathode ray tube (CRT) or oscilloscope. This type of presentation is called the "A-Scan." Ultrasonics does not give direct information about the exact nature of the reflection. This is deduced from several factors, the most important being a knowledge of the test piece material and its construction. Ultrasonic waves are reflected as echoes from both the discontinuity and the back surface of the test piece. The echo from the discontinuity is received before the back reflection is received. Figure 2-3 shows that the time required for the soundbeam to travel through the test
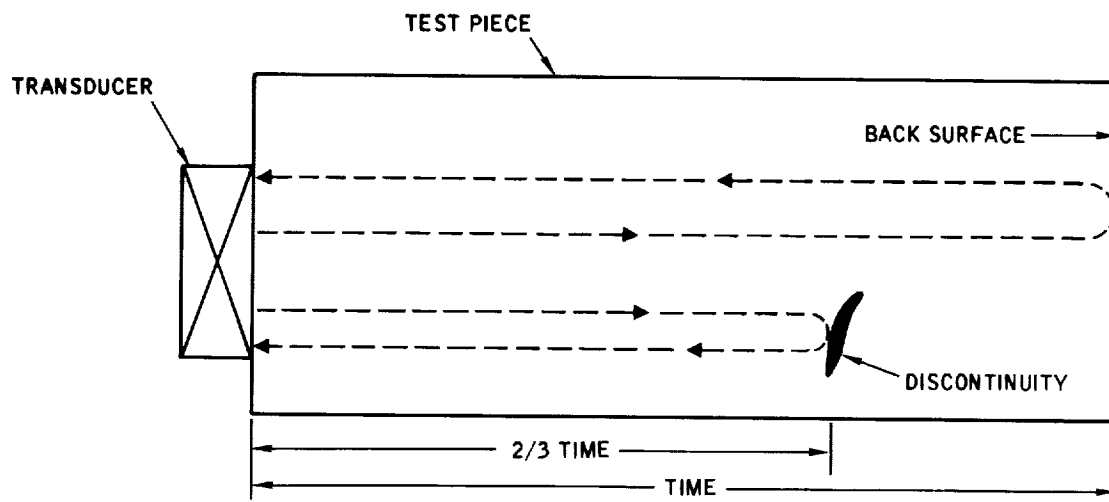
Figure 2-3. Soundbeam Reflection

piece to the discontinuity and back is only 2/3rds of the time and distance for the soundbeam to reach to the back surface and return.

207 TIME/DISTANCE RELATIONSHIP

The one-way distance for the soundbeam waves to travel to a reflecting surface can be measured on the CRT or oscilloscope screen, as shown in Figure 2-4. The initial pulse or main bang and the echo (soundbeam traveling through water in this illustration) from the reflecting surface produce two sharp rises or indications (usually called pips) from the horizontal trace or base line on the oscilloscope screen. The precise instant that the main bang occurs, the initial pulse appears on the left side of the screen. The longer the time before an echo is received, the farther the echo from a discontinuity or interface appears to the right on the screen.

As mentioned earlier, time and distance measurements are related. In later discussion, it will be seen that the oscilloscope screen base line may be adjusted to match the number of units involved in one-way distance (as shown).

208 OSCILLOSCOPE DISPLAY

Figure 2-5 shows a typical ultrasonic contact test setup and the resulting display on the oscilloscope screen. Notice the position of the displayed indications or pips on the screen in relation to the actual positions of the test piece front surface, discontinuity, and back surface.

In the above illumination, the indications on the oscilloscope screen were adjusted to superimpose the initial pulse or front surface pip on the grid marked "0" and the back surface pip on the grid marked "4." The discontinuity, without adjustment, appeared just to the right of the grid marked "1." These adjustments were accom-

TIME →

INITIAL
PULSE

FRONT
SURFACE
OF PLATE
(ECHO)

0   1   2
(UNITS)

OSCILLOSCOPE SCREEN

TRANSDUCER

WATER

ROUND TRIP
TIME (4 UNITS)

1

PLATE   2

IMMERSED REFLECTOR PLATE
IN GLASS BEAKER
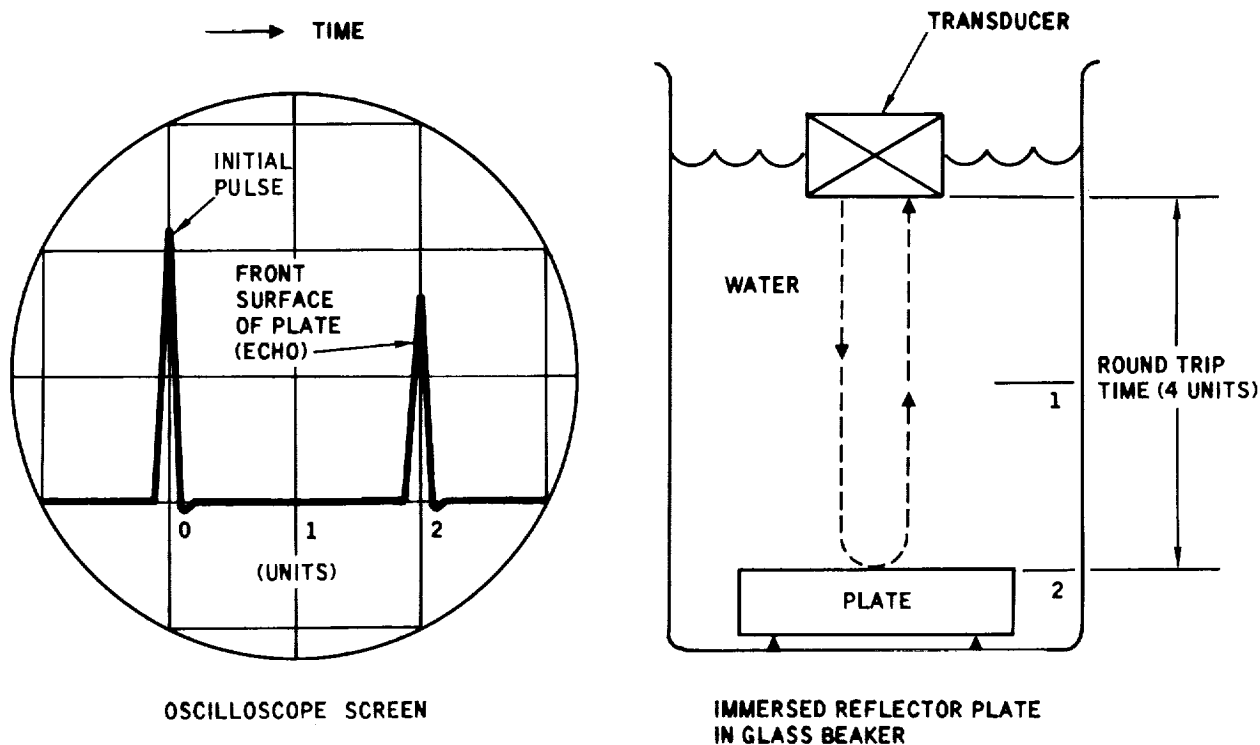
Figure 2-4.   Time/Distance Measuring

TIME →

FRONT
SURFACE
(INITIAL
PULSE)

BACK
SURFACE

DISCONTINUITY

0   1   2   3   4

OSCILLOSCOPE SCREEN

INCH SCALE

0   1   2   3   4

TEST SPECIMEN

FRONT SURFACE

DISCONTINUITY

BACK
SURFACE

TRANSDUCER

(DISCONTINUITY LOCATED ABOUT
1-1/4 INCHES WITHIN PART)
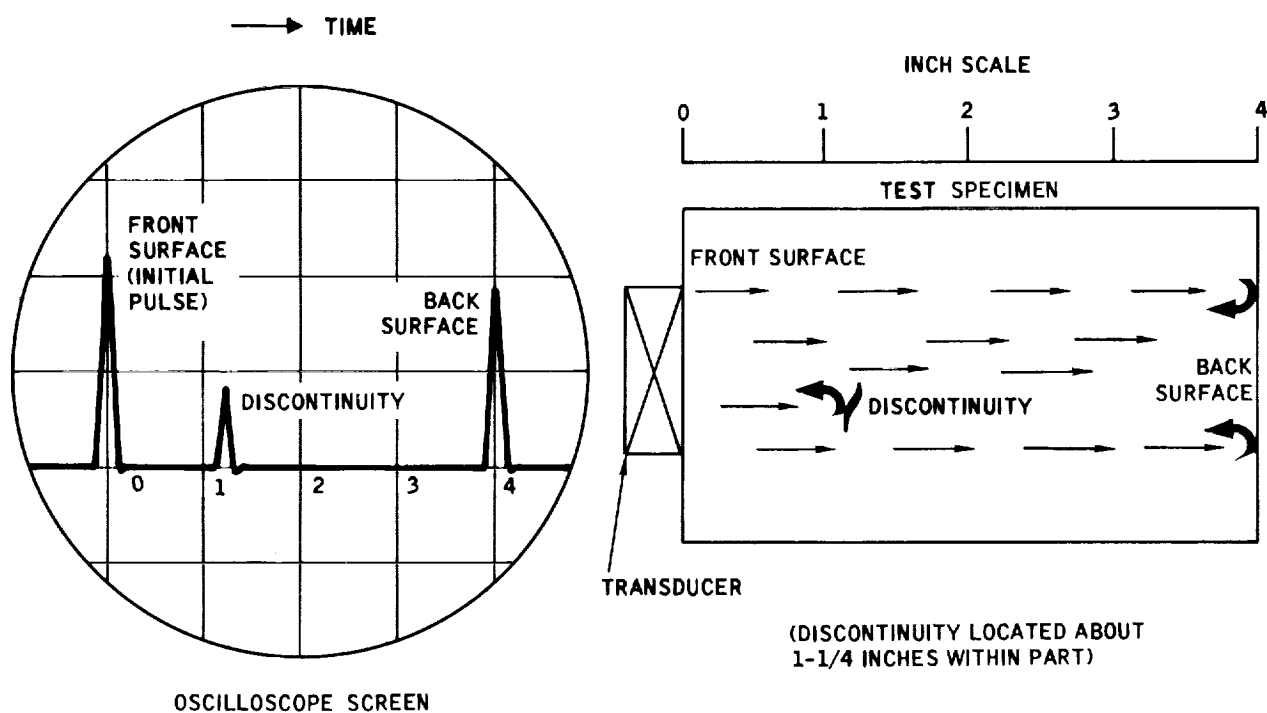
Figure 2-5.   Typical Ultrasonic Contact Test Display

2-9

plished by varying two controls on the instrument, the SWEEP DELAY and the SWEEP LENGTH or RANGE.

209   OSCILLOSCOPE OPERATION

1.   GENERAL

The oscilloscope displays ultrasonic indications on a cathode ray tube (CRT) which is similar to a television picture tube. Figure 2-6 shows a typical cathode ray tube and its electron gun. This electronic tube or bottle comes in many sizes and shapes. It is made of specially-tested glass, constructed with a screen at one end for the picture display. The screen is coated with a material called a phosphor compound. Phosphor compounds vary in composition to produce various brightness, colors, and time persistence. A phosphor glows and produces light when bombarded by high-speed electrons directed at the screen from the electron gun in the base of the tube. The operation may be considered similar to writing on a sheet of glass with a water spray nozzle. The phosphor emits light for a definite time period, its persistence is predetermined, and then ceases to glow. At the opposite end of the tube, electrons are produced behind the screen in the electron gun. The electrons are emitted from a hot filament, similar to the filament in an ordinary light bulb. By electromagnetic means, these electrons are accelerated and bunched to form a beam which is the size of a pin-
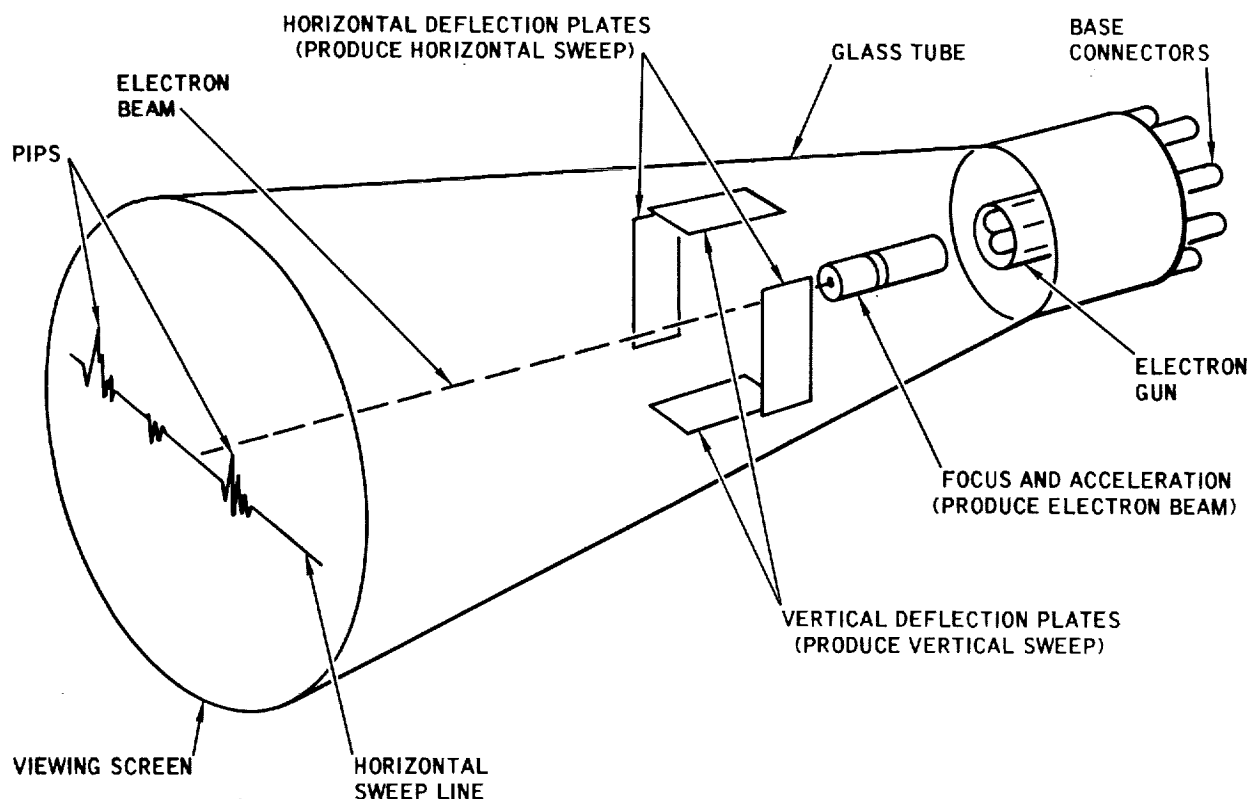
Figure 2-6.   Typical Cathode-Ray Tube

head when it strikes the phosphor screen. The position of the spot on the screen is altered by changing the direction, like pointing a garden hose, of the electron beam. In ultrasonic testing, the oscilloscope screen usually shows a bright horizontal line when there is no signal received. This horizontal line is called the sweep or base line. An electronic circuit causes the electron beam to sweep from the left edge of the screen to the right edge at a certain fixed speed. As soon as the beam reaches the right edge, it is caused to return to the left edge at a very high speed, too fast to be seen on the screen. In operation, an electron beam draws a line of light across the screen. The line length is a measure of the time required to move from left to right. Distance may be determined when time and speed are known. The distance along the line represents the time since zero time, and this time multiplied by speed equals distance from zero. When the speed is known, the horizontal sweep may be adjusted to represent distance. When a signal is relayed to the oscilloscope from the transducer, a voltage is applied to the vertical deflection plates, causing a pip to appear on the line. When the transducer relays signals reflected from the test piece front and back surfaces, the front surface pip appears first and the back surface pip appears some time later in the sweep. The spacing between these pips is a measure of the distance between the surfaces.

2. SWEEP DELAY

The SWEEP DELAY control of the instrument permits the base line, and the indications on it, to be shifted either to the right or to the left side, while the spacing between the indications remains constant. Figure 2-7 shows how the SWEEP DELAY control is used, to allow the operator to shift the base line to the right or left in order to see the indications related to the material under test (see Figure 2-5 for test setup).

In Figure 2-7, the operator first picked up the front surface pip (which is also the initial pulse) and the discontinuity pip. In adjusting the SWEEP DELAY, the front surface pip is moved to the far left, bringing the discontinuity and back surface pips into view. Notice that the distance between the first two pips has not changed.

3. SWEEP LENGTH

Now that the operator has adjusted the sweep delay, the SWEEP LENGTH or RANGE adjustment must be considered. The operator may wish to superimpose the front and back surface pips on the oscilloscope grid lines so that the distance relationship on the screen is related to the actual measurements of the test piece. To do this, the horizontal trace or base line is expanded, or contracted, to change the distance between the pips displayed. The locations of the discontinuity pip, in relation to the front and back surface pips, always has the same relationship, in proportion, in the test piece.

 a. The expansion or contraction of the base line is away from or toward the left side of the screen. That is, if the sweep delay is set so that the start of the presentation desired is at the left side of the screen, adjustment of the

TIME   TIME

OSCILLOSCOPE SCREEN

FRONT
SURFACE

0   1   2   3   4

FRONT
SURFACE

BACK
SURFACE

0   1   2   3   4

DISCONTINUITY

BEFORE ADJUSTING   AFTER ADJUSTING
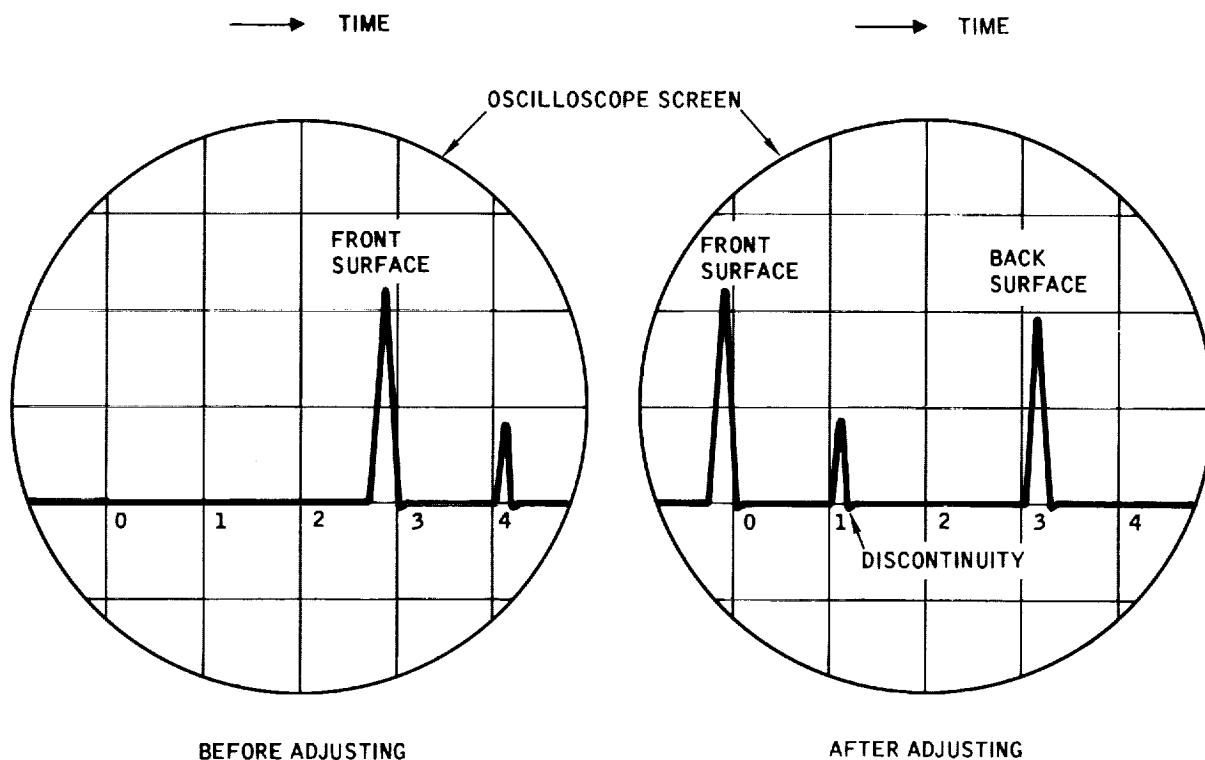
Figure 2-7. Sweep Delay Adjustment

SWEEP LENGTH moves the right-hand pips away from or toward the left-hand pip which appears to remain stationary. The sweep delay control also makes it possible to view the responses from the test piece in any desired segment of the total depth. In effect, the delay control allows the viewing screen to be moved along the depth of the part. In conjunction with the SWEEP LENGTH control, the sweep delay makes it possible to examine a magnified segment of the part depth with the segment across the entire width of the CRT screen.

b.   In Figure 2-8, the SWEEP LENGTH is adjusted to expand the view of the entire part depth across the screen and to align the pips with the screen grids.

c.   Two controls, the SWEEP DELAY and the SWEEP LENGTH regulate how much of the test part is presented at one time on the screen and what portion, if not the whole, of the part is presented.

4.   RANGE MARKERS

In the previous example, the grid lines on the oscilloscope screen were used to aid in locating the position of discontinuities. Figure 2-9 shows Range Markers, which are

OSCILLOSCOPE SCREEN

FRONT SURFACE   BACK SURFACE

0   1   2   3   4

FRONT SURFACE   BACK SURFACE

0   1   2   3   4

BEFORE ADJUSTING   AFTER ADJUSTING
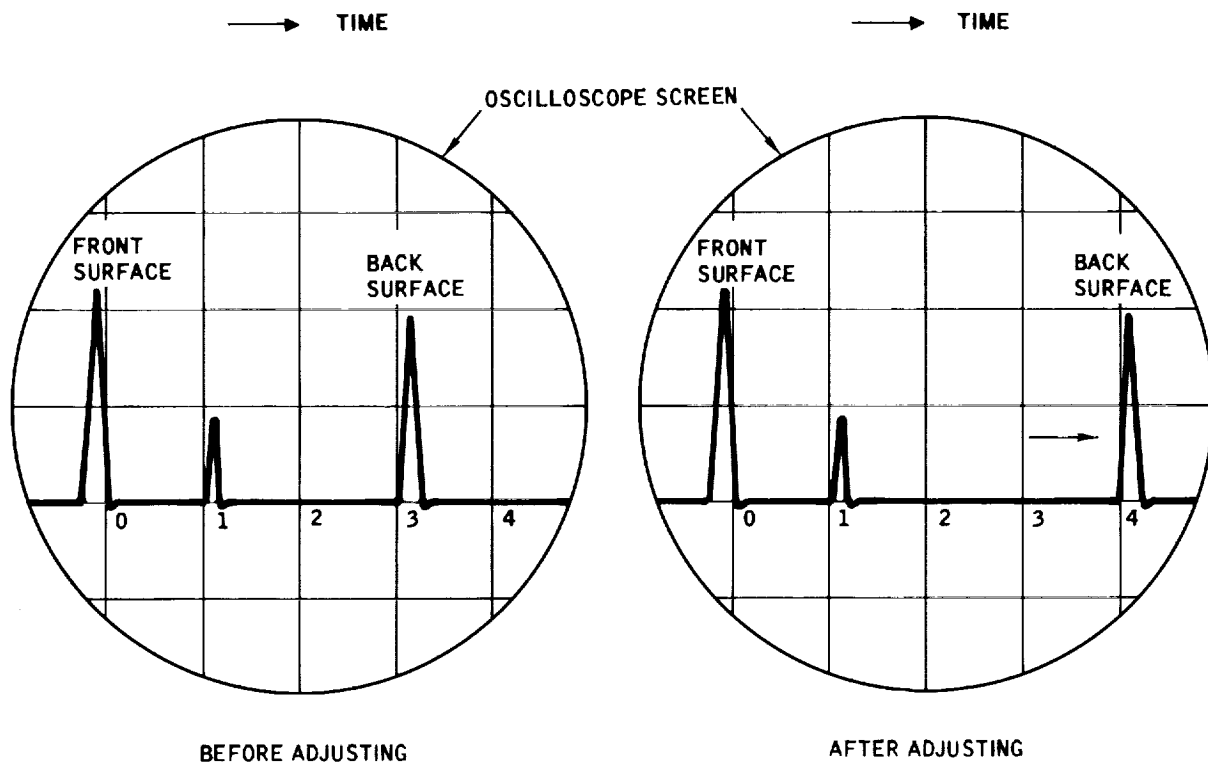
Figure 2-8. Sweep Length Adjustment

set into the display just under the base line to aid in immediately identifying the location of any discontinuity within the part. These markers are expanded or contracted to fit the space between the front surface pip and the first back reflection pip, dividing the space into convenient increments, such as centimeters, inches, feet, etc. The Range Markers are controlled by the RANGE MARKER switch (for on-off function) and the MARKER adjustment knob. The MARKER control knob permits selection of the marker frequency. The higher the frequency, the closer the spacing of square waves and the more accurate the measurements. Assuming the part is known to be 11 inches from the front surface to the back surface, in the example shown in Figure 2-9, the discontinuity is located at a depth of approximately 5 inches, as determined by the range markers.

5. SUMMARY

Actually, the first adjustments made, after the instrument is turned on and allowed to warm up, concern: scale illumination, sweep line intensity, focus, horizontal centering, and vertical centering. The power ON switch usually contains a control for the brightness of the scale scribed on the CRT screen. This brightness is considered a matter of personal choice. The intensity control determines the brightness of the spot moving across the screen to form the sweep line. Sweep line intensity is kept at a

(SET WITH 11 SPACES FROM
FRONT TO BACK SURFACE PIPS)
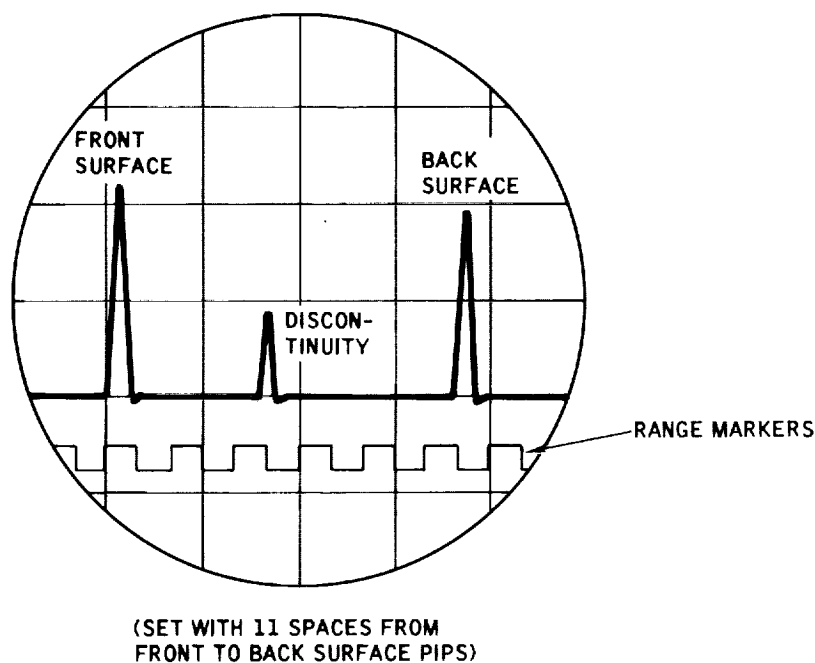
Figure 2-9. Range Markers

minimum with no bright spot at the left end. The astigmatism and focus controls adjust the sharpness of the screen presentation. The horizontal centering control determines the starting point of the sweep line on the CRT screen, usually set to place the sweep line start at the left edge of the screen. The vertical centering control raises and lowers the sweep line or base line on the CRT screen to coincide with the desired scale line on the screen. Usually, the base line is aligned with the zero scale line. The exact "how to" operate and adjust the many controls of various ultrasonic instruments are learned from the operation and maintenance manual for the individual instrument. The precise capabilities of each instrument comes from the same source. A simplified, block diagram of a typical pulse-echo ultrasonic testing instrument is shown in Figure 2-10. The illustration shows that the timer or rate generator is the heart of the system. In contact testing, as shown, the front surface pip and the initial pulse or main bang are identical. The transducer is spiked by an electrical pulse that is also routed to the receiver-amplifier. In immersion testing, the initial pulse and the front surface pips are separated by the water travel distance to the test piece.

210 SOUNDBEAM FREQUENCIES

Most ultrasonic units have frequencies available in a range from 200 Kc to 25 Mc. These vibrations are far beyond the audible range, but still propagate in the test

OSCILLOSCOPE SCREEN

RECEIVER AMPLIFIER CIRCUIT

SWEEP CIRCUIT

PULSER CIRCUIT

MARKER CIRCUIT

TIMER (RATE GENERATOR)

TRANSDUCER

POWER SUPPLY

(TO EACH CIRCUIT)

TEST PIECE

Figure 2-10. Pulse-Echo Unit, Block Diagram

material as waves of particle vibrations. Soundbeams of all frequencies penetrate fine-grained material. When using high frequencies in coarse-grained material, interference in the form of scattering may be expected. Greater depth of penetration may be achieved by using lower frequencies. Selection of test frequency is governed by the nature of the particular problem. Ultrasonic beams with low frequencies, up to about 1 Mc, readily penetrate the test material, because of the small amount of attenuation. They are also scattered less by a coarse structure and can be used when the surface is rough. On the debit side, their angle of divergence is large, making it difficult to resolve small flaws. High-frequency transducers emit a more concentrated beam with 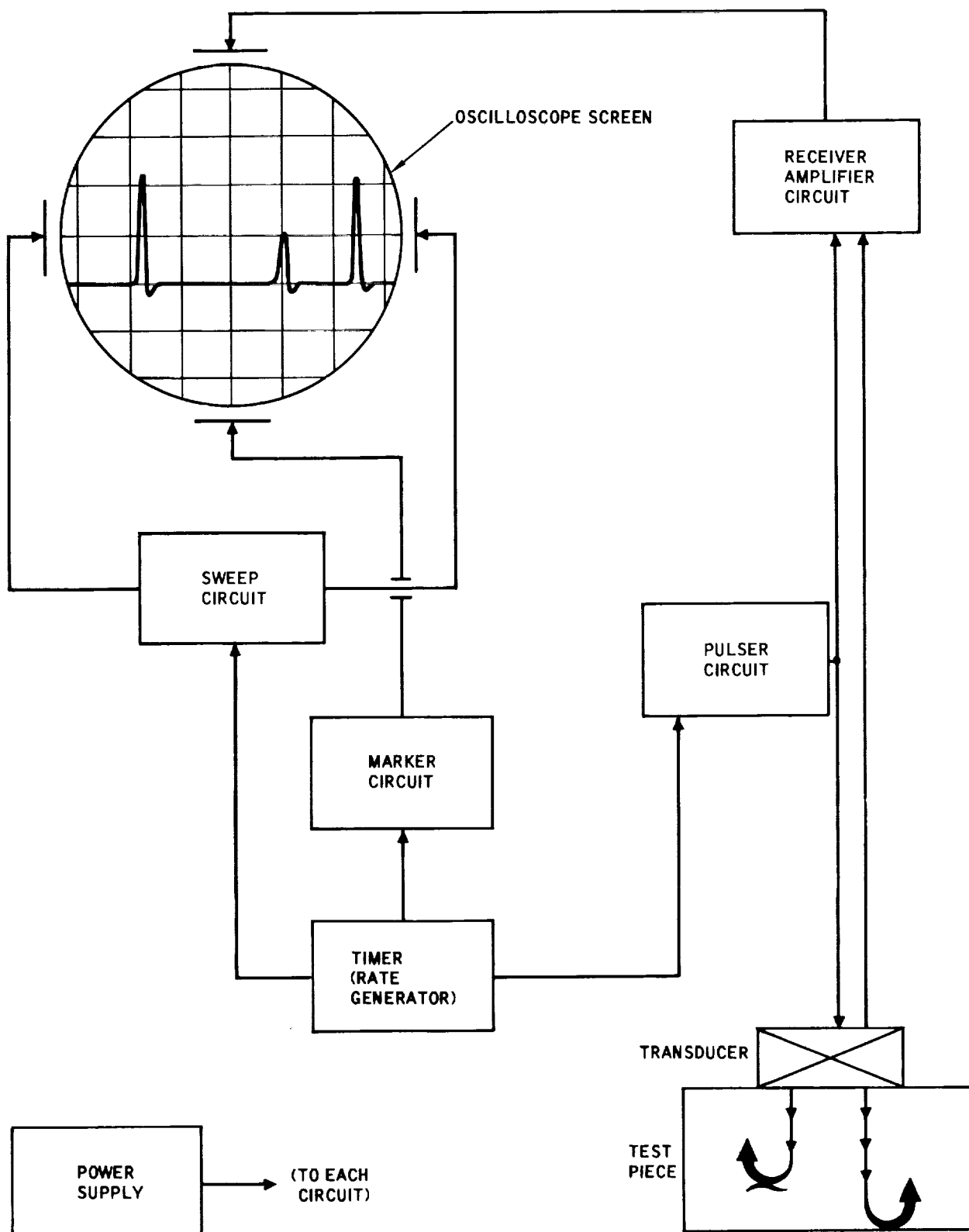a better resolving power. A disadvantage is that higher-frequency soundbeams are scattered more by coarse-grained material. All available frequencies may be used in immersion testing. Frequencies above 10 Mc are not generally used in contact testing, because of the fragility of the thinner high-frequency transducers. As the frequency of sound vibrations increase, the wavelength correspondingly decreases and approaches the dimensions of the molecular or atomic structure.

211 SOUNDBEAM VELOCITIES

Ultrasonic waves travel through solids and liquids at relatively high speeds, but are rapidly attenuated or die out in gases. The velocity of a specific mode, for example, longitudinal, is a constant through a given homogeneous material. The speeds of vibrational waves through various materials related to ultrasonic testing are listed by most authorities in centimeters per second x 100,000 (cm/sec x 10^5) or inches per second x 100,000 (ips x 10^5). For convenience, velocities are given in this manual in centimeters per microsecond (cm/μ sec). In Table 2-1, a meaningful comparison is given to illustrate the wide range of velocities. These differences in velocity are due, largely, to differences in the density and elasticity in each material, among other

Table 2-1. Ultrasonic Velocity Differences

MATERIAL	DENSITY (G/CM^3)	VELOCITY (LONGITUDINAL)	
		CM/μ SEC	MPH
AIR	0.001	.033	738
WATER	1.000	.149	3,333
PLASTIC (ACRYLIC)	1.180	.267	5,972
ALUMINUM	2.800	.625	13,981
BERYLLIUM	1.820	1.280	28,633

factors. Density alone cannot account for the extremely high velocity in beryllium, which is less dense than aluminum. The acoustic velocity of water and mercury are almost identical, yet mercury is thirteen times as dense as water.

212   WAVE TRAVEL MODES

1.   GENERAL

All materials are made up of atoms (or tiny particles) lined up in straight lines to form lattices, as shown in Figure 2-11. If we strike the side of this lattice, we find that the first column of atoms strikes the second column, which in turn strikes the third column, and so on, in sequence. This motion produces a wave movement in the direction shown. In this case, the particle-movement direction is the same as the wave-movement direction. This type of soundwave motion is called the longitudinal, or compression, wave mode.

2.   COMPARISON OF LONGITUDINAL & SHEAR WAVE MODES

Figure 2-12 shows two transducers generating ultrasonic waves in the same piece. Note that the transducer on the left is producing longitudinal waves and that the transducer on the right is producing a different kind of wave. These waves are called shear waves because the particle-movement direction is at right angles to the wave-

TRANSDUCER

WAVE DIRECTION

WAVE FRONT
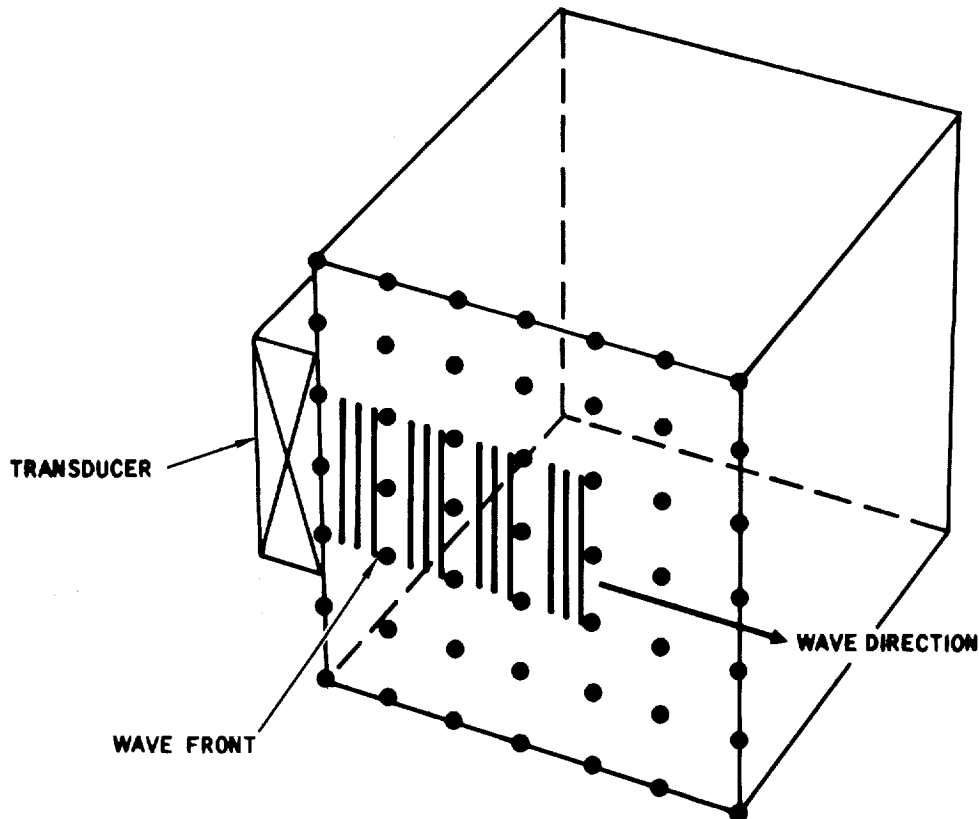
Figure 2-11. Longitudinal Wave Mode
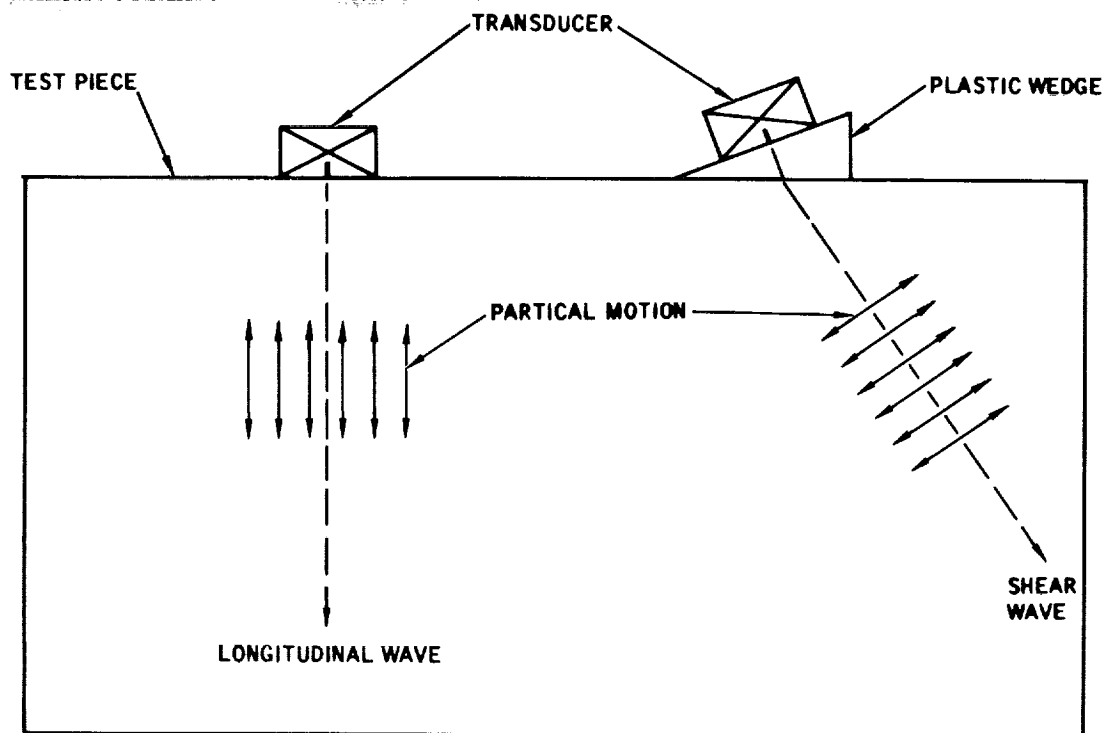
Figure 2-12. Longitudinal & Shear Wave Modes Compared

movement direction. The velocity of shear waves is approximately half that of the longitudinal waves. Note also, that the right-hand transducer is mounted on a plastic wedge so that the ultrasonic waves generated by the crystal enter the material at a specific angle, depending on the velocity of soundbeam travel within the material.

3. SHEAR AND SURFACE WAVES

Shear waves are, in a sense, polarized as the particle displacements are oriented in a plane normal to the direction of propagation. A special type of shear wave is generated in a thin layer of particles on the free boundary of a solid. These surface waves are called Rayleigh (pronounced "ray'lee") waves, and propagate with a velocity about 2 per cent less than shear waves. As shown in Figure 2-13, when a transducer is mounted on a steeply-angled plastic wedge, the longitudinal beam in the wedge strikes the test surface at an angle resulting in a surface mode of sound travel in the test specimen. As shown, a surface wave travels around a curve, reflection occurring only at a sharp corner. The contact transducers that produce shear waves and surface waves are called angle-beam transducers.
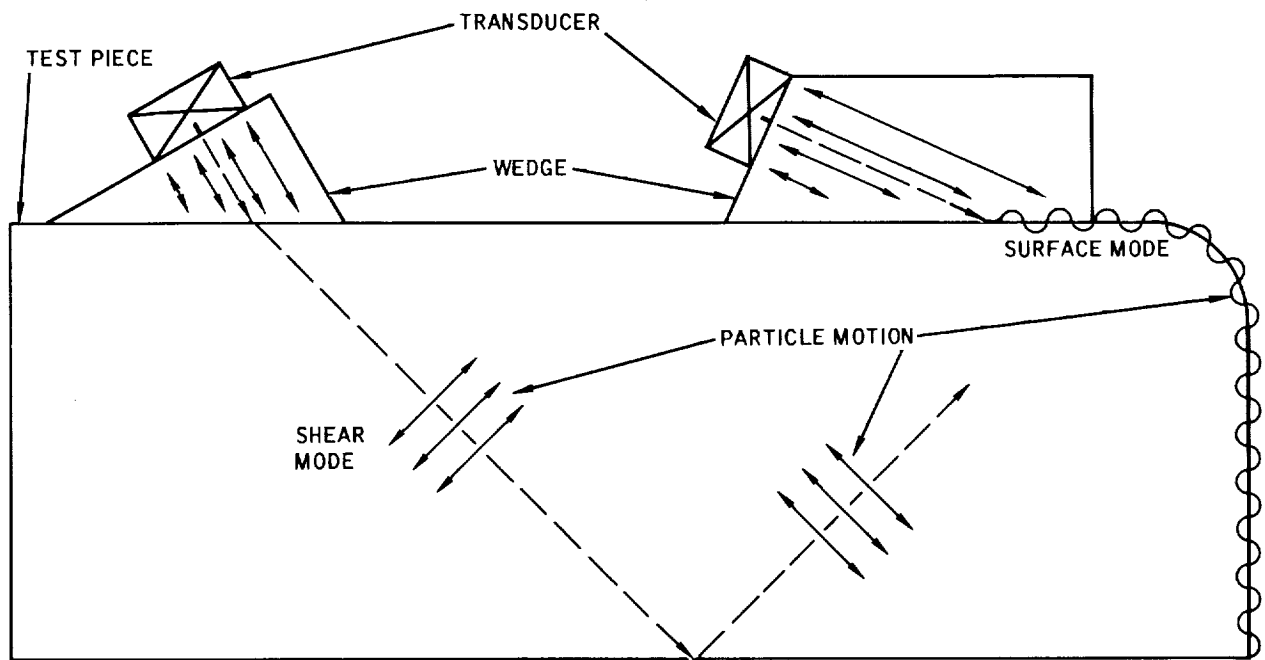
NOTE THAT BEAMS ARE IN THE LONGITUDINAL
MODE IN EACH WEDGE. MODE CONVERSION
OCCURS WHEN THE SOUNDBEAM ENTERS THE
TEST MATERIAL.

Figure 2-13. Mode Conversion

4. TRANSDUCER BEAM ANGLES

Confusion may be encountered when angle-beam transducers, designed to produce a
specific refracted angle in cold-rolled steel, for example, are applied to other mate-
rials with acoustic velocities different from that of steel. A transducer designed to
produce a shear-wave beam at 45° in steel, will produce a beam at 43° in aluminum,
or 30° in copper.

213 REFRACTION AND MODE CONVERSION

1. GENERAL

Refraction and mode conversion of the ultrasonic beam when passing at an angle from
one material to another is comparable to the refraction of light beams when passing
from one medium to another. The entire range of this phenomena is covered in the
following description. When a longitudinal (L) wave soundbeam is incident to the test
specimen in the normal (perpendicular) direction, it is transmitted through the first
and second medium, as shown in Figure 2-14, as a 100-per cent longitudinal beam,
and no refraction occurs.
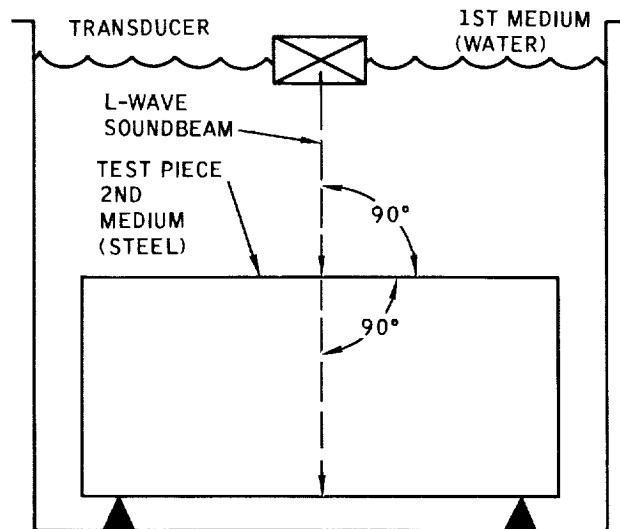
Figure 2-14. Normal Incident Beam

2. MIXED MODE CONVERSION

As the incident angle is rotated from the initial 90° position, refraction and mode conversion occur, and the longitudinal beam is transmitted, in the second medium, in both L and shear (S) wave beams of varying percentages. If the angle is rotated further, a point is reached that is known as the "1st Critical Angle." To sum up: in the area between 90° and this first critical angle, the longitudinal beam enters the second medium, where refraction and mode conversion both occur. As shown in Figure 2-15, both refracted L- and S-wave beams are produced. The quantity of each beam varies as the angle is changed. As shown, the refracted angle for the L-wave beam is four times the incident angle, and the S-wave beam angle is a little more than twice the incident angle. Refraction and mode conversion occurs because the L-wave velocity
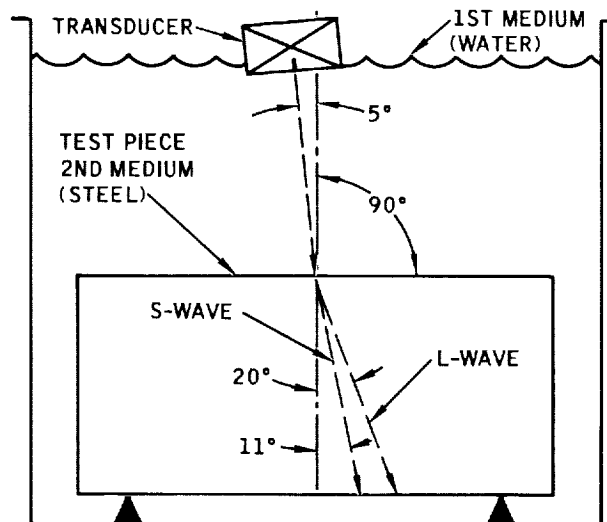
Figure 2-15. 5° Incident Beam

changed when the beam entered the second medium. The velocity of the shear wave is approximately half that of the longitudinal wave. As the incident angle is rotated further, both refracted angles increase. The first angle to reach 90° will be the L-wave angle, as discussed in the next paragraph.

3. SHEAR WAVE GENERATION

Rotating the transducer to produce an incident angle of 15°, the L-wave is increased to 90°, and is reflected from the test surface, as shown in Figure 2-16. The incident angle is now positioned at the 1st Critical Angle, where the L-wave beam is reflected, and only S-wave beams are transmitted through the second medium. Further rotation of the transducer increases the angle of the refracted shear-wave beam. When the S-wave beam reaches 90°, the incident angle is positioned at the 2nd Critical Angle. In the entire region, between the 1st and 2nd Critical Angle, only S-wave beams are produced.

4. SURFACE WAVE GENERATION

Rotating the transducer to produce an incident angle of 27°, the S-wave angle is increased to 90°. Figure 2-17 shows that the only reflected waves are L-waves; the S-wave has undergone mode conversion with some particle disturbance in the test surface. In an air medium, surface Rayleigh waves are easily detected; in the water medium, these waves are damped out. The shear waves are not reflected because they do not propagate in a liquid or gaseous medium.

5. SUMMARY

To summarize: the critical angles are those angles bounding each side of the area where shear waves alone are transmitted. For those points beyond the 2nd Critical
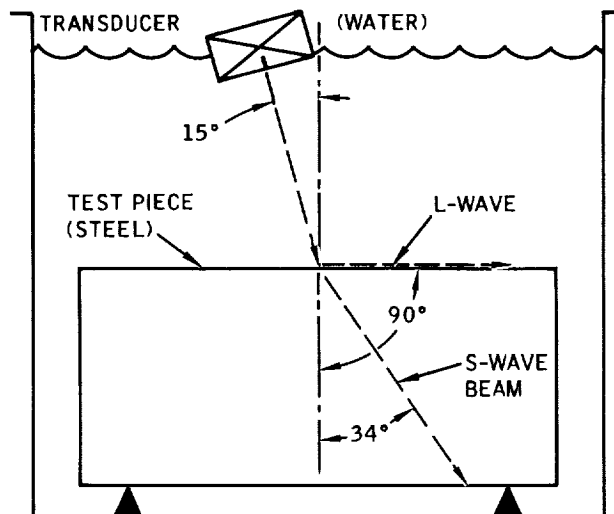
Figure 2-16. 1st Critical Angle
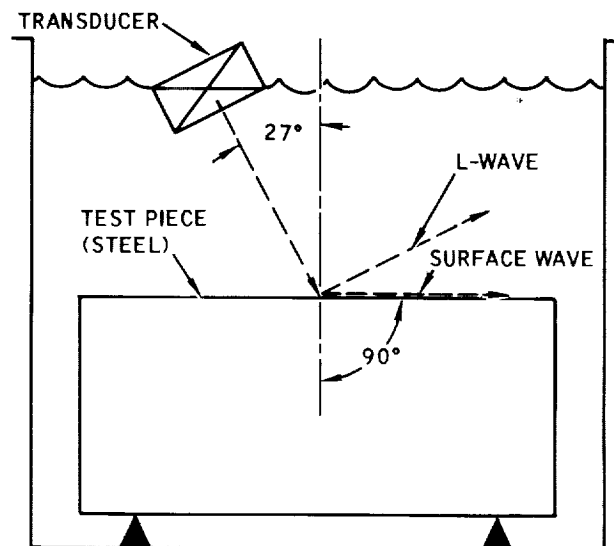
Figure 2-17. 2nd Critical Angle

Angle and grazing incidence, there is total reflection (in immersion testing), and no sound energy is transmitted into the second medium. In contact testing, the angular area at the 2nd Critical Angle produces surface Rayleigh waves in the test specimen. Both critical angles are calculated by the formula for Snell's Law, if the velocities of the soundbeam in the first and second medium are known. The sine of 90°, i.e., 1, is substituted for the sine of the angle in the second medium, and the equation solved for the other. In other words, the velocity of the soundwave, L or S, in the second medium is simply divided into the L-wave velocity in the first medium to obtain the critical angle for the wave type being transmitted.

214   SNELL'S LAW

1.   GENERAL

When the soundbeam velocities in the couplant used in immersion testing, or the wedge material used in contact testing, are different than the sound velocity in the test specimen, the longitudinal (L) beams passing through the wedge or couplant are refracted when the soundbeam enters the test material. Incident or refracted angles are computed by a formula developed from Snell's Law, after Willebrord Snell or Snellius, c. 1621, a Dutch mathematician. For use in ultrasonics, Snell's Law has been modified slightly from its original application, which was meant to explain optical refraction.

2.   SNELL'S LAW CALCULATIONS

The following formula may be used to calculate the incident angle, the resultant refracted angle, and the mode of materials, including solids immersed in water, oil, or other couplants:

$$\frac{\text{Sin } \phi_1}{\text{Sin } \phi_2} = \frac{V_1}{V_2}$$

Where ϕ_1 = incident angle from normal of the beam in the liquid or wedge.

            ϕ_2 = angle of the refracted beam in the test material.

            V_1 = velocity of incident vibrations in the liquid or wedge.

            V_2 = velocity of vibrations in the material under test.

NOTE: The calculations for determining angles of incidence or refraction require the use of trigonometric tables. The sine (abbr: Sin) ratios are given in decimal fractions. Velocities are given in centimeters per microsecond (cm/μ sec) for easiest handling. To convert cm/μ sec to cm/sec x 10^{-5}, move decimal one place to the right. Multiply in/sec by 2.54 to obtain cm/sec.

3. TYPICAL PROBLEM-SOLVING METHOD

Figure 2-18 shows a contact transducer mounted at an incident angle of 35° 30' on a plastic wedge. As the incident angle and the velocity of the soundbeam in the first and second medium are known, the angle of the refracted beam is calculated with the formula for Snell's Law. In this case, only shear waves are produced in the steel, as the incident angle is fixed in the region between the 1st and 2nd Critical Angles.

215 CRITICAL ANGLES OF REFRACTION

1. GENERAL

As discussed previously, soundbeams passing through a medium such as water or plastic (medium 1 for velocity 1, V_1) are refracted when entering a second medium at an incident angle; the second medium is usually the material under test with a differing velocity (medium 2 for velocity 2, V_2). For small angles of the incident beam, soundbeams are refracted and subjected to mode conversion, resulting in a combination of shear and longitudinal waves. This region, between normal incident and the 1st Critical Angle, is not as useful for testing as is the region beyond the first critical angle where only shear waves are produced, thus lessening confusing signals from the combined modes.

2. FIRST CRITICAL ANGLE

As the angle of incidence is widened, the 1st Critical Angle is reached when the refracted longitudinal beam angle reaches 90°. At this point, only shear waves exist in the second medium. When selecting a contact shear wave angle-beam transducer, or when adjusting an immersed transducer at an incident angle to produce shear waves, two conditions are considered. First, and of prime importance, is that the refracted

35°30'

ϕ_1

INCIDENT SOUNDBEAM

TRANSDUCER

PLASTIC WEDGE

REFRACTED SOUNDBEAM

ϕ_2
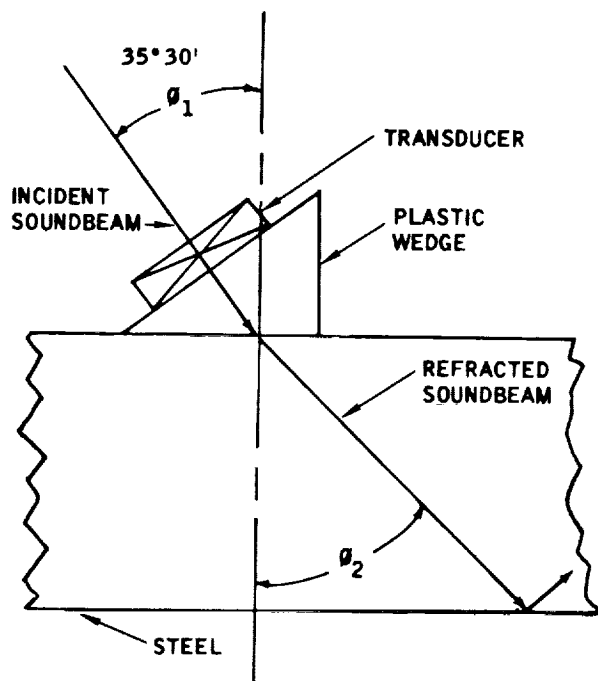
STEEL

SNELL'S LAW: $\dfrac{\text{SIN } \phi_1}{\text{SIN } \phi_2} = \dfrac{V_1}{V_2}$

SOUND VELOCITY: V_1 = VELOCITY LONGITUDINAL

V_S = VELOCITY SHEAR

PLASTIC: V_L = .267 CM/μSEC

STEEL: V_L = .585 CM/μSEC

V_S = .323 CM/μSEC

GIVEN: SIN ϕ_1 = SIN 35°30' = SIN 0.58070

FROM TRIGONOMETRIC FUNCTION TABLES.

SOLUTION OF PROBLEM FOR LONGITUDINAL WAVES	SOLUTION OF PROBLEM FOR SHEAR WAVES
$\dfrac{\text{SIN } \phi_1 \,(0.58070)}{\text{SIN } \phi_2} = \dfrac{V_L \;.267 \text{ CM}/\mu\text{SEC}}{V_L \;.585 \text{ CM}/\mu\text{SEC}}$	$\dfrac{\text{SIN } \phi_1 \,(0.58070)}{\text{SIN } \phi_2} = \dfrac{V_L \;.267 \text{ CM}/\mu\text{SEC}}{V_S \;.323 \text{ CM}/\mu\text{SEC}}$
$\dfrac{0.58070}{\text{SIN } \phi_2} = \dfrac{.267}{.585}$	$\dfrac{0.58070}{\text{SIN } \phi_2} = \dfrac{.267}{.323}$
$\text{SIN } \phi_2 = \dfrac{.585(0.58070)}{.267}$	$\text{SIN } \phi_2 = \dfrac{.323(0.58070)}{.267}$
$\text{SIN } \phi_2 = 1.2723$	$\text{SIN } \phi_2 = 0.7024$
ϕ_2 = ALL LONGITUDINAL WAVES ARE REFLECTED; NO LONGITUDINAL WAVE CAN EXIST, IF ϕ_2 IS 90° OR MORE.	ϕ_2 = 44°37' FROM TRIGONO-METRIC SINE FUNCTION 0.70236. ONLY SHEAR WAVES ARE PRODUCED BY REFRACTION.

Figure 2-18.   Calculation of Refracted Angle

longitudinal wave is totally reflected (its angle of refraction must be 90°) so that the penetrating ultrasound is limited to shear waves only. Second, within the limits of the first condition, the refracted shear wave enters the test piece in accordance with the requirements of the test standard. The 1st Critical Angle is calculated in the immersion method of testing to make certain that the soundbeam enters the test material at the desired angle.

3. SECOND CRITICAL ANGLE

Widening the incident angle further, the 2nd Critical Angle is reached when the refracted shear beam angle reaches 90°. At this point, all shear waves are reflected, and in the case of contact testing with the test piece in an air medium, surface Rayleigh waves are produced. In immersion testing, the liquid medium dampens the production of surface waves to a large degree. Surface waves have been produced in experimental tests on immersed articles. These experiments show promise for use in detecting areas of bond failure in metal-to-metal bonded units.

4. CALCULATION OF CRITICAL ANGLES

If the soundbeam velocities for the materials of the first and second medium are known (V_1 and V_2), either critical angle may be calculated with the formula for Snell's Law, using the sine of 90°, i.e., 1, as the sine of the refracted angle in the second medium. Thus, in the case of the contact transducer mounted on a plastic wedge for testing steel:

$$\text{Snell's Law:} \qquad \frac{\text{Sin } \phi_1}{\text{Sin } \phi_2} = \frac{V_1}{V_2 \text{ (longitudinal wave)}}$$

$$\frac{\text{Sin } \phi_1}{\text{Sin } \phi_2 (1.0000)} = \frac{0.267 \text{ cm}/\mu \text{ sec}}{0.585 \text{ cm}/\mu \text{ sec}}$$

Divide V_2 into $V_1 = 0.45641 = 27°9'$ for 1st Critical Angle. If the 2nd Critical Angle is desired, V_2 is given with the soundbeam velocity for a shear wave in steel: 0.323 cm/μ sec. V_2 is again divided into $V_1 = 0.82662 = 55°45'$ for the 2nd Critical Angle.

a. Table 2-2 lists approximate critical angles for various test materials, using water (couplant) as the first medium ($V_1 = 0.149$ cm/μ sec).

b. Table 2-3, using a plastic wedge as the first medium ($V_1 = 0.267$ cm/μ sec), lists approximate critical angles for the same test materials given in Table 2-1, with the exception of uranium. This is because the L-wave soundbeam velocity for plastic is greater than the S-wave velocity for uranium. For angle-beam testing, the couplant used is one for which the L-wave velocity is less than either velocity in the test piece. V_2 should be greater than V_1.

Table 2-2. Critical Angles, Immersion Testing

TEST MATERIAL	1ST CRITICAL ∅	2ND CRITICAL ∅	VELOCITY (CM/µSEC).
BERYLLIUM	7°	10°	VL=1.280, VS=.871
ALUMINUM, 17ST	14°	29°	VL= .625, VS=.310
STEEL	15°	27°	VL= .585, VS=.323
STAINLESS 302	15°	29°	VL= .566, VS=.312
TUNGSTEN	17°	31°	VL= .518, VS=.287
URANIUM	26°	51°	VL= .338, VS=.193
NOTE: VL = LONGITUDINAL VELOCITY, VS = SHEAR VELOCITY			

Table 2-3. Critical Angles, Contact Testing

FIRST MEDIUM IS PLASTIC

TEST MATERIAL	1ST CRITICAL ∅	2ND CRITICAL ∅	VELOCITY (CM/ SEC).
BERYLLIUM	12°	18°	VL=1.280, VS=.871
ALUNIMUM, 17ST	25°	59°	VL= .625, VS=.310
STEEL	27°	56°	VL= .585, VS=.323
STAINLESS, 302	28°	59°	VL= .566, VS=.312
TUNGSTEN	31°	68°	VL= .518, VS=.287
NOTE: VL = LONGITUDINAL VELOCITY, VS = SHEAR VELOCITY			

216   SOUNDBEAM ATTENUATION

High-frequency ultrasonic waves, passing through a material, are reduced in power or are attenuated by reflection and scattering at the grain boundaries within the material. This loss is proportional to the grain volume in the material and the wavelength. Scattering losses are most important where the wavelength is less than one-third grain size. As the frequency is lowered, where the wavelength is greater than grain size, attenuation is due to damping. In damping losses, attenuation is considered as though the soundbeam travels a free path without interruption by grain boundaries, where energy is lost through heat transfer due to friction of the vibrating particles.

217 SOUNDBEAM SPREADING

1. **GENERAL**

An ultrasonic beam travels through matter with very little divergence or spreading. Because of the short wavelengths involved, a characteristic of the beam is its rectilinear or straight-sided shape. As the wavelength becomes shorter, the beam shape approaches the ideal of absolute rectilinear propagation. This characteristic is pronounced enough to be detected at almost all test frequencies. Although the soundbeam is considered as a straight-sided projection of the face of the transducer, in reality there is always some spreading. Fraunhofer diffraction causes the beam to spread at $D^2/4\lambda$ distance from the face of the transducer. At this distance, the beam spreads outward to appear to originate from the center of the radiating face of the transducer. This spread is a function of the ratio λ/D, where λ is the wavelength of the ultrasonic wave and D is the diameter of the face of the transducer. The sine of the half-angle spread is calculated as follows:

$$\text{Sin } \phi = 1.22 \frac{\lambda}{D}$$

For example: Assume that a 1-inch diameter contact transducer is used on aluminum at a frequency of 1 Mc. The wavelength of the soundbeam is 0.625 centimeter.

What is the half-angle of beam spread?

Convert D to metric system by multiplying inches by 2.54 to obtain centimeters.

$$\text{Sin } \phi = 1.22 \frac{0.625}{2.54}$$

$$\text{Sin } \phi = 0.30012$$

$$\phi = 17° 28'$$

2. **BEAM SPREAD**

Beam spread in steel, at various frequencies, is given in Figure 2-19. At any frequency, the larger the crystal, the straighter the beam; the smaller the crystal, the greater the beam spread. Also, there is less beam spread for the same diameter of crystal at higher frequencies than at lower frequencies. The diameter of the transducer is often limited by the size of the available contact surface. Transducers as small as 1/8-inch diameter have been used. For shallow depth testing, 3/8-and 1/2-inch diameter transducers are used at the higher frequencies, such as 5.0 to 25.0 Mc. A large-diameter transducer is usually selected for testing through greater depths of material.

$$\text{SIN } \emptyset = 1.22 \frac{\lambda}{D}$$

WHERE λ = WAVELENGTH

D = DIAMETER

∅ = HALF-ANGLE OF
BEAM SPREAD TO
HALF-POWER
POINTS
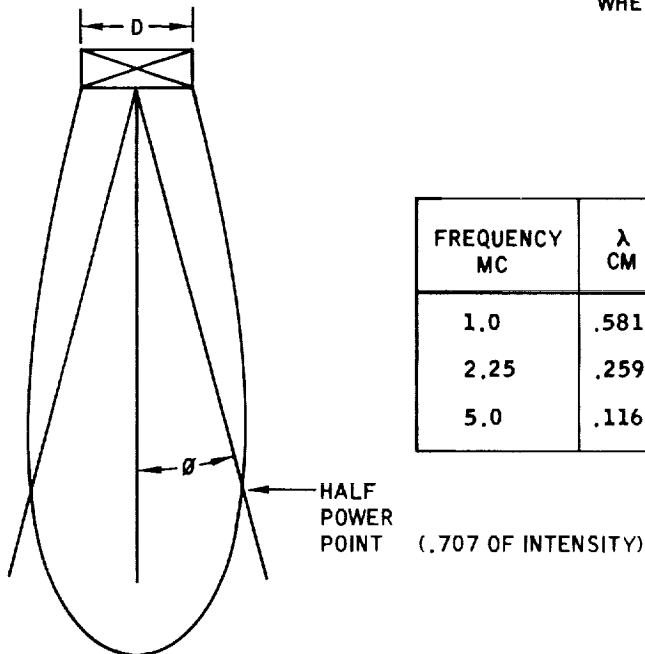
FREQUENCY MC	λ CM	TRANSDUCER DIAMETER (D) INCHES			
		3/8	1/2	3/4	1.0
1.0	.581	48°10'	34°	21°52'	16°13'
2.25	.259	19°23'	14°25'	9°33'	7°9'
5.0	.116	8°34'	6°25'	4°16'	3°12'

HALF
POWER
POINT   (.707 OF INTENSITY)

Figure 2-19. Beam Spread in Steel

3. SOUNDBEAM PATTERNS

Figure 2-20 shows the reduction in beam spreading in steel for a 1/2-inch diameter transducer when the frequency is raised from 1.0 Mc to 2.25 Mc. The secondary or side lobes shown in the figure are edge effects caused by the manner of crystal mounting. In practical work, the primary beam is the only one of consequence. Secondary beams are considered when the geometry of the test specimen is such that they are reflected back to the transducer, creating spurious effects. The strongest intensity of the soundbeam is along its central axis, with a gradual reduction in amplitude away from the axis.

218 RAYLEIGH WAVES

Rayleigh waves travel over the surface of a solid and bear a rough resemblance to waves on the surface of water; they were studied by Lord Rayleigh (c. 1875) because they are the principal component of disturbance in an earthquake at a distance from the center. Reflections from cracks in the surface or from discontinuities lying just beneath the surface may be seen on the oscilloscope screen. Rayleigh waves traveling on the top face of a block are reflected from a sharp edge corner, but if the edge is rounded off, the waves continue down the side face and are reflected at the lower edge,

D = DIAMETER OF CRYSTAL

λ = WAVE LENGTH OF ULTRASONIC WAVE IN STEEL

0° ∅ = 34°   ∅ = 14° 0°

SECONDARY
LOBES

F = 1.0 MC   F = 2.25 MC
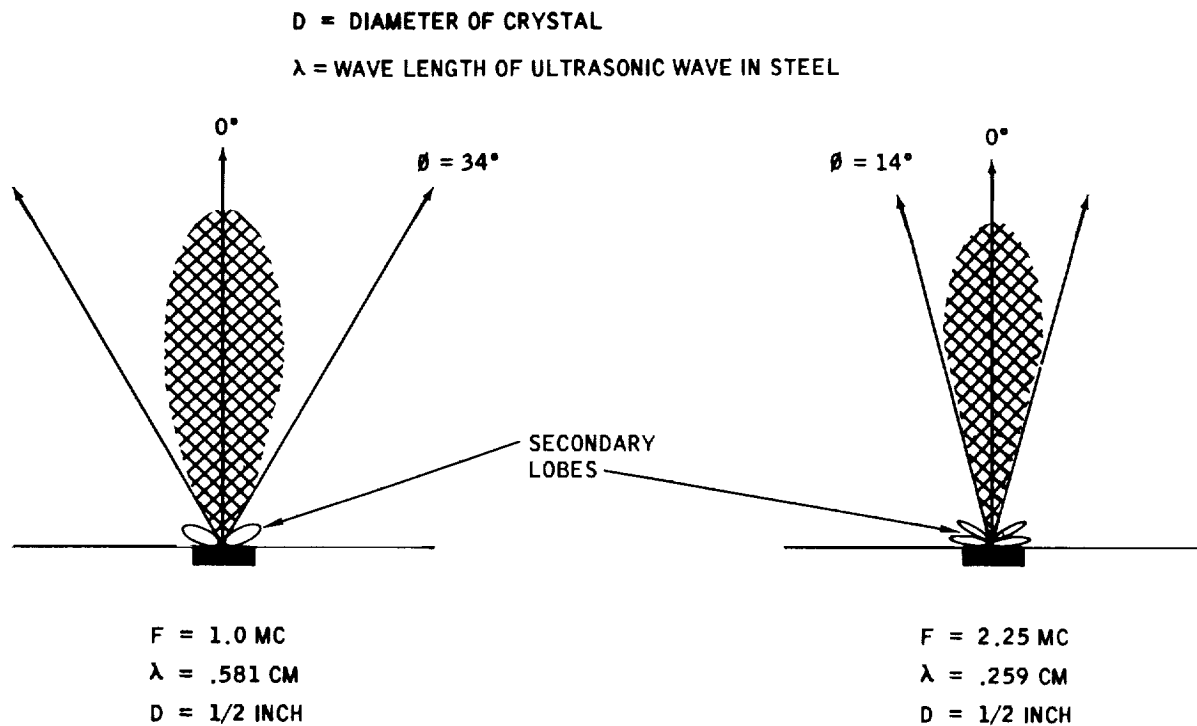λ = .581 CM   λ = .259 CM
D = 1/2 INCH   D = 1/2 INCH

Figure 2-20. Soundbeam Radiation Patterns

returning to the sending point. These waves travel the entire way around a cube if all of its edges are rounded off. They also travel around a cylinder. Rayleigh waves are almost completely absorbed by touching a finger to the surface, so the path of any reflection can be easily traced by observing the oscilloscope screen while moving the finger over the surface of the work. Rayleigh waves are also called surface waves as their depth along the surface direction of travel is usually no more than one wavelength. The soundbeam travels along the surface with an elliptical particle motion, as shown in Figure 2-21.

219 LAMB WAVES

1. GENERAL

Lamb wave theory was developed by Horace Lamb (c.1916). Lamb waves are produced when ultrasonic waves travel along a test specimen with a thickness comparable to the wavelength. Lamb waves can be generated in thin sheets by using longitudinal waves of a predetermined velocity and frequency. These waves are transmitted into the surface of a sheet at a given angle of incidence. The proper angle of incidence may be computed as follows:
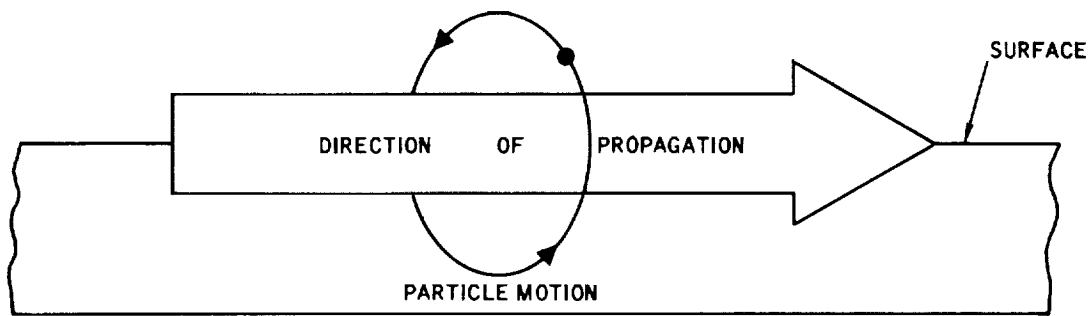
Figure 2-21. Rayleigh or Surface Waves

$$\text{Sin } \phi = \frac{V_L}{V_P}$$

Where V_L = Incident wave velocity.

V_P = Desired Lamb wave phase velocity which is a function of frequency, plate thickness, and the test material.

2. LAMB WAVE TYPES

There are two general classes of waves produced in Lamb wave testing. These are termed symmetrical and asymmetrical waves. Up to an infinity of modes of each class of vibration are possible in a given plate. Each mode propagates with a phase velocity that depends on plate thickness and frequency, and which varies from infinity down to Rayleigh wave velocity. Both types of Lamb waves are shown in Figure 2-22.

3. LAMB WAVE MODES

In Table 2-4, the following incident angles, transmitting a 5 Mc ultrasonic beam, produced Lamb waves in a 0.051-inch thick aluminum plate; with a longitudinal velocity of 0.635 cm/μ sec in the plate and 0.149 cm/μ sec in water.

The ability of Lamb waves to flow in thin plates make them applicable to a wide variety of problems requiring the detection of subsurface discontinuities. The first modes do not reveal subsurface defects, since their energy is contained close to the surface of the medium, as with Rayleigh waves. Where it is desirable that energy travel a considerable distance along the plate, or where detection of subsurface discontinuities is required, modes with a phase velocity near longitudinal velocity are employed. Examples of practical problems, for which the higher modes are useful, are
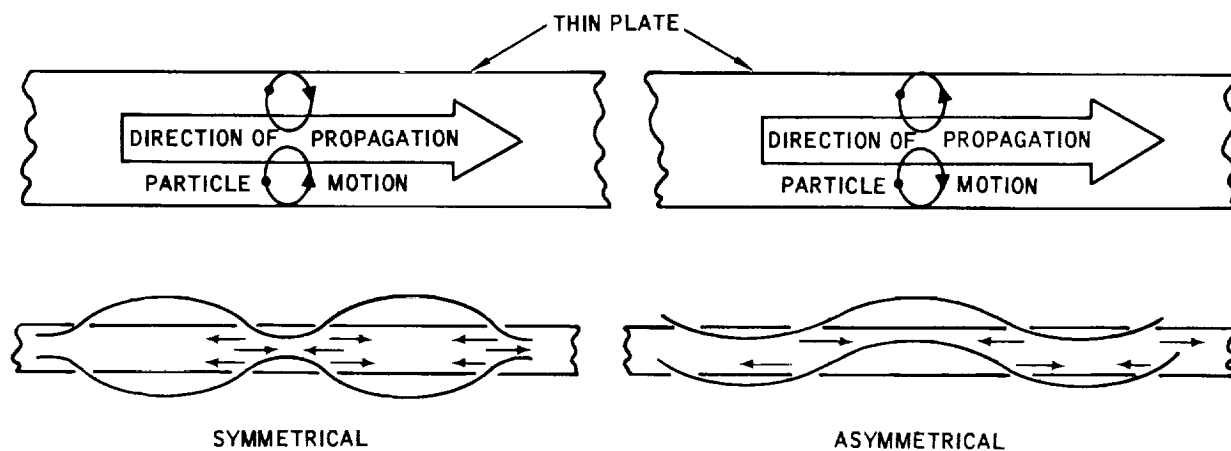
2-30

Figure 2-22. Symmetrical & Assymmetrical Lamb Waves

Table 2-4. Lamb Wave Modes

INCIDENT ANGLE	PHASE VELOCITY	MODE PRODUCED
33.0°	.267 CM/μSEC.	1ST ASYM.
31.0°	.279	1ST SYM.
25.6°	.335	2ND ASYM.
19.6°	.432	2ND SYM.
14.7°	.572	3RD ASYM.
12.6°	.660	3RD SYM.
7.8°	1.067	4TH SYM.

1) immersed inspection of thin-walled tubing and plates for internal defects or grain size determinations; and 2) the testing of welds in butt-welded plates and tubes.

220 COUPLANTS

1. GENERAL

One of the practical problems in ultrasonic testing is transmitting the ultrasonic energy from the source into the test specimen. This is done by interposing a "couplant" between the source and the test material. If a transducer is placed in contact with the surface of a dry part, very little energy is transmitted through the interface into the material because of the great difference in acoustic impedance at the interface.

2. ACOUSTIC IMPEDANCE

When an ultrasonic wave, traveling through one material or medium, reaches a boundary between it and a second medium, part of the energy continues through the second medium while the remainder is reflected back into the first medium. The characteristic of each test material that determines the amount of reflection is known as the acoustic impedance (z) and is a product of the density (p) and velocity (v), expressed:

$$z = p \, v$$

3. REFLECTED ENERGY

In a pulse-echo system the wave passes through an interface twice, once in each direction of travel. If the second medium is air, almost 100 percent of the energy is reflected; if the second medium is not air, each combination of interface material will result in a different theoretical percentage of reflection. For example, in a water-steel interface the reflection is 88 percent, in water-aluminum it is 72 percent, and in water-magnesium it is 54 percent. However, the actual reflection may be vastly different from the calculated theoretical reflection. Many variables such as surface roughness or minute discontinuities will affect the percentage of reflection. Experience has shown that the best method of coupling ultrasonic waves to a solid is with liquid couplants.

4. COUPLANT SELECTION

Acoustic impedances may be matched by keeping them alike; however, situations often occur in ultrasonic testing where energy must be transmitted from one medium into another of greatly different impedance. When that occurs, some method of matching impedance with a couplant becomes necessary. The ideal couplant is an interposed medium with an impedance that is between the impedances of the source and the test specimen. This couplant may be viewed as a transducer which matches the impedance of the transducer to that of the work. Experiments have been made using transformer oil, SAE 20 motor oil, water, glycerin, benzene, Prestone, soap-suds, sugar solutions, mercury, and various amalgams. For contact testing, a thin transformer oil appears ideal. For immersion testing, water is adequate. Usually, wetting agents are added to the oil or water to ensure the elimination of air bubbles and to thoroughly wet the part with the couplant.

221 INFLUENCE OF TEST SPECIMEN ON SOUNDBEAM

1. GENERAL

The highest degree of reliability in ultrasonic testing is obtained when the influence of test specimen variables and their effects are understood and considered. A shortcut for evaluating the effects of test-specimen geometry and material properties is to drill flat-bottomed holes, or other suitable targets, in one of the test parts and then to use that part as a reference standard. With or without such a standard, the operator must be familiar with the influence of geometric and material variables, six in all. In one

form or another, the operator will receive spurious or confusing indications from any of the following test specimen variables:

2. SURFACE ROUGHNESS

Rough surfaces distort ultrasonic indications as follows:

    a. Loss of echo amplitude from discontinuities within the part. This loss may be due to scatter at the surface of the part or to roughness of the surface on the discontinuity.

    b. Loss of resolving power which is caused by a lengthening of the front-surface echo. This is seen as a wide front-surface pip on the oscilloscope and is caused by reflection of transducer side or secondary lobe energy. Side lobe energy is normally not reflected back into the transducer from smooth surfaces. This condition may mask the presence of a discontinuity just below the surface.

    c. Widening of beam due to scatter from the rough surface or to a requirement for a lower frequency to reduce scatter.

3. SHAPE OR CONTOUR OF TEST SPECIMEN

Angular boundaries or contoured surfaces of the test specimen cause partial or total loss of back reflection. Figure 2-23 shows a test specimen with an irregular back surface. In the area where the back surface is parallel to the front surface, the sound waves are returned to the transducer. On the left side, in the area where the back surface is sloped at an angle from the front surface, the sound waves are caromed from one boundary to another until they die out from attenuation. In actual practice, portions of the soundbeam are spread from each reflection point so that a few weak
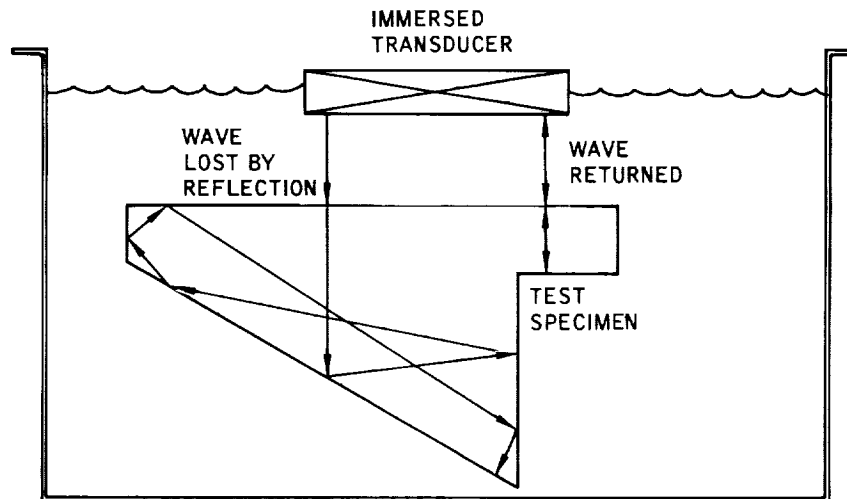
Figure 2-23. Irregular Back Surface Effect

signals are received by the transducer, creating confusing indications.

a. A convex surface is illustrated on the test specimen shown in Figure 2-24. The soundbeam is widened by refraction after passing through the convex boundary. Considerable acoustic power is lost by reflection at the test specimen surface, as shown, and by beam spread. Signals reflected from the discontinuity have less amplitude than signals received from the same size discontinuity in a flat test specimen.
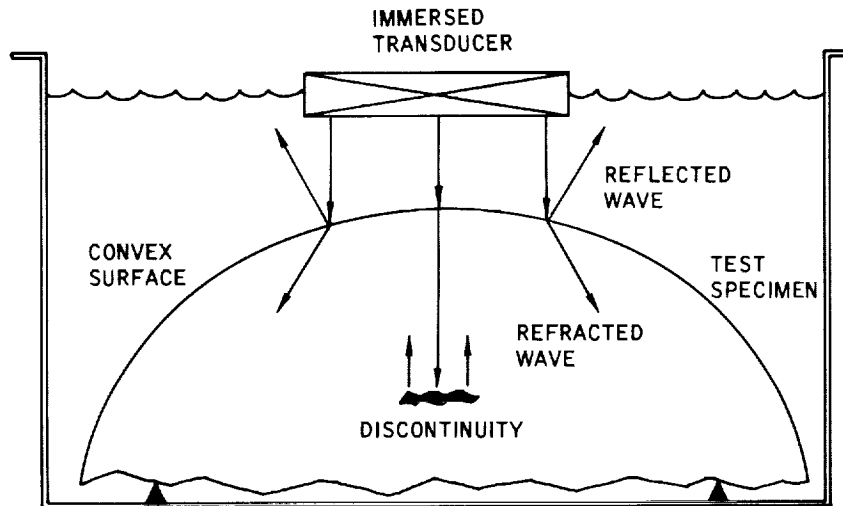
Figure 2-24. Convex Surface Effect

b. Figure 2-25 shows a test specimen with a concave surface. After passing through the concave boundary, the soundbeam is narrowed or focused. The discontinuity signals are relatively high in amplitude, but may be difficult to identify because of unwanted reflections from the test surface.
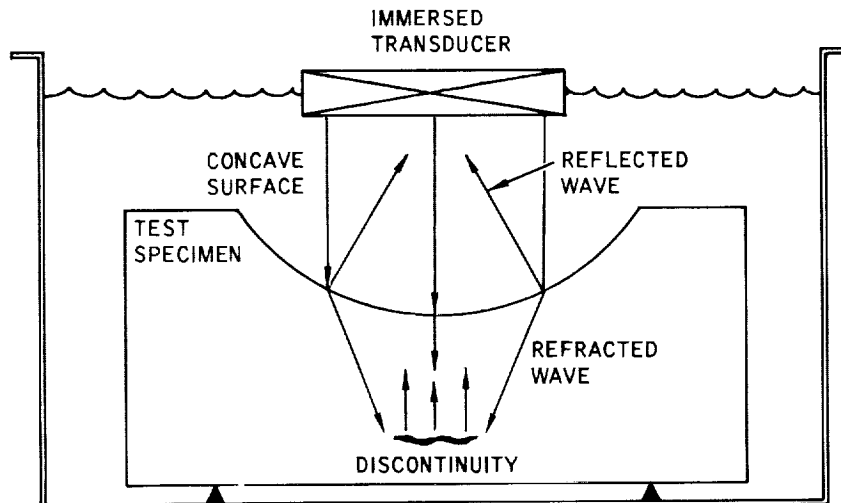
Figure 2-25. Concave Surface Effect

4. MODE CONVERSION WITHIN TEST SPECIMEN

When the shape or contour of the test specimen is such that the soundbeam, or a portion of it as in the case of beam spread, is not directly reflected back to the transducer, mode conversion occurs at the boundary points contacted by the beam. If a direct back reflection is obtained, mode conversion indications may be identified as they will appear behind the first back reflection. These echoes are slow to appear because they are slowed by velocity changes during mode conversion, when they are changed from longitudinal waves to shear waves and then back to longitudinal waves. Soundbeams are reflected at angles which are calculated by the reflected at angles which are calculated by the reflection equivalent of Snell's Law:

$$\frac{\text{Sin } \phi_L}{\text{Sin } \phi_S} = \frac{V_L}{V_S}$$

Where: ϕ_L = Incident angle of the longitudinal beam.

   ϕ_S = Reflected shear beam angle.

   V_L = Velocity of the longitudinal beam in the test specimen.

   V_S = Velocity of the shear beam in the test

As the incident angle of the longitudinal beam is known, or can be easily determined, the sine of the longitudinal reflected beam is equal to it, in accordance with the rule that the angle of incidence is equal to the angle of reflection. The reflected shear beam angle will be about half the longitudinal beam angle, as the velocity of the shear beam is about half the velocity of the longitudinal beam. Figure 2-26 shows soundbeam re-
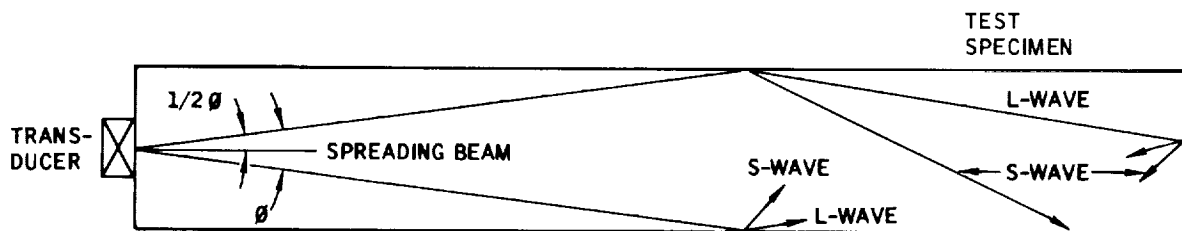

Figure 2-26. Mode Conversion Caused by Beam Spread

flections within a long solid test part. The spreading beam contacts the sides of the part with grazing incidence. Depending on the material, the resulting mode conversion consists of mixed modes of longitudinal and shear waves.

5. COARSE GRAIN PARTICLES WITHIN TEST SPECIMEN

Coarse or large grain particles within the test specimen can cause scatter and loss of back reflection, particularly when the size of the particle and the wavelength are comparable. If the frequency is lowered to the point where the wavelength is greater than grain size, scattering losses are reduced, but sensitivity is also lowered.

6. ORIENTATION AND DEPTH OF DISCONTINUITY

The orientation and depth of the discontinuity may cause confusing indications or may result in the loss of the discontinuity echo. In the case of orientation, the discontinuity may lie with its long axis parallel to the soundbeam, causing a small indication in proportion to the size of the discontinuity. If the discontinuity is angled from the soundbeam, its reflections are directed away from the transducer. A sudden loss of back reflection, when scanning, indicates the presence of a discontinuity. If the decrease in amplitude is proportional to the pip caused by reflections from the discontinuity, the discontinuity is flat and parallel to the test surface. If the discontinuity pip is small, compared to the loss of back reflection, the discontinuity is probably turned at an angle to the test surface. Indications are also affected by the depth of the discontinuity. Figure 2-27 shows three principal zones: the dead zone, the near zone, and the far zone. The depth of the dead zone is determined by the pulse length as shown. When the trailing edge of the pulse is at the surface of the test specimen, the leading edge is extended to the dead-zone limit. If the discontinuity is just beneath the surface within the dead zone, no indication will be displayed. If it is just beyond the dead zone, in the near zone, phasing effects will vary the echo amplitude to a considerable degree as a function of position.
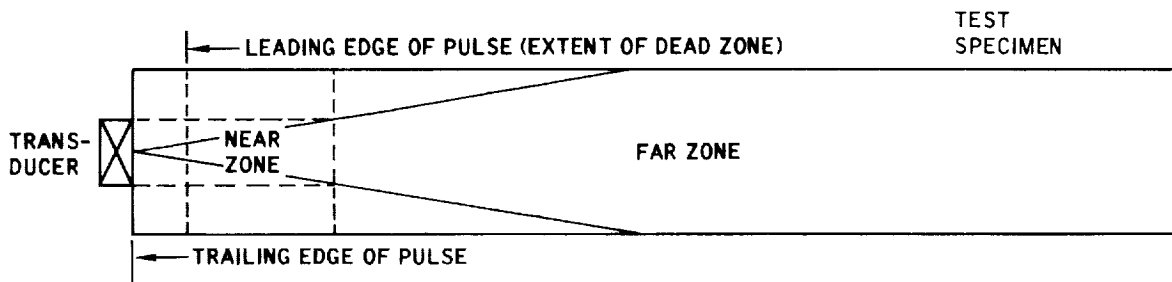

Figure 2-27. Dead Zone, Near Zone, and Far Zone

2-36

The depth of the near zone is determined by extending dimension lines from the transducer diameter, as shown, to intersect with the spreading beam on each side. At this distance, the beam spreads outward as if it had originated from the center of the transducer face. This effect is sometimes referred to as Fraunhofer diffraction (from optics) which causes the beam to spread at $D^2/4\lambda$ distance from the transducer, to the far limit of the near zone (D = diameter of the transducer and λ = wavelength of the soundbeam). Soundbeam intensity is irregular in the near zone, causing a condition where varying indications may be obtained from the same discontinuity as the transducer is moved across it. Beyond the near zone in the far zone, the amplitude of the indication from the discontinuity diminishes exponentially as the distance increases.

222 RESONANCE THICKNESS MEASURING

1. GENERAL

With the resonance thickness measuring method, a crystal is excited, by means of an oscillator tube, at some frequency well below the crystal's frequency, and held on the surface of the test piece. Acoustic contact is maintained by means of a suitable coupling medium. Longitudinal waves from the crystal cause the sample to vibrate in the direction of its thickness. The frequency of vibration of the crystal is varied until the sample resonates or oscillates with maximum intensity. The sample vibration results in an amplitude increase of crystal vibration with a consequent increase in its induced voltage. Resonance occurs at one of the resonant frequencies of vibration of the test piece in its thickness direction, where the thickness of the sample is equal to an exact number of half wavelengths. These are called harmonic resonance frequencies. Thus, it is possible to express the thickness of a material as:

$$T = N\frac{\lambda}{2}$$

Where N = Any whole number of harmonics

λ = Wavelength

T = Thickness

2. MATERIAL CHARACTERISTICS

Each thickness of a given material has a characteristic or fundamental resonant frequency. At this frequency or multiples of it, when the transmitted and reflected waves are in phase, a relatively large increase in the amplitude of the waves in the material occurs. Since the velocity is a known constant, the frequency required to produce resonance is an accurate and reliable measure of an unknown thickness. The resonance method is used primarily for thickness measurements of material with two sides smooth and parallel, but it will also detect discontinuities lying in the same plane as

the test surface. In general, resonance is applied much like the other ultrasonic testing systems. It differs in that the frequency of transmission is, or can be, continuously varied. The point at which the frequency matches the resonance point of the material under test is the thickness determining factor. Similar materials, such as a series of aluminum alloys, have an almost constant resonant frequency.

3. STANDING WAVES

Thickness resonance occurs whenever the thickness of the material is equal to an integral number of half wavelengths of the ultrasonic wave. Figure 2-28 shows various standing wave patterns in test material. In a standing wave, the points of maximum displacement are referred to as nodes and the points of minimum displacement as antinodes. The distance between adjacent nodes or adjacent antinodes is a half wavelength. In resonance testing, there is always a node at the transducer and a node at the opposite side of the test piece. In the standing wave illustration, the thickness of the material (T) is equal to $\lambda/2$, $3\lambda/2$, λ, and 2λ, respectively.

TEST PIECE   TRANSDUCER

T = 0.5λ   T = λ
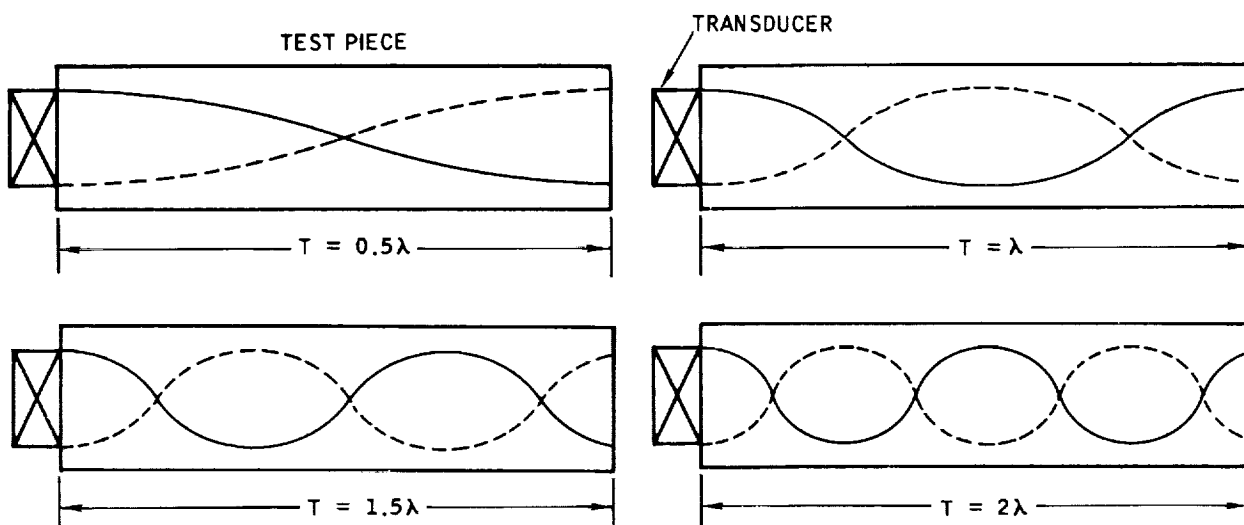
T = 1.5λ   T = 2λ

Figure 2-28. Standing Waves

4. THICKNESS CALCULATIONS

Velocity is always equal to the product of frequency and wavelength, thus wavelength may be expressed as:

$$\lambda = \frac{V}{F}$$

Substituting $\frac{V}{F}$ for λ in the equation $T = N, \frac{\lambda}{2}$ results in $T = N\frac{\frac{V}{F}}{2} = N\frac{V}{2F}$ which may be expressed as $2T = N\frac{V}{F}$.

Since N is any whole number it may be disregarded. Thus $2T = \dfrac{V}{F}$ or $T = \dfrac{V}{2F}$ and thickness may be calculated if the velocity and resonant frequency are known.

Example: In a resonance thickness test, a steel sample causes a resonant display, harmonic peaks on the screen of the oscilloscope, at 2.4 Mc, 3.31 Mc, 4.21 Mc, and 5.11 Mc. What is the thickness of the sample?

Using the equation $T = \dfrac{V}{2F}$

where F = Resonant frequency in Mc (0.90 Mc average distance between peaks)

V = 0.585 cm/μ sec, velocity in steel

T = Thickness (cm)

$$T = \frac{0.585}{1.80} \text{ (using 0.90 frequency)}$$

$$T = 0.32 \text{ cm} = 0.128 \text{ inches}$$

Actual thickness determinations are made by placing a thickness scale over the oscilloscope screen, or by referring to a table of constants (called a K table) which is a listing of velocity constants given in million inch/seconds divided by two. The K table is used to convert frequency to thickness of the part in inches, using the equation:

$$T = \frac{K}{F}$$

Where T = Thickness of material in inches.

K = Constant (velocity in million inch/second divided by 2).

F = Frequency in Mc (Resonant or Fundamental Frequency).

For example:
$$T = \frac{0.116 \text{ (K for steel)}}{0.90 \text{ Mc}}$$

$$T = 0.128 \text{ inch}$$

5. SUMMARY

A variable-frequency oscillator transmits high-frequency electrical energy to a transducer. There, the electrical energy is transformed into mechanical vibrations and transmitted continuously into the test specimen. When resonance occurs, a surge of vibrational energy is received by the transducer, transformed into electrical energy, amplified, and indicated on a display system. This may be a trace deflection on an oscilloscope screen, an audible tone, a meter deflection, or a flashing neon indicator.

The greatest accuracy is usually obtained with the oscilloscope display. As the oscillator sweeps through the resonant frequency of the test specimen or through any harmonics of that frequency, vertical indications appear on the oscilloscope screen. These indications are used to determine thickness as they indicate the frequencies required to produce resonance at the fundamental frequency or its harmonics.

CHAPTER 3: EQUIPMENT
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CHAPTER 3: EQUIPMENT

300 GENERAL

This chapter covers the more commonly-used ultrasonic testing equipment. The manufacturer's manual, in most cases, provides a review of theory, operation, and maintenance instructions for the unit and other more specific information. Manufacturers' recommendations supersede this chapter in the event of conflicting information.

301 PULSE-ECHO UNITS

1. GENERAL

All makes of pulse-echo equipment have similar electronics circuitry, providing basic functions common to all makes. Nomenclature of the given functions varies from one instrument to another according to the manufacturer. Each unit provides the following essentials.

    a.   Power Supply. Circuits for supply of current, for all basic functions of the instrument, constitute the power supply which is served from line supply or, for some units, from a battery contained in the unit.

    b.   Transducer. The transducer consists of the crystal and its holder. The crystal converts electrical energy to ultrasonic energy and introduces vibrations into the test specimen; it also receives reflected vibrations from within the test specimen and converts them into electrical signals for amplification and display.

    c.   Pulser/Receiver. The pulser or pulse generator (a thyratron tube) is the source of short high-energy bursts of electrical energy (triggered by the timer) which are applied to the transducer. Return pulses from the test specimen are received, amplified, and routed to the display unit.

    d.   Display/Timer. The display is usually an oscilloscope with a sweep generator, marker generator, and needed controls to provide a visual image of the signals received from the test specimen. The timer is the source of all timing signals to the pulser and is sometimes referred to as the rate generator or clock.

2. CONTROLS (Figure 3-1)

Controls are provided for various functions of the instrument system, such as power supply, pulser, receiver, timer, and display. The nomenclature used in the following description of controls may vary from one type of unit to another.

    a.   Power Supply. The power supply is usually controlled by ON-OFF switches and fuses. After turning on power, there are certain time delays to protect
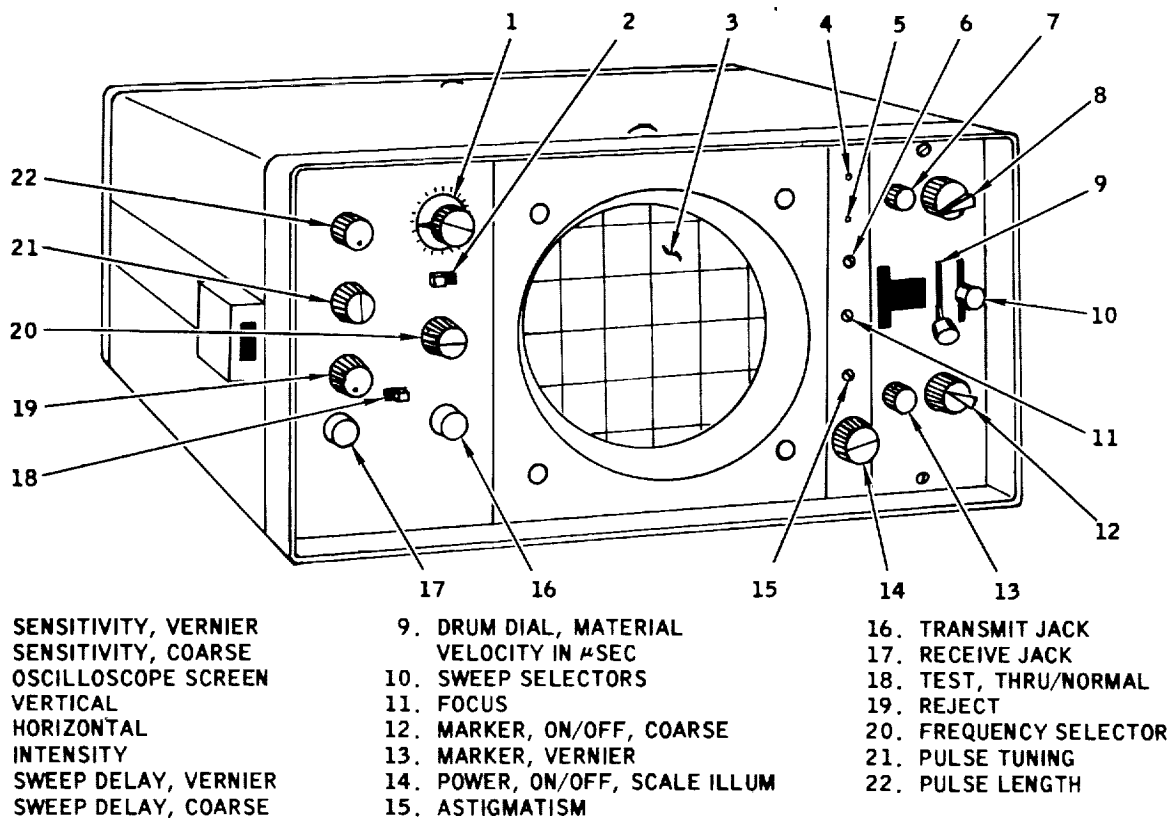
Figure 3-1. Typical Pulse-Echo Unit Controls

1. SENSITIVITY, VERNIER	9. DRUM DIAL, MATERIAL	16. TRANSMIT JACK
2. SENSITIVITY, COARSE	VELOCITY IN μSEC	17. RECEIVE JACK
3. OSCILLOSCOPE SCREEN	10. SWEEP SELECTORS	18. TEST, THRU/NORMAL
4. VERTICAL	11. FOCUS	19. REJECT
5. HORIZONTAL	12. MARKER, ON/OFF, COARSE	20. FREQUENCY SELECTOR
6. INTENSITY	13. MARKER, VERNIER	21. PULSE TUNING
7. SWEEP DELAY, VERNIER	14. POWER, ON/OFF, SCALE ILLUM	22. PULSE LENGTH
8. SWEEP DELAY, COARSE	15. ASTIGMATISM	

circuit elements during instrument warm-up.

b. Pulser/Receiver. The pulse of ultrasonic energy transmitted into the test specimen is adjusted by PULSE LENGTH and PULSE TUNING controls. For single transducer testing, the transmit and receive circuits are connected to one jack for the same transducer. For double transducer testing, called through transmission or pitch-and-catch testing, a T (transmit) jack is provided to permit connecting one transducer for use as a transmitter, with an R (receive) jack provided for use of another transducer for receiving only. A TEST switch for THRU or NORMAL transmission is provided for control of the T and R jacks. A selector for a range of operating frequencies is usually marked FREQUENCY with the available frequencies given in megacycles. Gain controls usually consist of FINE and COARSE sensitivity selectors or one control marked SENSITIVITY. For a clean video display with low level noise eliminated, a REJECT control is provided.

c. Display/Timer. The display controls are usually screwdriver-adjusted with the exception of the SCALE ILLUMINATION and ON-OFF POWER. After initial adjustments are made, the screwdriver controls seldom require adjustment. The controls and their functions for the display unit are:

(1) VERT. Controls vertical position of the display on the oscilloscope screen.

(2) HORIZ. Controls horizontal position of display on the oscilloscope screen.

(3) INTENSITY. Varies brightness of display as desired.

(4) FOCUS. Adjusts focus of trace on the oscilloscope screen.

(5) ASTIG. Corrects for distortion or astigmatism introduced by changing transit time of electron beam across oscilloscope screen.

(6) POWER and SCALE ILLUM. Dual control that turns power on for entire unit. Clockwise rotation adjusts illumination of grid lines.

Timer unit controls usually consist of SWEEP DELAY and SWEEP controls which provide coarse and fine adjustments, at the rate that pulses are generated, to suit the material and thickness of the test specimen. The DELAY control is also used to position the initial pulse on the left side of the display screen with a back reflection or multiples of back reflections visible on the right side of the screen.

d. Other Controls. Other controls, which are refinements not always provided are:

(1) Markers. The marker circuit provides square waves on the sweep line to serve the same purpose as scribe marks on a ruler. This circuit is activated or left out of the display by a MARKER switch for ON-OFF selection. Usually, there will also be a MARKER CALIBRATION or MARKER ADJUSTMENT control to permit selection of the marker frequency. The higher the frequency, the closer the spacing of square waves, and the more accurate the measurements. Since marker circuits are involved with timing from the timer or clock, marker controls may be located on the timer control unit.

(2) DAC or STC. DAC (Distance Amplitude Correction), STC (Sensitivity Time Control), and other like units called TCG (Time Corrected Gain), or TVG (Time Varied Gain) are used to compensate for a drop in amplitude of signals reflected from discontinuities deep within the test specimen.

(3) Damping. The pulse duration is shortened by the DAMPING control which adjusts the length of the wave train applied to the transducer. Resolution is improved by higher values of damping.

(4) IF-VIDEO. The IF-VIDEO switch is used to select the desired type of display, full-range IF (intermediate frequency) or VIDEO.

(5) Transducer Voltage. High or low voltage driving current is selected for the transducer with the TRANSDUCER VOLTAGE switch.

(6) Gated Alarm. Gated-alarm units enable the use of automatic alarms when discontinuities are detected. This is accomplished by setting up specific, controllable gated or zoned areas within the test specimen. Signals appearing within these gates may be monitored automatically to operate visual or aural alarms. These signals are also passed on to facsimile or strip chart recorders and to external control devices. Gated-alarm units usually have three controls as follows:

(a) Start or Delay. The gate START or DELAY control is used for adjustment of the location of the leading edge of the gate on the oscilloscope screen.

(b) Length or Width. The gate LENGTH or WIDTH control is used for adjustment of the length of the gate or the location of the gate trailing edge.

(c) Alarm Level or Sensitivity. The alarm LEVEL or SENSITIVITY control is used for adjustment of the gate vertical threshold to turn on signal lights or to activate an alarm relay. On some units, a socket is provided for connecting the alarm relay to external components.

3. A-SCAN EQUIPMENT

The A-scan system is a data presentation method to display the returned signals from the material under test on the screen of an oscilloscope as shown in Figure 3-2. The horizontal base line on the oscilloscope screen indicates elapsed time (from left

A   FRONT SURFACE REFLECTION
B   DISCONTINUITY RESPONSE
C   BACK SURFACE REFLECTION
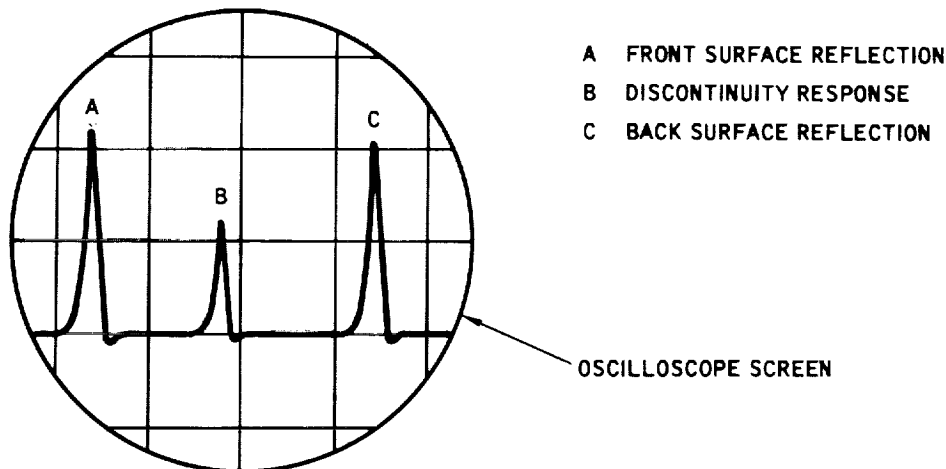
OSCILLOSCOPE SCREEN

Figure 3-2. A-Scan Presentation

to right), and the vertical deflection shows signal amplitudes. For a given ultrasonic velocity in the specimen, the sweep can be calibrated directly, across the screen, in terms of distance or depth of penetration into the sample. Conversely, when the dimensions of the sample are known, the sweep time may be used to determine ultrasonic velocities. The vertical indications or pips represent the intensities of the reflected soundbeams. These may be used to determine the size of the discontinuity, depth or distance to the discontinuity from the front or back surface, soundbeam spread, and other factors. Most A-scan units incorporate an oscilloscope screen coated with a medium-persistence phosphor. Chief advantage of this equipment is that it provides amplitude information needed to evaluate the size and position of the discontinuity.

4. B-SCAN EQUIPMENT

The B-scan equipment, in addition to the basic components of the A-scan unit, provides these functions:

 a. Retention of the image on the oscilloscope screen by use of a long-persistence phosphor coating.

 b. Deflection of the image-tracing spot on the oscilloscope screen in synchronism with motion of the transducer along the sample.

 c. Image-tracing spot intensity modulation or brightening in proportion to the amplitude of the signals received.

The B-scan system is particularly useful where the distribution and shape of large discontinuities within a sample cross-section is of interest. As shown in Figure 3-3, the sweep connections on the oscilloscope are made to the vertical Y axis of the cathode ray tube, and the amplifier/position signals are routed to the horizontal X axis. Chief advantage of the B-scan equipment is that a long-persistence cross-section view of the sample and the discontinuities within it are displayed. In high-speed scanning, the cross-section image is retained long enough to evaluate the entire sample and to photograph the oscilloscope screen for a permanent record.

5. C-SCAN EQUIPMENT

C-scan equipment is intended to provide a permanent record of the test when high-speed automatic scanning is used in ultrasonic testing. C-scan displays the discontinuities in a plan view, but provides no depth or orientation information. The most commonly used recorders use a chemically-treated paper that is passed between a printing bar and a helix drum as shown in Figure 3-4. The printing bar has a narrow edge and is connected electrically to one of the output terminals of the amplifier in the ultrasonic test unit. The other terminal is connected to the helix mounted on the helix drum. As the drum turns, the sliding contact point between the bar and the helix

Figure 3-3. B-Scan Presentation

moves back and forth across the paper. Variations in electric current at the contact point determine the amount of print-out produced on the paper. One revolution of the drum produces one line of scan. The paper movement is synchronized with the movement of the transducer across the test surface. The amplifier is also connected to the oscilloscope so that, whenever a signal (pip) of predetermined amplitude is displayed,

Figure 3-4. C-Scan Presentation

a change of current occurs in the printing bar contact. In this manner, a record of the discontinuities is produced as the transducer scans the test surface. The C-scan recording indicates the projected length and width of the discontinuity and the outline of the test specimen, as seen from directly above the specimen. The C-scan recording does not indicate the depth of the discontinuity in the test specimen. Some recorders produce a shaded scan line, as shown in Figure 3-5, to indicate the outline of the discontinuity. On others, the discontinuity outline may be indicated by the absence of the scan lines, as shown in Figure 3-6, where the white (no line) areas represent the discontinuities. The print-out of some recorders may be reversed so that the discontinuities are represented by the lines and the remainder of the specimen is represented by blank space. The extent of the marked (or unmarked) area of the recording indicates the size of the recording. The same signals that generate the pips on the A-scan, produce a change on the C-scan recording. The front and back surface signals from the specimen are eliminated from the recording by the instrument gating circuits, and the alarm sensitivity control setting determines the amplitude of the signal (pip) required to produce a change on the recording. Figure 3-7 shows a functional diagram of the C-scan system.

302   ULTRASONIC TANK AND BRIDGE/MANIPULATOR

1.   GENERAL

Ultrasonic tanks and bridge/manipulators are necessary equipment for high-speed scanning of immersed test specimens. Modern units consist of a bridge and manipulator, mounted over a fairly large water tank, to support a pulse-echo testing unit and a recorder as shown in Figure 3-8. Drive power units move the bridge along the tank side rails, while transversing power units move the manipulator from side to side along the bridge. Most of these units are automated, although some early units are manually
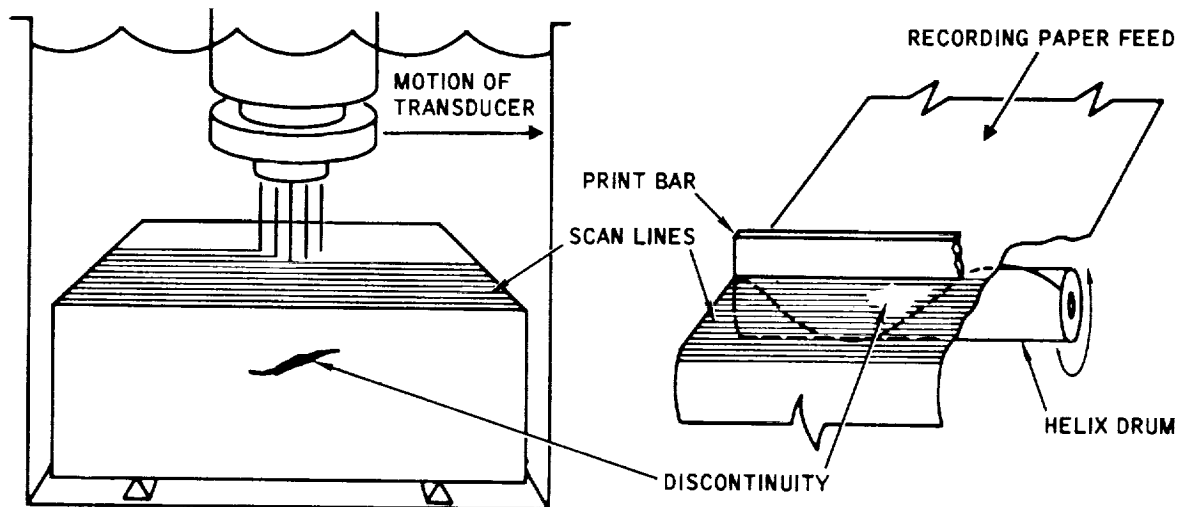

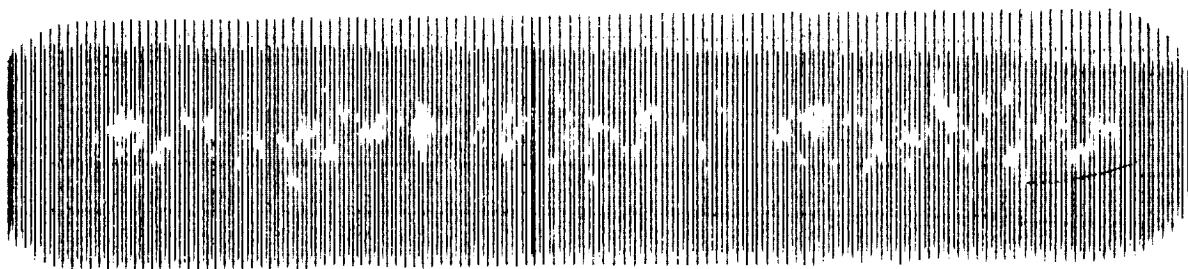Figure 3-5.   C-Scan Principle of Operation

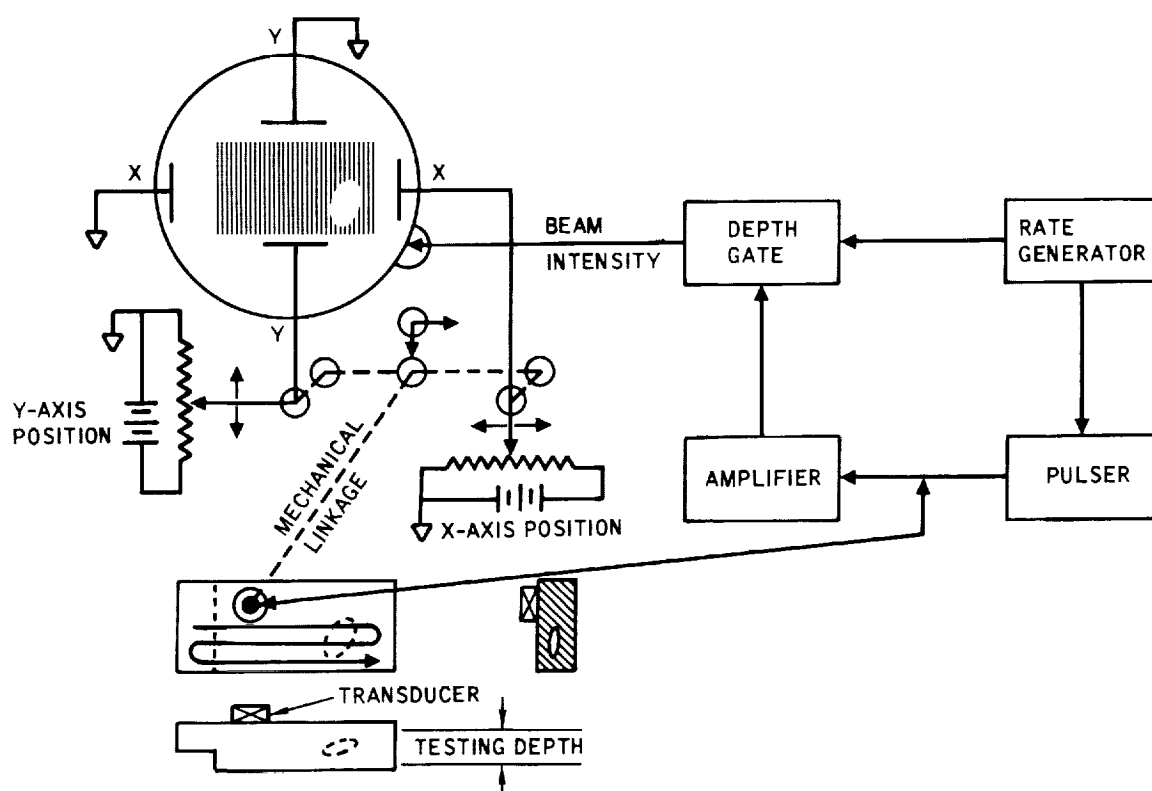Figure 3-6. Typical C-Scan Recording

Figure 3-7. Functional Diagram, C-Scan System

operated. On most automatic units, a C-scan recorder is also mounted on the bridge as shown.

2. ULTRASONIC TANK

The ultrasonic tank may be of any size or shape to accommodate the test specimen.
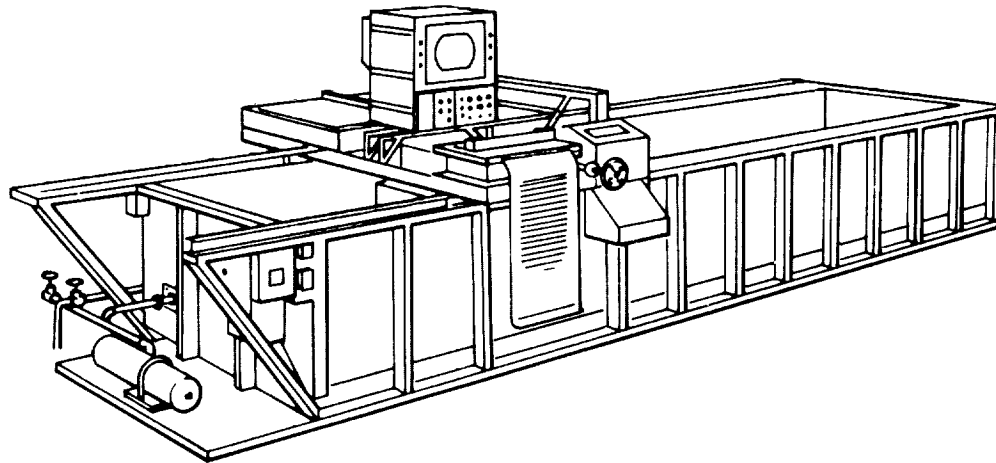
Figure 3-8. Ultrasonic Tank and Bridge/Manipulator

The water depth is usually sufficient for coverage of the specimen by a foot or more of water. Adjustable brackets and lazy-susan turntables are provided on the tank bottom for support of the test specimen. The water couplant in the tank is clean, deaerated water containing a wetting agent. For operator comfort, the water temperature is usually maintained at 70° F by automatic controls.

3. BRIDGE/MANIPULATOR

The bridge/manipulator unit is primarily intended to provide a means of scanning the test specimen with an immersed transducer. The stripped-down version shown in Figure 3-9 has a bridge with a carriage unit at each end so the bridge may be easily moved along the tank side rails. The manipulator is mounted on a traversing mecha-
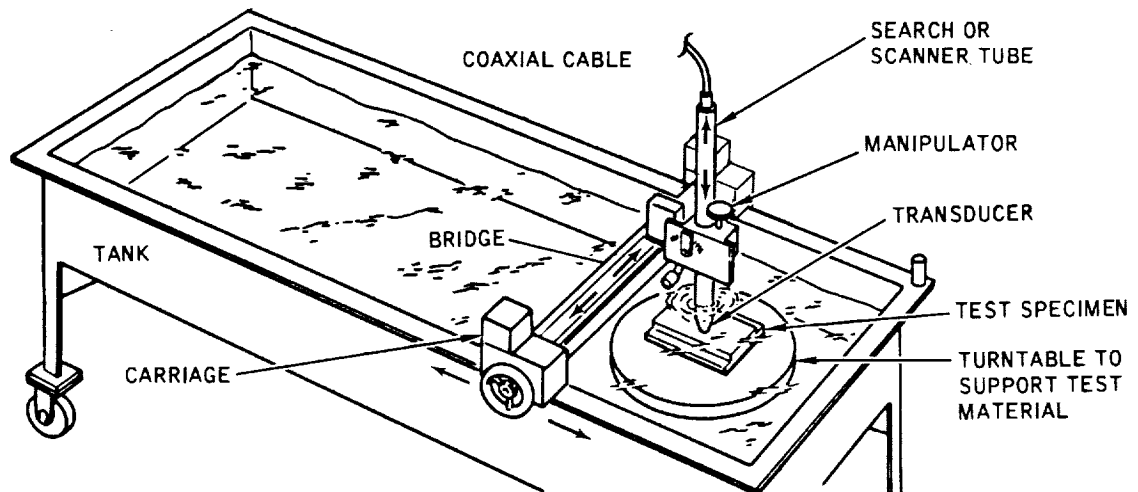

Figure 3-9. Bridge/Manipulator

nism, enabling movement of the manipulator from side to side. The traversing mechanism is an integral component of the bridge assembly. The search tube is usually held rigid, as shown, at right angles to the surface of the test specimen. Locking knobs are provided on the manipulator to allow positioning of the search tube in two planes for angle-beam testing. When automated, electric motors are added to power the bridge carriage, the traversing mechanism, and the up-down movement of the search tube. The pulse-echo unit and the recording unit are also mounted on the bridge, with all power cords secured overhead to allow movement of the bridge along the full length of the tank.

303 TRANSDUCERS

1. GENERAL

In ultrasonic testing, the ear of the system is the transducer. After transmitting sound energy, the transducer hears echoes of the condition of the material and relays the information back to the instrument where it is visually displayed on the oscilloscope screen. The capabilities of a transducer, and for that matter the testing system, are for the most part described by two terms: sensitivity and resolution.

2. SENSITIVITY

The sensitivity of a transducer is its ability to detect echoes from small discontinuities. Transducer sensitivity is measured by the amplitude of its response from an artificial discontinuity in a standard reference block. Precise transucer sensitivity is unique to a specific transducer. Even transducers of the same size, frequency, and material by the same manufacturer do not always produce identical indications on a given oscilloscope screen. Transducer sensitivity is rated by its ability to detect a given size flat-bottomed hole, at a specific depth, in a standard reference block.

3. RESOLUTION

The resolution or resolving power of a transducer refers to its ability to separate the echoes from two targets close together in depth: for example, the front-surface echo and the echo from a small discontinuity just beneath the surface. The time required for the transducer to stop "ringing" or vibrating, after having been shocked by a large voltage pulse, is a measure of its resolving power. Long "tails" or bursts of sound energy from a ringing transducer cause a wide, high-amplitude, front-surface echo. A small discontinuity, just beneath the surface, is masked by the ringing signal.

4. MATERIALS

The three most common piezoelectric materials used in ultrasonic transducers are quartz, lithium sulfate, and polarized ceramics. The most common ceramics at present are barium titanate, lead metaniobate, and lead zirconate titanate.

a. Quartz. In the past, quartz transducers were used almost exclusively, but, with the development of new materials it is being used less and less. Quartz has excellent chemical, electrical, and thermal stability. It is insoluble in most liquids and is very hard and wear-resistant. Quartz also has good uniformity and resists aging. Unfortunately, it is the least efficient generator of acoustic energy of the commonly used materials. It also suffers from mode conversion interference and requires high voltage to drive it at low frequencies.

b. Ceramic. The polarized ceramic transducers, on the other hand, are the most efficient generators of ultrasonic energy; they operate well on low voltage, are practically unaffected by moisture, and are usable up to about 300° C. They are limited by relatively low mechanical strength, some mode conversion interference, and have a tendency to age.

c. Lithium Sulfate. Lithium sulfate transducers are the most efficient receivers of ultrasonic energy and are intermediate as a generator of ultrasonic energy. They do not age and are affected very little by mode conversion interference. Lithium sulfate is very fragile, soluble in water, and limited to use at temperature below 165° F.

5. CRYSTAL PLANES

Natural crystals, such as quartz, used in transducers are cut in either one of two planes. X-cut crystals are cut perpendicular to the X-axis and produce longitudinal sound waves. The Y-cut crystals are cut perpendicular to the Y axis and produce shear sound waves.

6. TRANSDUCER TYPES

Transducers are made in a limitless number of sizes and shapes from extremely small to 6-inch wide paint-brush transducers. The many shapes are the result of much experience and the requirement for many special applications. Size of a transducer is a contributing factor to its performance. For instance, the larger the transducer, the straighter the soundbeam (less beam spread) for a given frequency. The narrower beams of the small high-frequency transducers have greater ability for detecting very small discontinuities. The larger transducers transmit more sound energy into the test part, so are used to gain deeper penetration. The large single-crystal transducers are generally limited to lower frequencies because the very thin high-frequency transducers are susceptible to breaking and chipping.

a. Paint-Brush Transducers. The wide paint-brush transducers are made up of a mosaic pattern of smaller crystals, carefully matched so that the intensity of the beam pattern varies very little over the entire length of the transducer. This is necessary to maintain uniform sensitivity. Paint-brush transducers provide a long, narrow rectangular beam (in cross-section) for scanning

large surfaces, and their purpose is to quickly discover discontinuities in the test specimen. Smaller, more sensitive transducers are then used to define the size, shape, orientation, and exact location of the discontinuities. Figure 3-10 shows a typical paint-brush transducer.
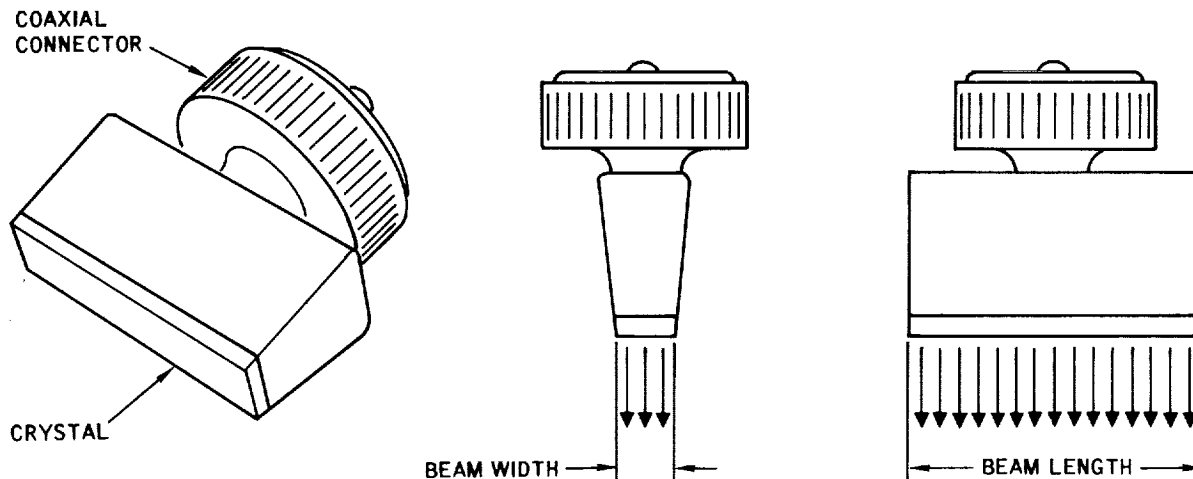

Figure 3-10. Typical Paint-Brush Transducer

b. Double Transducers. The double transducer differs from the single transducer in that, while the single transducer may be a transmitter only, a receiver only, or both transmitter and receiver, the double unit is in essence two single transducers mounted in the same holder for pitch-and-catch testing. In the double unit, one transducer is the transmitter and the other is the receiver. They may be mounted side by side for straight-beam testing, and stacked or paired for angle-beam testing. In all cases, the crystals are separated by a sound barrier to block cross interference. Figure 3-11 shows both types of double transducers.

c. Angle-Beam Transducers. Transducers are also classified as either straight-beam transducers or angle-beam transducers. The term "straight-beam" means that the sound energy from the transducer is transmitted into the test specimen, normal (perpendicular) to the test surface. Angle-beam transducers direct the soundbeam into the test specimen surface at an angle other than 90 degrees. Angle-beam transducers are used to locate discontinuities oriented at right angles to the surface and to determine the size of discontinuities oriented at an angle between 90 and 180 degrees to the surface. Angled transducers are also used to propagate shear, surface, and plate waves into the test specimen by mode conversion. In contact testing, angle-beam transducers use a wedge, usually of plastic, between the transducer face and the surface of the test specimen, to direct the sound energy into the test surface at the desired angle. In immersion testing, angulation
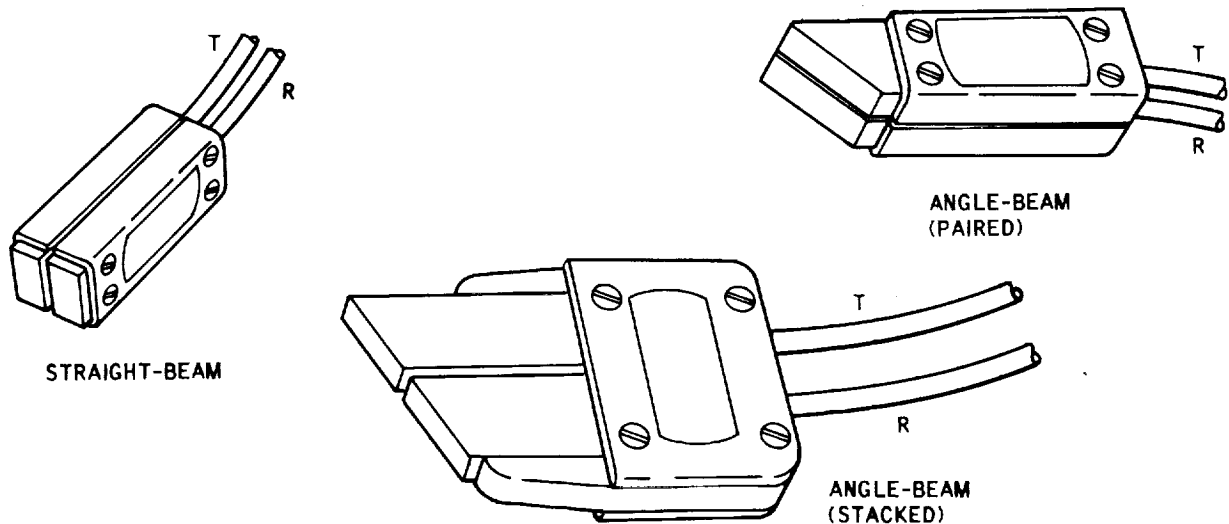
Figure 3-11. Typical Double Transducers

of the soundbeam is accomplished by varying the angle of a straight-beam transducer to direct the soundbeam into the test part at the desired angle. Both straight and angled transducers are shown in Figure 3-12.

d. Faced Unit or Focused Transducers. Other frontal members are added to the transducer for various reasons. On contact transducers, wear plates are often added to protect the fragile crystal from wear, breakage, or the harmful effects of foreign substances or liquids, and to protect the front electrode. Frontal units shaped to direct the sound energy perpendicular to the surface at all points on curved surfaces and radii are known as contour-correction lenses. These cylindrical lenses sharpen the front-surface indication by evening out the sound-travel distance between the
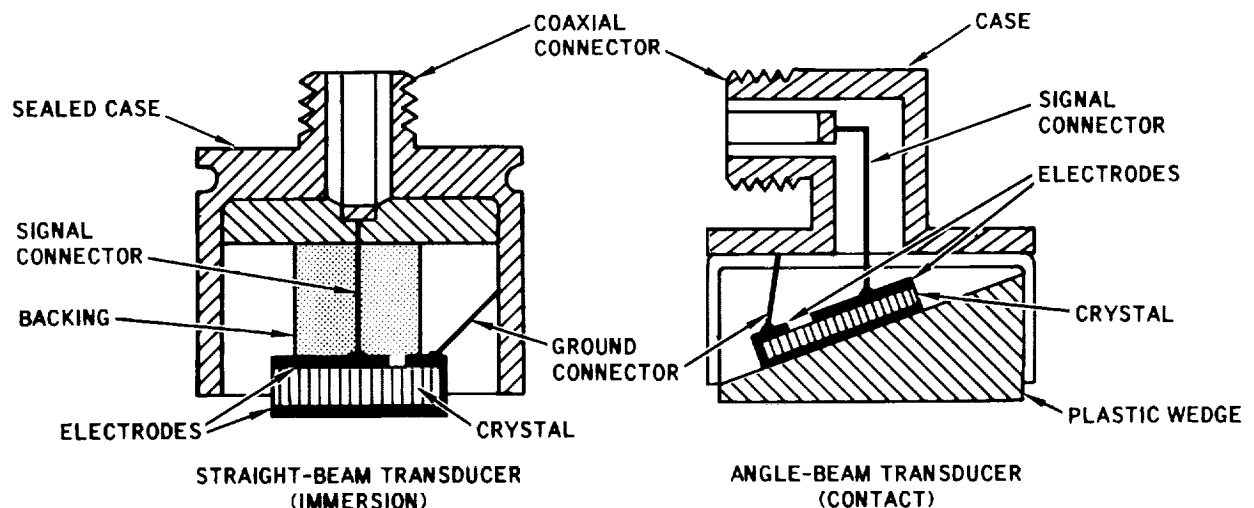

Figure 3-12. Straight-Beam and Angle-Beam Transducers

transducer and the test surface. A comparison of flat and contoured trans-
ducers is shown in Figure 3-13. Other acoustic lenses focus the soundbeam

FLAT
TRANSDUCER

UNCORRECTED   CORRECTED
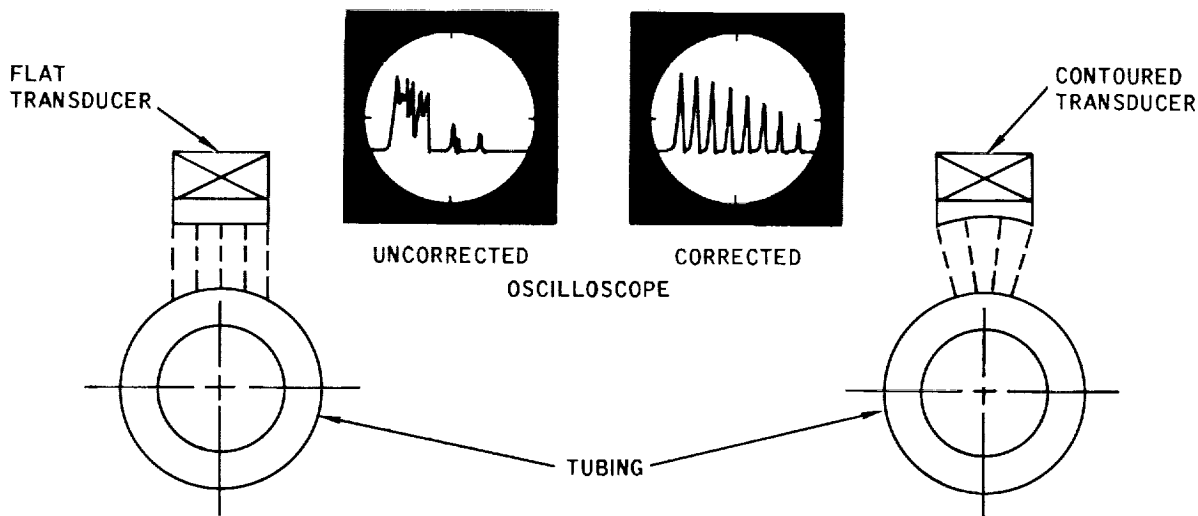OSCILLOSCOPE

CONTOURED
TRANSDUCER

TUBING

Figure 3-13. Flat and Contour-Corrected Transducers

from the transducer, much as light beams are focused. Focused transducers
concentrate the sound energy into a long, narrow, blunt-pointed beam of in-
creased intensity, which is capable of detecting very small discontinuities
in a relatively small area. Focusing the soundbeam moves its point of
maximum intensity towards the transducer, but shortens its usable range.
The test specimen has the effect of a second lens, in this case, because the
beam is refracted, as shown in Figure 3-14, when the beam enters the test
surface. The increased intensity produces increased sensitivity; also,
moving the point of maximum intensity closer to the transducer (which is
also closer to the test surface) improves the near-surface resolution. The

WATER

FOCUSED
TRANSDUCER

SPHERICAL LENS

SOUND BEAM

METAL

DIVERGENCE
BEYOND FOCUS

BEAM REFRACTED WITH
GREATER CONVERGENCE

NEW POINT OF
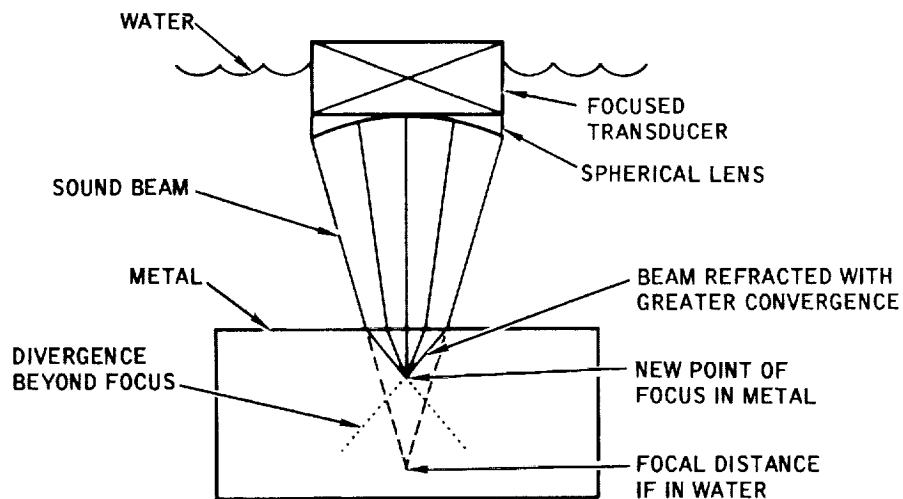FOCUS IN METAL

FOCAL DISTANCE
IF IN WATER

Figure 3-14. Focused-Beam Shortening in Metal

disturbing effects of rough surfaces and metal noise are also reduced by concentrating the sound energy into a smaller beam. This is true, simply because a smaller area is being looked at. In a smaller area, the true discontinuity indications will be relatively large compared to the combined noise of other irrelevant indications. The useful thickness range of focused transducers is approximately 0.010 to 2.0 inches.

e. Contact Transducers. Contact transducers are made for both straight- and angle-beam testing. Straight-beam contact transducers are grounded in one of two ways. Figure 3-15 shows the type in which one face of the crystal contacts the test surface and the ground is made through the test surface.
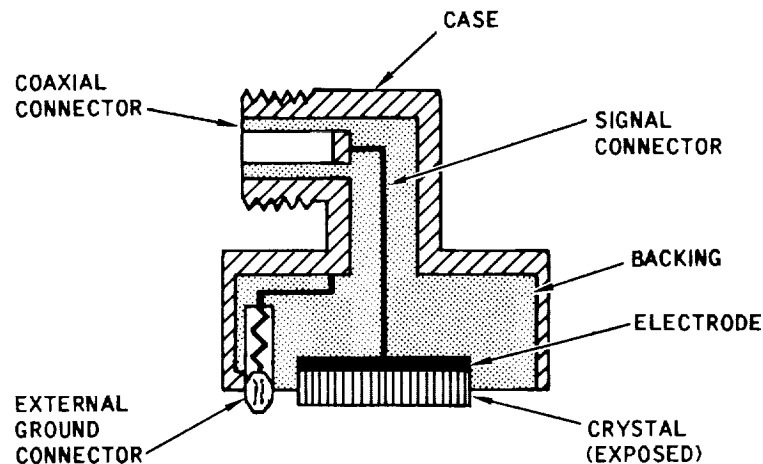

Figure 3-15. Contact Transducer, Externally Grounded

These transducers are used only on electrically-conductive materials with reasonably smooth surfaces. When the unit is faced, as shown in Figure 3-16, an electrode on the front face of the crystal provides for an internal ground. All angle-beam and immersion-type transducers are internally grounded. In addition, the immersion-type transducers including the coaxial cable connection, are completely water-proofed, since in use they are completely submerged.

7. FREQUENCY SELECTION

The frequency of a transducer is a determining factor in its use. Basic characteristics are affected by the need for sensitivity. Sensitivity is related to wavelength: the higher the frequency, the shorter the wavelength; the shorter the wavelength, the higher the sensitivity. Transducer frequency and crystal thickness are also related. The higher the frequency, the thinner the crystal. Most ultrasonic testing is done at frequencies between 0.2 and 25 Mc, but contact testing is generally limited to 10 Mc

CASE

COAXIAL
CONNECTOR

SIGNAL
CONNECTOR

BACKING

INTERNAL
GROUND
CONNECTOR

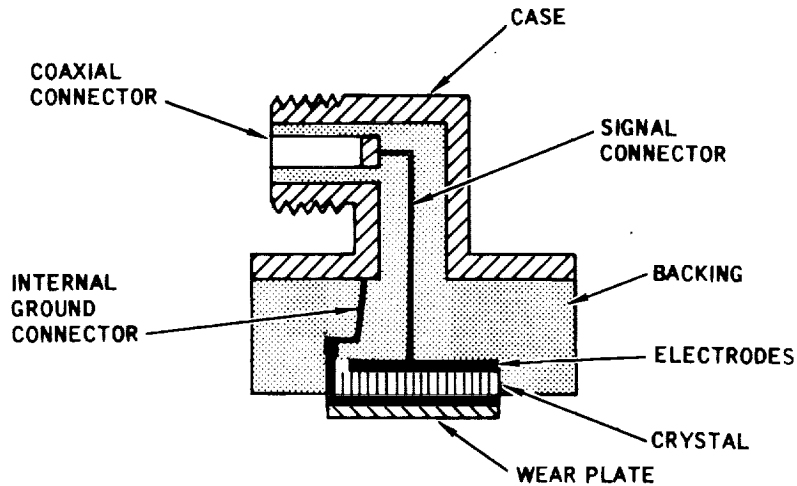ELECTRODES

CRYSTAL

WEAR PLATE

Figure 3-16. Contact Transducer, Internally Grounded

because crystals ground for use above 10 Mc are too thin and fragile for practical contact testing. Other considerations are:

a. The higher the frequency of a transducer, the straighter (least beam spread) the soundbeam and the greater the sensitivity and resolution, but the attenuation is also greatest and the penetration is poor.

b. The lower the frequency of a transducer, the deeper the penetration and the less the attenuation; but the greater the beam spread, the less the sensitivity and resolution.

c. At any given frequency, the larger the transducer, the straighter the soundbeam, but the less the sensitivity.

304   COUPLANTS

1.   GENERAL

The couplant, as the name implies, couples the transducer to the surface of the test specimen. A couplant is used between the transducer face and the test surface to ensure efficient sound transmission from transducer to test surface. The couplant accomplishes this by smoothing out the irregularities of the test surface and by excluding all air between the transducer and the test surface. The couplant can be any of a vast variety of liquids, semi-liquids, pastes, and even some solids, that will satisfy the following requirements:

a. A couplant wets both the surface of the test specimen and the face of the transducer and excludes all air between them.

b. A couplant is easy to apply.

c. A couplant is homogeneous and free of air bubbles, or solid particles in the case of a nonsolid.

d. A couplant is harmless to the test specimen and transducer.

e. A couplant has a tendency to stay on the test surface, but is easy to remove.

f. A couplant has an acoustic impedance between that of the transducer face and the test specimen, preferably approaching that of the test surface.

2. IMMERSION COUPLANT

In immersion testing, nothing more than clean, deaerated tap water, with an added wetting agent, is used for a couplant. For operator comfort, the water temperature is usually maintained at 70° F by automatic controls.

3. CONTACT COUPLANT

In contact testing, the choice of couplant depends primarily on the condition of the surfaces contacted by the transducer. One-part glycerine with two-parts water, and a wetting agent, is often used on relatively smooth surfaces, and is an excellent couplant. For slightly rough surfaces, light oils (such as SAE 20 motor oil) with a wetting agent, are used. Heavier oil and grease are used on rough surfaces and on hot or vertical surfaces. In all cases, the couplant selected is as thin as possible, with effective, consistent results.

305 STANDARD REFERENCE BLOCKS

1. GENERAL

In ultrasonic testing, all discontinuity indications are compared to a reference standard. The reference standard may be any one of many reference blocks or sets of blocks specified for a given test. Ultrasonic standard reference blocks, often called test blocks, are used in ultrasonic testing to standardize the ultrasonic equipment and to evaluate the discontinuity indication from the test part. Standardizing does two things: it verifies that the instrument/transducer combination is performing as required; it establishes a sensitivity or gain setting at which all discontinuities of the size specified, or larger, will be detected. Evaluation of discontinuities within the test specimen is accomplished by comparing the indications from them with the indication from an artificial discontinuity of known size, at the same depth in a ·standard reference block of the same material. Standard test blocks are made from carefully selected, ultrasonically-inspected stock to meet predetermined standards of sound attenuation, grain size, and heat treat. Discontinuities are represented by carefully drilled flat-bottomed holes. Test blocks are made with painstaking care so that the only disconti- -nuity present is the one that was added intentionally. The three most familiar sets of reference blocks are the Alcoa series A, area/amplitude blocks; the Alcoa series B or

Hitt, distance/amplitude blocks; and the ASTM basic set of blocks that combine area/ and distance/amplitude blocks in one set.

2. AREA/AMPLITUDE BLOCKS SET

The Alcoa series A set consists of eight blocks, 3 3/4-inches long and 1 15/16-inches square. A 3/4-inch deep flat-bottomed hole (FBH) is drilled in the bottom center of each block. The hole diameters are 1/64-inch in the No. 1 block through 8/64-inch in the No. 8 block, as shown in Figure 3-17. As implied, the block numbers refer to the FBH hole diameter, e.g., a No. 3 block has a 3/64-inch diameter flat-bottomed hole. Area/amplitude blocks provide a means of checking the linearity of the test system; that is, they confirm that the amplitude (height) of the indication on the oscilloscope screen increases in proportion to the increase in size of the discontinuity. Similar area/amplitude reference blocks are made from 2-inch diameter round stock.
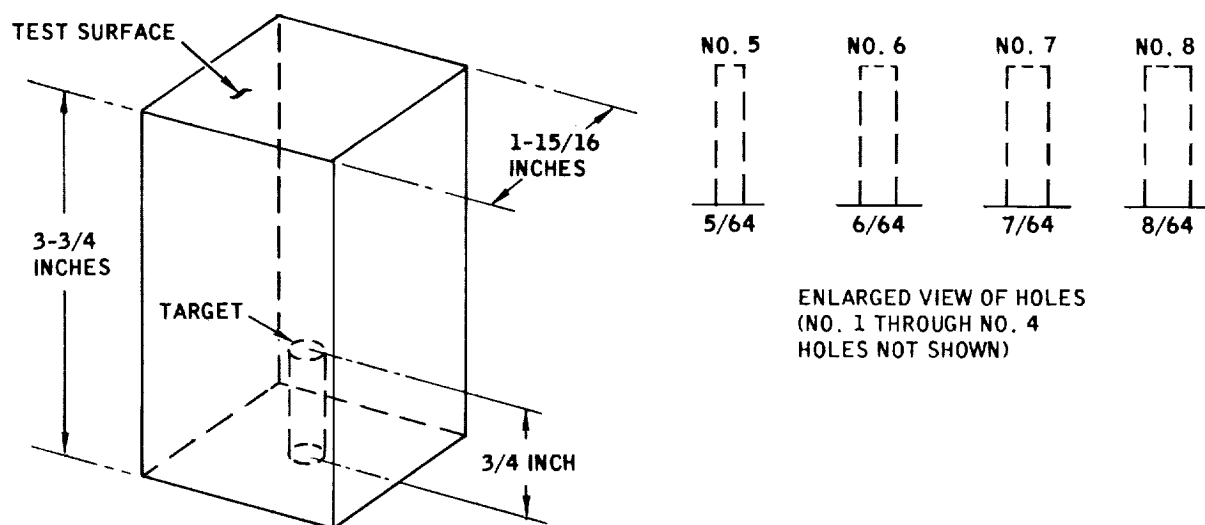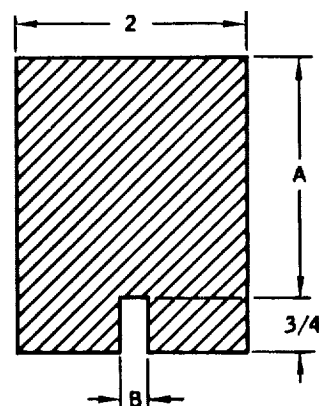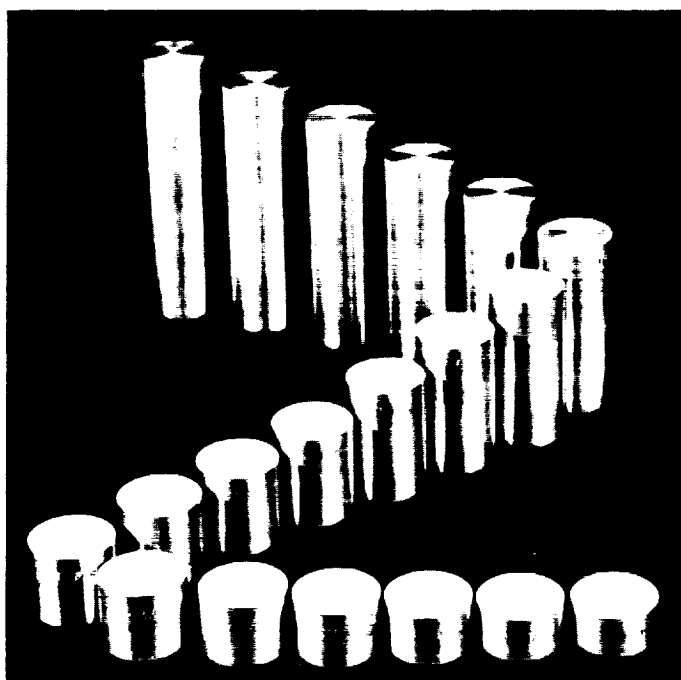

Figure 3-17. Area/Amplitude Reference Blocks

3. DISTANCE/AMPLITUDE BLOCKS SET

The Alcoa series B or Hitt blocks set consists of nineteen 2-inch diameter cylindrical blocks, all with 3/4-inch deep flat-bottomed holes of the same diameter, drilled in the center at one end. These blocks vary in length to provide metal distances of 1/16-inch to 5-3/4-inches from the test surface to the flat-bottom hole. Sets are available with 3/64, 5/64, and 8/64-inch diameter holes. The metal distances are: 1/16-inch, 1/8-inch through 1-inch in eightg-inch increments, and 1-1/4 inch through 5-3/4-inch in half-inch increments, as shown in Figure 3-18. Distance/amplitude blocks serve as a reference to evaluate the size of discontinuities at varying depths within the test material. They also serve as a reference for setting or standardizing the sensitivity or gain of the test system so that it will display readable indications on the oscilloscope screen for all discontinuities of a given size and over, but will not flood the screen with indications of smaller discontinuities that are of no interest. On instruments so

Figure 3-18. Distance/Amplitude Reference Blocks (Hitt)

| DIMENSION A |
| 1/16 |
| 1/8 |
| 1/4 |
| 3/8 |
| 1/2 |
| 5/8 |
| 3/4 |
| 7/7 |
| 1 |
| 1 1/4 |
| 1 3/4 |
| 2 1/4 |
| 2 3/4 |
| 3 1/4 |
| 3 3/4 |
| 4 1/4 |
| 4 3/4 |
| 5 1/4 |
| 5 3/4 |

DIMENSION B

| 3/64 |
| 5/64 |
| 8/64 |

equipped, these blocks are used to set the STC (sensitivity time control) or DAC (distance amplitude correction) so that a discontinuity of a given size will produce an indication of the same amplitude on the oscilloscope screen, regardless of its distance from the front surface.

4. BASIC BLOCKS SET

The ASTM basic set consists of ten 2-inch blocks that also have 3/4-inch deep, flat-bottomed holes drilled in the center at one end. One block has a 3/4-inch diameter FBH and a metal distance of 3 inches from the test surface to the flat-bottom hole. The next seven blocks each have a 5/64-inch FBH and metal distances of 1/8, 1/4, 1/2, 3/4, 1-1/2, 3, and 6 inches from the test surface to the FBH. The two remaining blocks have 8/64-inch diameter FBH and metal distances of 3 inches and 6 inches. In this basic set, the three No. 3, 5, and 8 blocks with the 3-inch metal distance, provide the area/amplitude relationship, and the seven blocks with the 5/64-inch diameter FBH (No. 5) and varying metal distances, provide the distance/amplitude relationship. Figure 3-19 shows a basic set. It is important that the test block material be the same, or similar to that of the test specimen. Alloy content, heat treatment, degree of hot or cold working from forging, rolling, etc., all affect the acoustical properties of the material. If test blocks of identical material are not available, they must be similar in sound attenuation, velocity, and impedance.

3-21
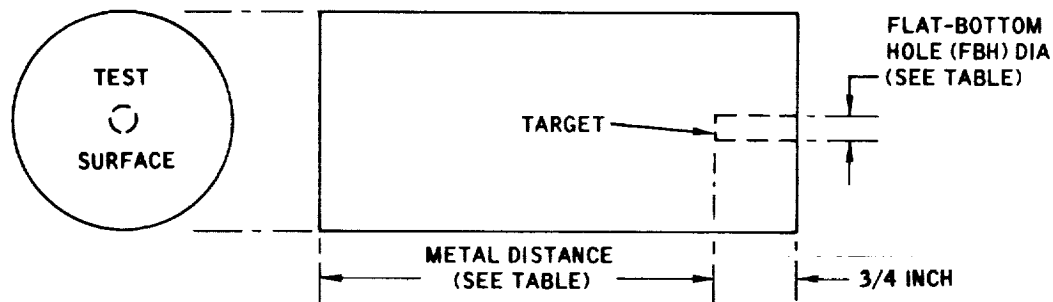
METAL DISTANCE, INCHES	1/8	1/4	1/2	3/4	1-1/2	3	3	3	6	6
FBH DIA IN 64THS INCH	5	5	5	5	5	3	5	8	5	8

Figure 3-19. ASTM Reference Blocks, Basic Set

5. SPECIAL BLOCKS

The IIW (International Institute of Welding) reference block, and the miniature angle beam field calibration block, shown in Figure 3-20, are examples of other reference standards in common use. For irregularly-shaped articles, it is often necessary to make one of the
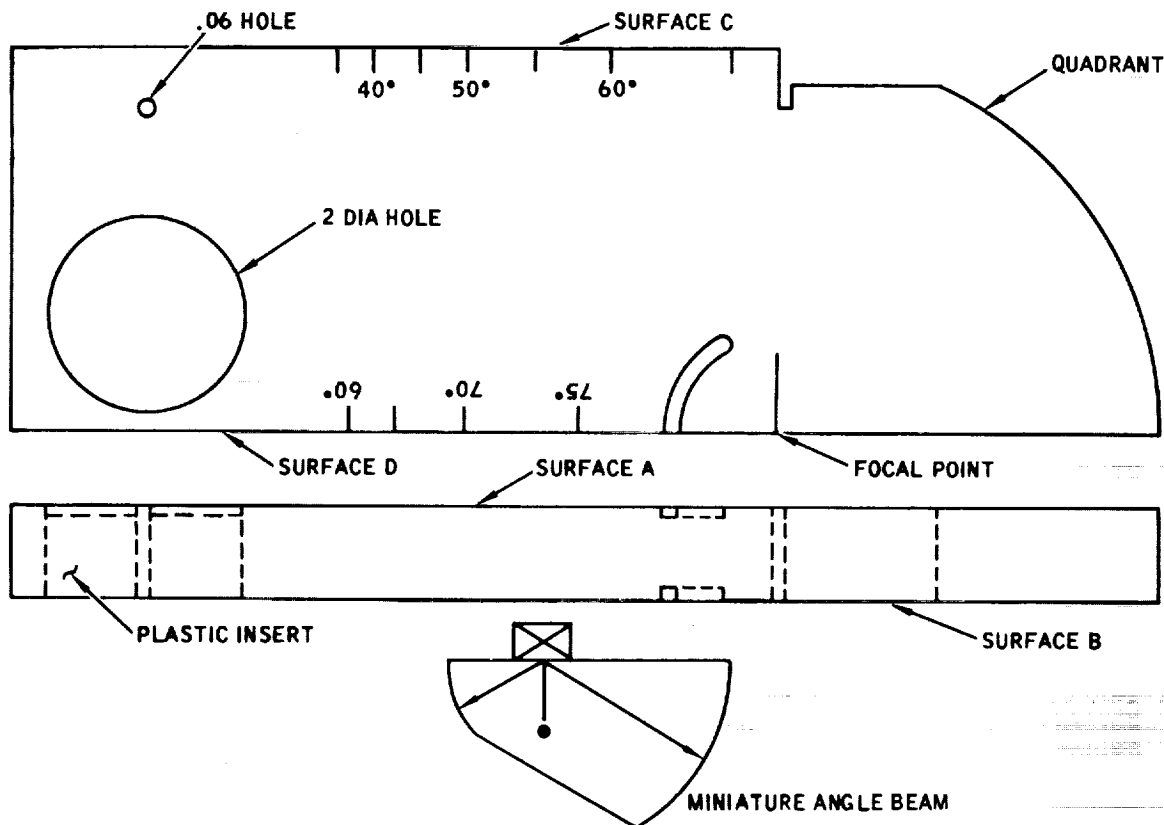

Figure 3-20. Special Reference Blocks

test articles into a reference standard by adding artificial discontinuities in the form of flat-bottom holes, saw cuts, notches, etc.   In some cases, these artificial discontinuities are placed so that they will be removed by subsequent machining of the article. In other cases, a special individual technique is developed by careful study of an article ultrasonically, and then verifying the detection of discontinuities, in the article, by destructive investigation.   The results of the study then become the basis for the testing standard.

306   RESONANCE TESTING EQUIPMENT

1.   GENERAL

Several types of ultrasonic testing equipment are available commercially.   Primarily, these instruments differ in the type of presentation and in the method and width of frequency modulation.   Figure 3-21 shows a functional diagram of a typical instrument with an oscilloscope display.   The oscillator circuit is modulated either by an electrically-variable inductor or by a motor-driven capacitor.   The tuning range of frequency is adjusted by changing the control current on the variable inductor or the motor-driven capacitor.   At high frequencies of 15-30 Mc, high accuracy is obtained over a limited thickness range, such as 0.005 to 0.035 inch.   Wide tuning ranges at lower frequencies and the use of scales calibrated for multiple harmonic lines are
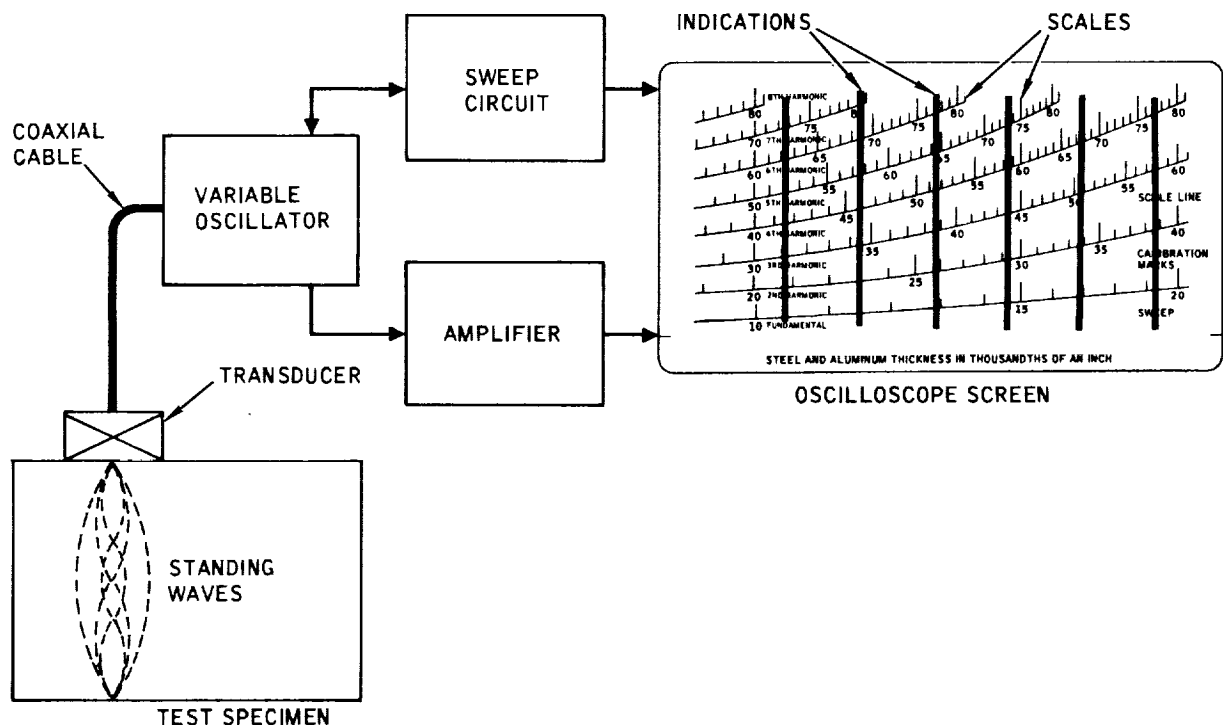

Figure 3-21.   Functional Diagram, Resonance Thickness Tester

used for coverage of a wide thickness range. Typical wide-scale ranges are 0.080 to 0.640 inch at 0.75 to 1.5 Mc and 0.065 to 0.510 inch at 1 to 2 Mc.

2. INDUCTANCE-MODULATED INSTRUMENT (Figure 3-22 and 3-23)

Inductance-modulated instruments have an electrically variable inductor in the oscillator circuit. The control current on the variable inductor is adjusted to change the tuning range. Inductance-modulated instruments have relatively low oscillator capacitance; therefore, when frequencies near 30 Mc are attained, they are capable of indicating measurements of steel and aluminum at a minimum thickness of 0.004 inch. Thicknesses, up to 3 inches, may be read directly by use of interchangeable harmonic scales, made of transparent plastic, placed over the oscilloscope screen. Coaxial cable length from the oscillator to the transducer is usually limited, ranging from 3 feet at high frequencies to 25 feet at low frequencies. If the oscillator is removed from the instrument, extension cables are inserted between these components to extend the working distance of the transducer.
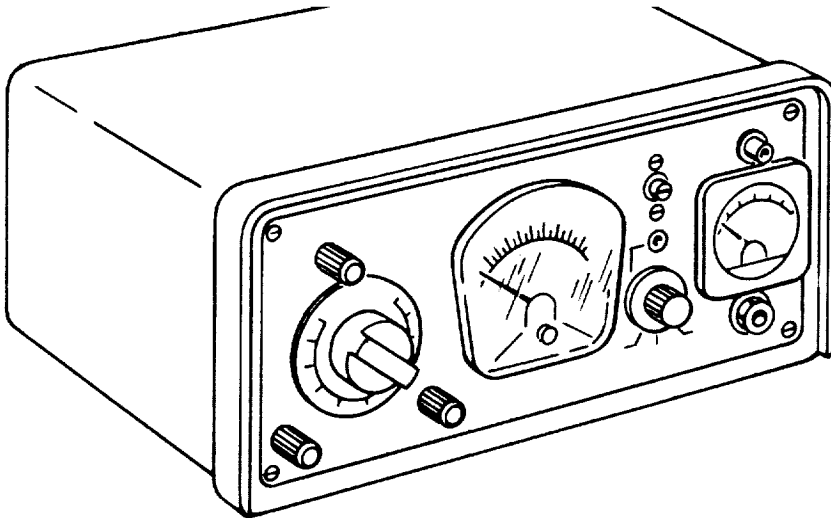

Figure 3-22. Meter-Type Thickness Tester, Inductance Modulated

3. CAPACITANCE-MODULATED INSTRUMENT

Capacitance-modulated instruments have an oscillator circuit which contains a motor-driven capacitor whose rotor is connected into the circuit through brushes or wipers. For oscilloscope display, the rotation of the capacitor is synchronized with the horizontal sweep of the trace across the oscilloscope screen. Each cycle of capacitance change of the motor-driven capacitor produces a corresponding frequency change. The horizontal axis of the cathode-ray tube indicates a frequency range. If this frequency range has resonant frequencies, the trace line is deflected vertically, giving a series of harmonic frequency indications on the oscilloscope screen. The stroboscopic-type instrument, as shown in Figure 3-24, has a rotating disc with a neon lamp mounted on the outer edge. As the disc rotates with the capacitor, the neon lamp flashes in phase
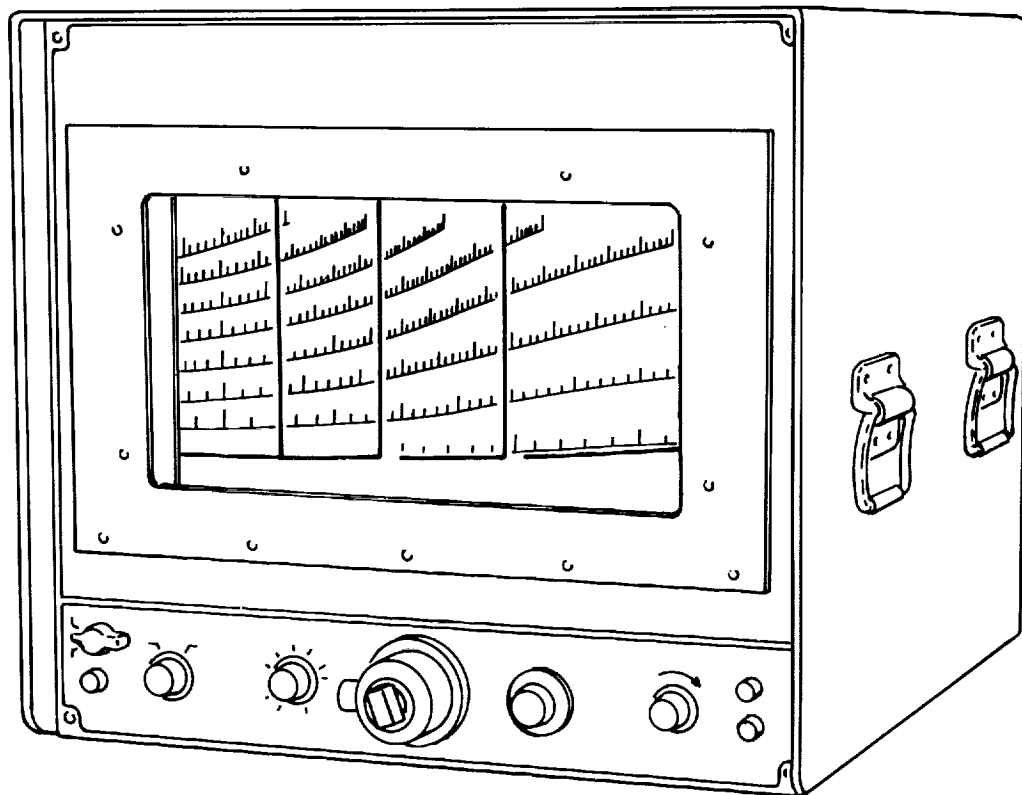
Figure 3-23. Oscilloscope-Type Thickness Tester, Inductance Modulated

with the scanned frequency of each rotation. Viewed through the readout slot in the upper quadrant of the dial, these flashes form a pattern of apparently stationary lights because of the stroboscopic effect. The operator then rotates the harmonic scale disc (center knob shown) until division lines most nearly coincide with the light pattern. The thickness indicator then points to the thickness, in inches, on the thickness scale.
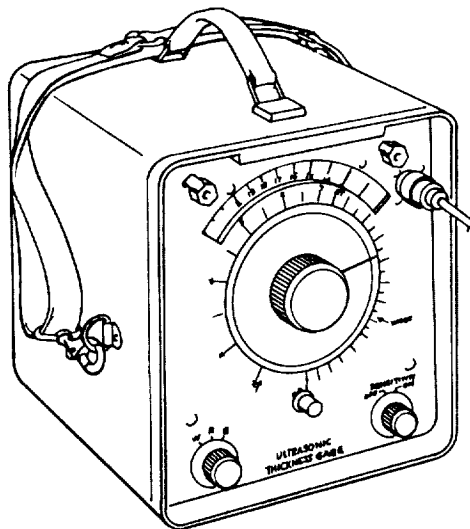

Figure 3-24. Stroboscopic-Type Thickness Tester, Capacitance Modulated

4. MANUALLY-TUNED INSTRUMENTS

Manually-tuned instruments are usually small, portable units that are less complicated than the larger units. Figure 3-25 shows a typical functional diagram for a resonance system that is manually tuned. These instruments are available with either narrow or wide frequency modulating ranges. The narrow-modulating type of instrument is manually tuned over a very narrow range, such as 0.5 to 2.0 percent of the base frequency. If this range produces a resonant frequency from the test specimen, an audible tone is produced in a loudspeaker or a headset. Simultaneously, resonance is indicated by increased deflection of a panel meter. Frequency/thickness conversion is made on a circular slide rule attached to the instrument or is computed on a conversion table. Using wide modulation, the instrument will detect laminar discontinuities in thick plates: for example, an 8-inch thick steel plate with a fundamental frequency of 0.0145 Mc. If the modulating width is 0.1 Mc, each sweep produces seven resonance signals. Modulating at 100 sweeps per second produces an audible 700-cps signal in a headset. A decrease in thickness indication, due to a laminar discontinuity produces a proportionate decrease in the pitch of the audible sound.
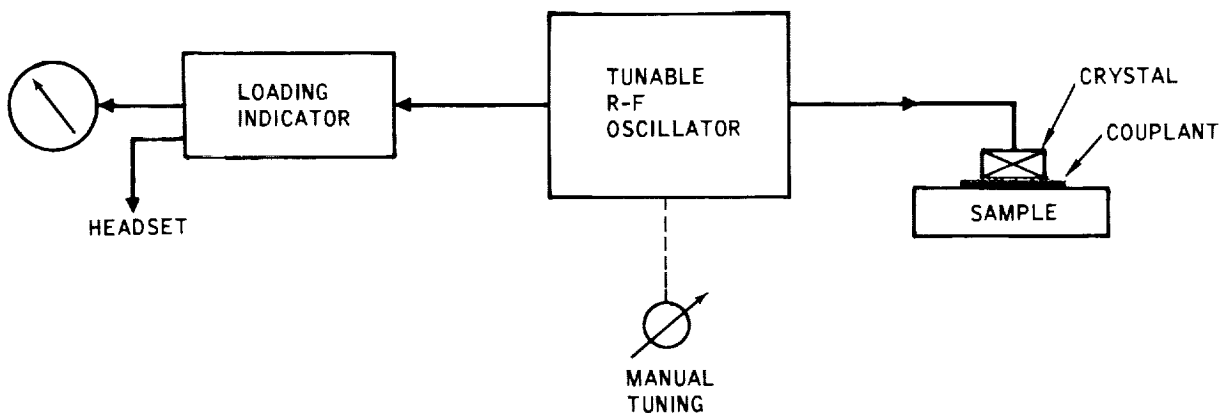

Figure 3-25. Functional Diagram, Manually-Tuned Resonance Tester

5. BOND TESTER

The bond tester is an ultrasonic-impedance instrument system used for checking lack of bond or delamination in bonded structures. The unit transducer is driven by a variable-frequency current of constant amplitude. The voltage developed at the face of the transducer is proportional to the amplitude of the crystal vibration and is displayed as a function of frequency on the oscilloscope screen. Characteristics of crystal vibration are thus shown as a distinctive pattern on the oscilloscope screen. When the transducer is acoustically coupled to a bonded panel, information regarding panel vibration, its resistance to vibration, and therefore its physical characteristics, are

shown on the oscilloscope. Figure 3-26 shows two types of bond testers. Typical test patterns are shown on the face of each oscilloscope screen.
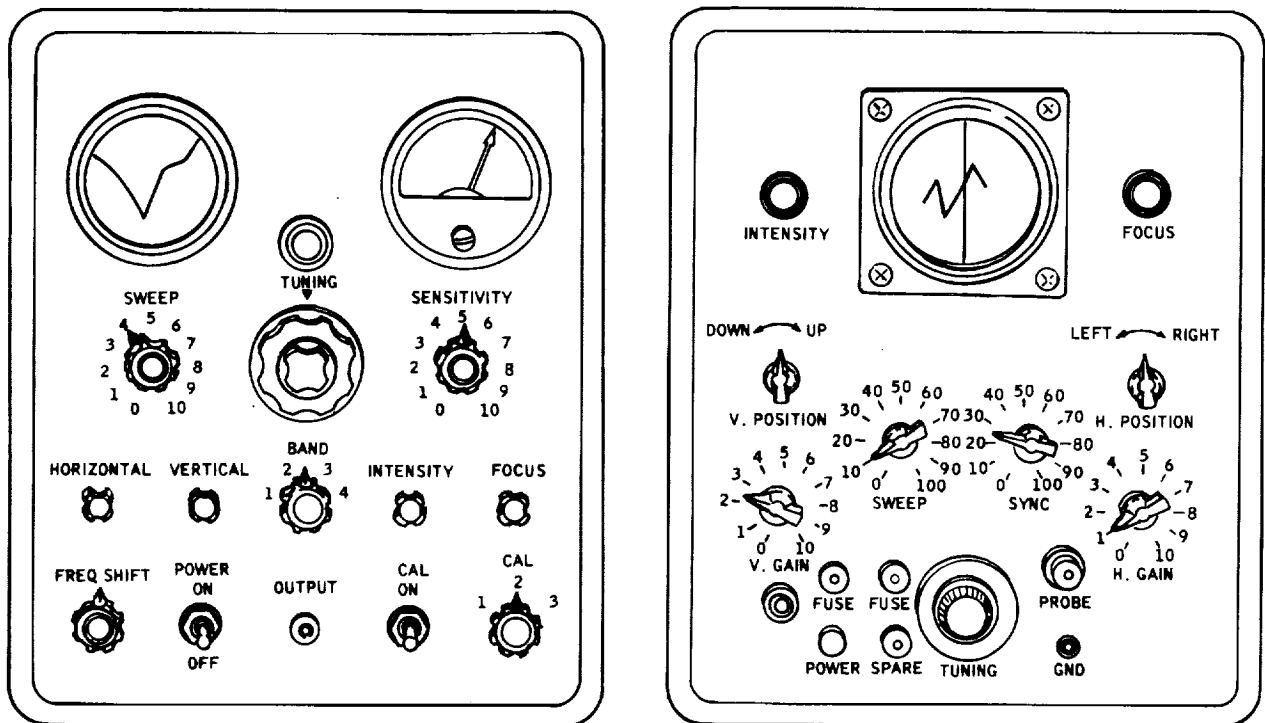

Figure 3-26. Bond Testers

6. RESONANCE INSTRUMENT INDICATIONS

Resonance instrument indications are of two basic types; visual or audible. Visual responses may be displayed by warning lights, on a meter, by stroboscopic lights, or on an oscilloscope screen. Audible notes, heard from a loudspeaker or a pair of headphones, indicate resonant responses. Each type of indication including automatic recording, are discussed in the following paragraphs.

    a.   <u>Oscilloscope Indication</u>. Oscilloscope resonance indications are presented as bright-line vertical peaks on large-screen cathode ray tubes, with a time base 17 to 21 inches long, which cover the operating frequency range of the transducer. These indications are interpreted by placing a transparent scale over the face of the cathode ray tube.

    b.   <u>Stroboscopic Indication</u>. One type of battery-powered portable instrument displays thickness readings with a stroboscopic light presentation. The instrument contains a capacitance-modulated, motor-driven, sweep oscillator arrangement in conjunction with a modified slide rule of the harmonic

matching type. A small neon lamp, shown in Figure 3-27, is made to flash at the instant the sweep capacitor sweeps the oscillator through the fundamental frequency or any harmonic frequency. This neon lamp is fastened to a disc that rotates with the sweep capacitor, and is viewed through an arc-shaped window under a circular slide rule. The stroboscopic effect of the rotating disc results in a steady light pattern related to the thickness of the test specimen. The slide rule is then rotated until the marks on its harmonic scale match up with the light pattern. The thickness of the test specimen is then read on the thickness scale.
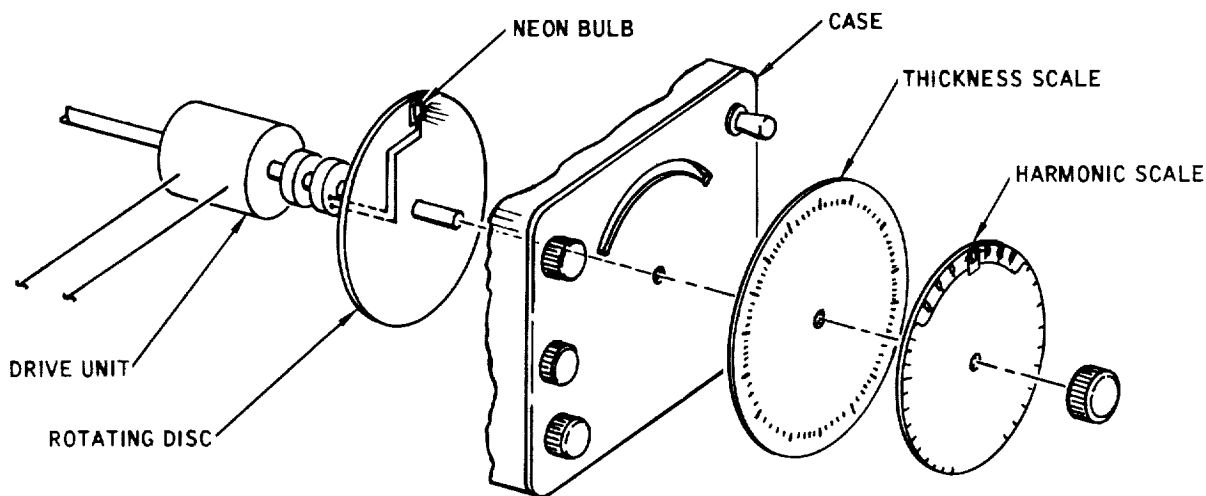

Figure 3-27. Stroboscopic Light Display

c. Headphone, Meter or Warning Light Indication. For field work, other battery-powered units are equipped for indication with meters, warning lights, or headphones. When the instrument produces a resonant frequency from the test specimen, an audible tone is produced in a loudspeaker or a headset. With some units, warning lights are mounted on the instrument; in others, a wire is connected to a ring lamp, worn on a finger of the hand holding the transducer, that lights up when thickness variations or discontinuities are encountered.

d. Automatic Recording Indication. For automatic recording of the indications, gating circuits are added to oscilloscope instruments to detect resonance signals within pre-set limits. The allowable thickness range of the test specimen usually determines the width and location of the gate. Gating limits are marked on the screen of the oscilloscope by small, vertical edge lines or markers. The gate is adjusted so that a strong resonant signal indicating a "normal" condition is included within the gated limits. A loss or absence of this gated signal trips a relay, which in turn operates a recorder, marking device, automatic sorter, or alarm system. To sort material into a number of groups according to thickness, multiple gating circuits are used, as they do not interfere with each other.

7. TRANSDUCERS FOR RESONANCE TESTING

Transducers with crystals made of quartz, ceramic, and barium titanate are generally used for ultrasonic resonance testing. Many types of transducers are available in a variety of shapes and sizes for specific test applications, as shown in Figure 3-28. The resonant frequency of the transducer is matched to the oscillator selected. For example, an oscillator selected. For example, an oscillator with a 4 to 8 Mc tuning range is used with a 9 Mc transducer. The resonant frequency of the transducer is normally 10 to 20 percent higher than the maximum frequency of the oscillator tuning range. Figure 3-29 shows the operating frequency of a 9 Mc transducer in relation to sensitivity. As shown, the transducer is most sensitive at its natural frequency.

8. RESONANCE TESTING REFERENCE BLOCKS

Ultrasonic resonance testing units require the use of reference standards for adjusting the instrument at the beginning of each test. The equipment is standardized to the reference block before proceeding with the test. The thickness and material of the test specimen is related to the reference block selected. Standard reference blocks, shown in Figure 3-30, are carefully ground to predetermined thicknesses in steps or wedges with a very fine degree of taper. On these blocks, the thickness at each test

FINGERTIP

PENCIL

SWIVEL

RIGID RIGHT ANGLE

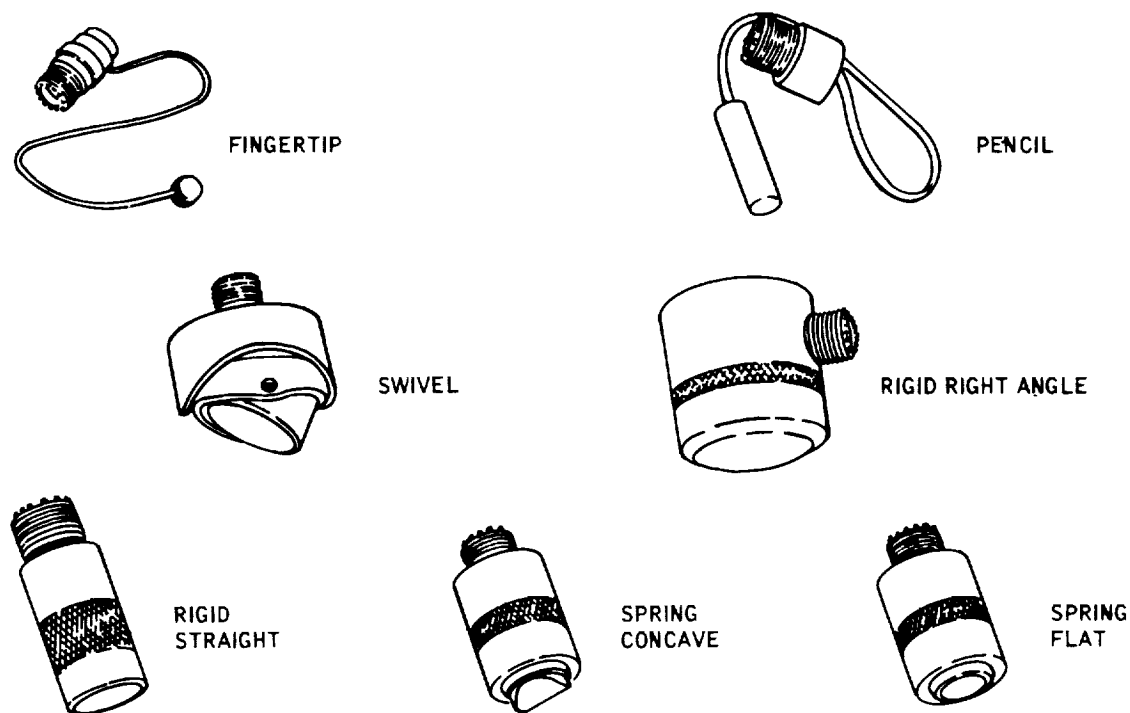RIGID STRAIGHT

SPRING CONCAVE

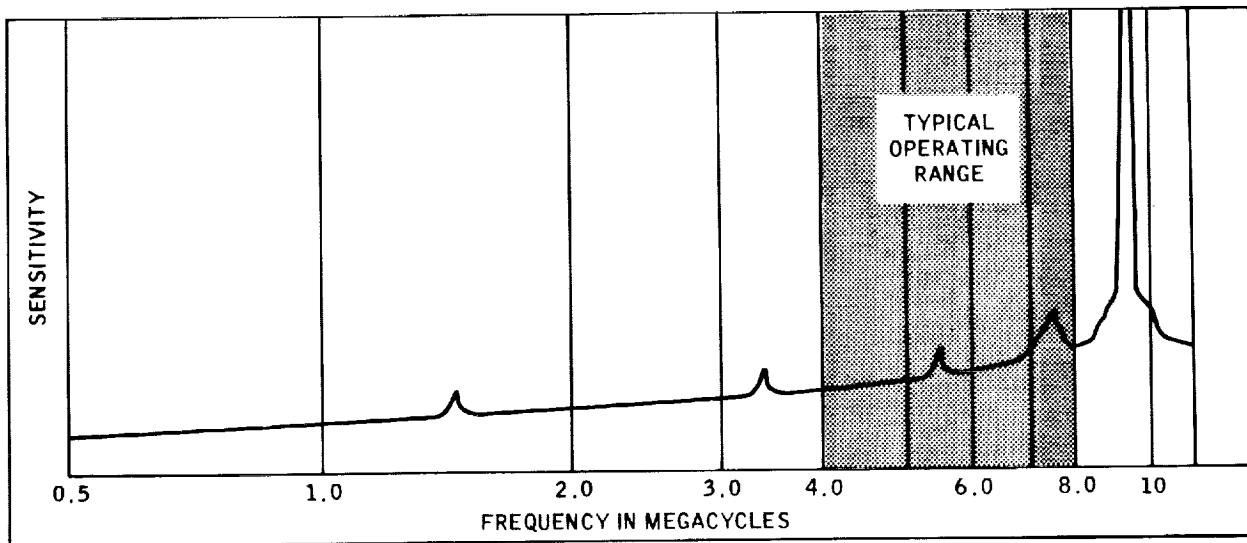SPRING FLAT

Figure 3-28. Resonance Transducers

Figure 3-29. 9 Mc Resonance Transducer Operating Frequency Range

point is clearly indicated. When the test specimen can be measured with calipers or micrometers, the test specimen is used for standardizing the instrument.
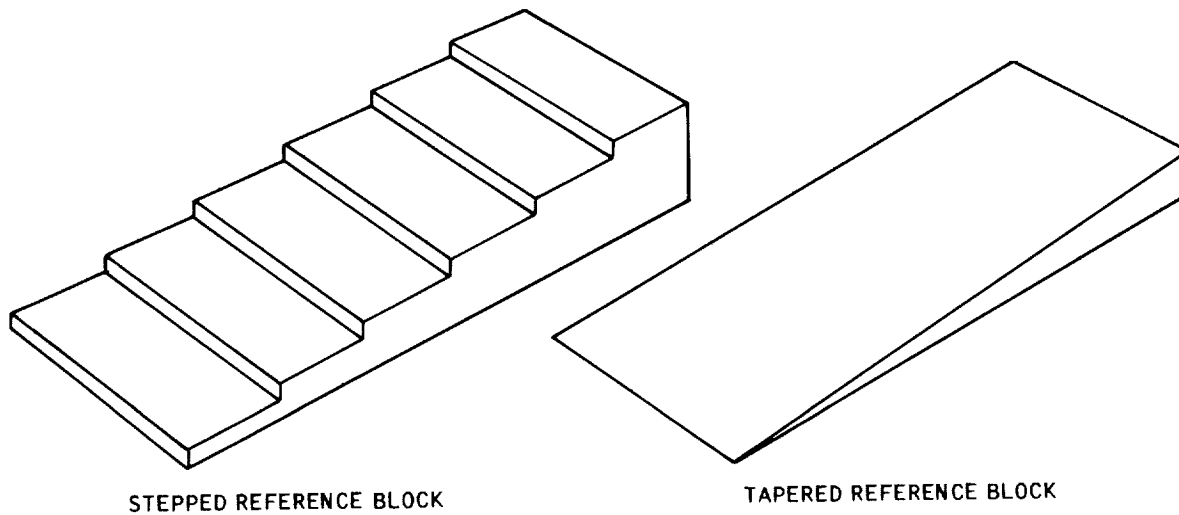

STEPPED REFERENCE BLOCK   TAPERED REFERENCE BLOCK

Figure 3-30. Resonance Testing Reference Blocks

CHAPTER 4: TECHNIQUES
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CHAPTER 4: TECHNIQUES

400 GENERAL

Techniques of ultrasonic testing are accomplished with one of two basic methods: contact or immersion testing. In contact testing, the transducer is used in direct contact with the test specimen, with only a thin liquid film for a couplant. On some contact units, plastic wedges, wear plates, or flexible membranes are mounted over the face of the crystal. These units are considered as contact when the soundbeam is transmitted through a substance other than water. The display from a contact unit usually shows the initial pulse and the front surface reflection as superimposed or very close together. In immersion testing, a waterproof transducer is used at a distance from the test specimen, with the ultrasound transmitted into the material through a water path or column. The water distance appears on the display as a fairly wide space between the initial pulse and the front surface reflection because of the reduced velocity of sound in water. In the following paragraphs, immersion techniques are discussed first, with coverage of contact techniques following.

401 IMMERSION TECHNIQUES

1. GENERAL

Any one of three techniques is used in the immersion method: immersed technique, where both the transducer and the test specimen are immersed in water; bubbler or squirter technique, where the soundbeam is transmitted through a column of flowing water; and wheel-transducer technique, where the transducer is mounted in the axle of a liquid-filled tire that rolls on the test surface. An adaptation of the wheel-transducer technique is a unit with the transducer mounted in the top of a water-filled tube. A flexible membrane on the lower end of the tube couples the unit to the test surface. In all three of these techniques, a further refinement is the use of focused transducers that concentrate the soundbeam (much like light beams when passed through a magnifying glass). The bubbler and wheel-transducer techniques are shown in Figure 4-1.

2. IMMERSED TECHNIQUES

In the immersed technique, both the transducer and the test specimen are immersed in water. The soundbeam is directed through the water into the material, using either a straight-beam technique for generating longitudinal waves or one of the many angle-beam techniques for generating shear waves. In many automatic scanning operations, focused-beams are used to detect near-surface discontinuities or to define minute discontinuities with the concentrated soundbeam.

The transducers usually used in immersion testing are straight-beam units that accomplish both straight- and angle-beam testing through manipulation and control of the soundbeam direction. The water-path distance must be considered in immersion

BUBBLER TECHNIQUE

WHEEL-TRANSDUCER TECHNIQUE
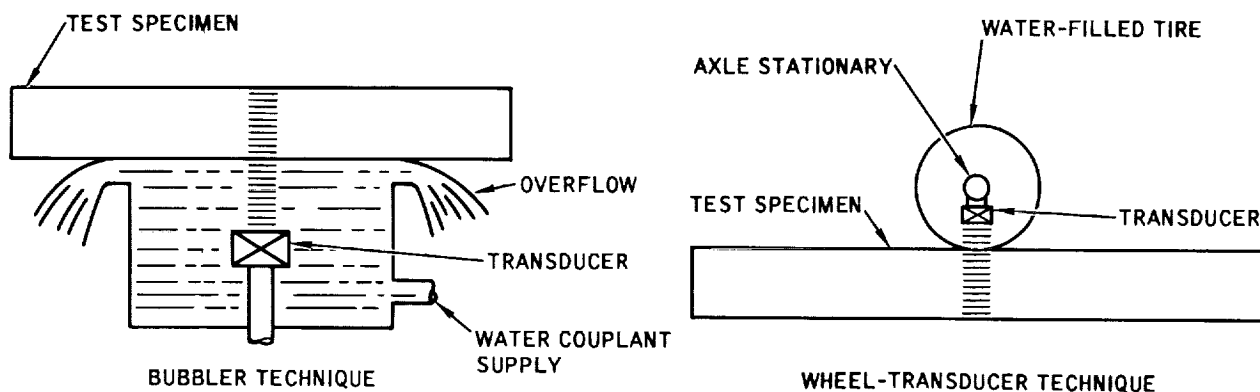
Figure 4-1. Bubbler and Wheel-Transducer Techniques

testing. This is the distance between the face of the transducer and the test surface. This distance is usually adjusted so that the time required to send the soundbeam through the water is greater than the time required for the sound to travel through the test specimen. When done properly, the second front surface reflection will not appear on the oscilloscope screen between the first front and first back surface reflections. In water, sound velocity is about 1/4 that of aluminum or steel; therefore, one inch of water path will appear on the oscilloscope screen as equal to four inches of metal path in steel. A rule of thumb for setting the water distance, is 1/4 thickness of the part, plus 1/4 inch. The correct water-path distance is particularly important when the test area shown on the oscilloscope screen is gated for automatic signalling and recording operations. Careful setting of this distance is done to clear the test area of unwanted signals that cause confusion and misinterpretation. Figure 4-2 shows the water path relationship.
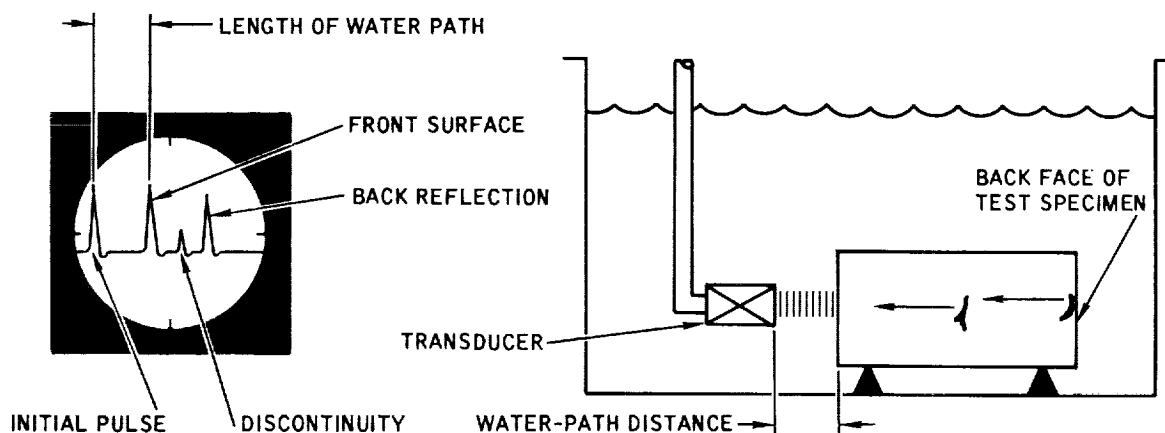
Figure 4-2. Water-Path Distance Adjustment

3. BUBBLER TECHNIQUES

The bubbler technique is essentially a variation of the immersion method, where the soundbeam is projected through a water column into the test specimen. The bubbler is usually used with an automated system for high-speed scanning of plate, sheet, strip, cylindrical forms, and other regularly-shaped parts. The soundbeam is projected into the material through a column of flowing water, and is directed normal (perpendicular) to the test surface for longitudinal waves or is adjusted at an angle to the surface to produce shear waves.

4. WHEEL-TRANSDUCER TECHNIQUES

The wheel-transducer technique is an aspect of the immersion method in that the soundbeam is projected through a water-filled tire into the test specimen. The transducer, mounted in the wheel axle, is held in a fixed position, while the wheel and tire rotate freely. The wheel may be mounted on a mobile apparatus that runs across the material, or it may be mounted on a stationary fixture, where the material is moved past it. Figure 4-3 illustrates the stationary and the moving wheel transducer. The position and angle of the transducer mounting on the wheel axle may be constructed to project straight-beams, as shown in Figure 4-3, or to project angled beams as shown in Figure 4-4.

402 CONTACT TECHNIQUES

1. GENERAL

Contact techniques are divided into three categories, which are determined by the soundbeam wave mode desired: straight-beam technique for transmitting longitudinal waves in the test specimen, angle-beam technique for generating shear waves, and surface-wave technique for producing Rayleigh or Lamb waves. Transducers used in
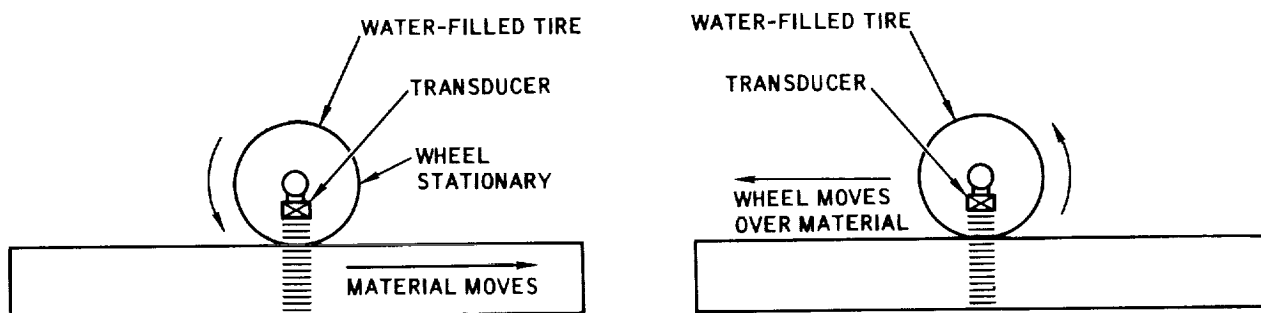
Figure 4-3. Stationary and Moving Wheel Transducers

SOUND BEAM DIRECTED IN FORWARD DIRECTION

SOUND BEAM DIRECTED TO THE SIDE 90°

SOUND BEAM ANGLED TO THE SIDE AND FORWARD

SOUND PROPAGATED INTO MATERIAL AT 45° ANGLE

ANGLE OF PROPAGATION MAY BE VARIED BY
ADJUSTING POSITION OF WHEEL MOUNTING YOKE
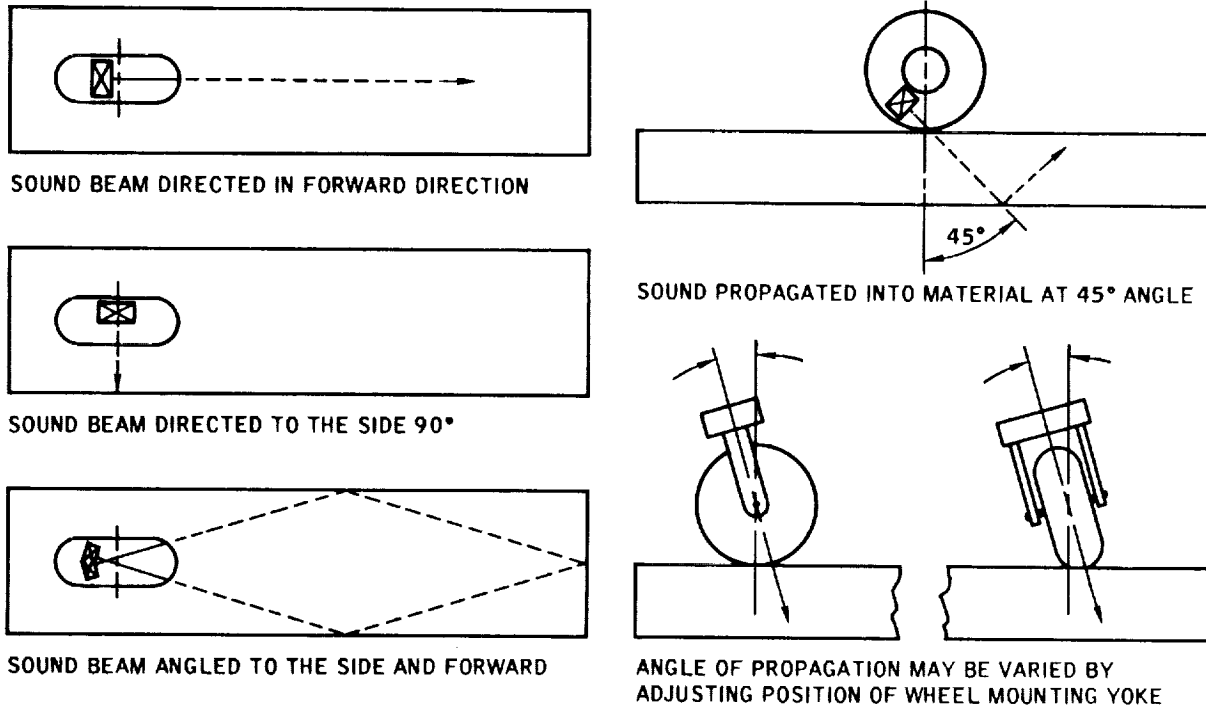
Figure 4-4. Wheel Transducer Angular Capabilities

these techniques are held in direct contact with the material using a thin, liquid film for a couplant. The couplant selected is high enough in viscosity to remain on the test surface during the test. For most contact testing, the couplant is relatively thin; refer to Chapter 3: Equipment, for more information on contact transducers and couplants.

2. STRAIGHT-BEAM TECHNIQUES

The straight-beam technique is accomplished by projecting a soundbeam into the test specimen (perpendicular to the test surface) to obtain pulse-echo reflections from the back surface or from intermediate discontinuities. This technique is also used to test for through transmission with two transducers, where the internal discontinuities interrupt the soundbeam, causing a reduction in the received signal.

    a.   Echo Techniques. Echo reflections are produced with single or double, straight-beam transducers. Figure 4-5 shows the single unit, straight-beam transducer in use. With the single unit, the transducer acts as both transmitter and receiver, projecting a beam of longitudinal waves into the specimen and receiving echoes reflected from the back surface and from any discontinuity lying in the beam path. The double transducer unit is useful when the test surface is rough or when the specimen shape is irregular and the back sur-

4-8

TRANSDUCER

SOUND REFLECTED BACK
TO TRANSDUCER FROM
DISCONTINUITY AND BACK
SURFACE
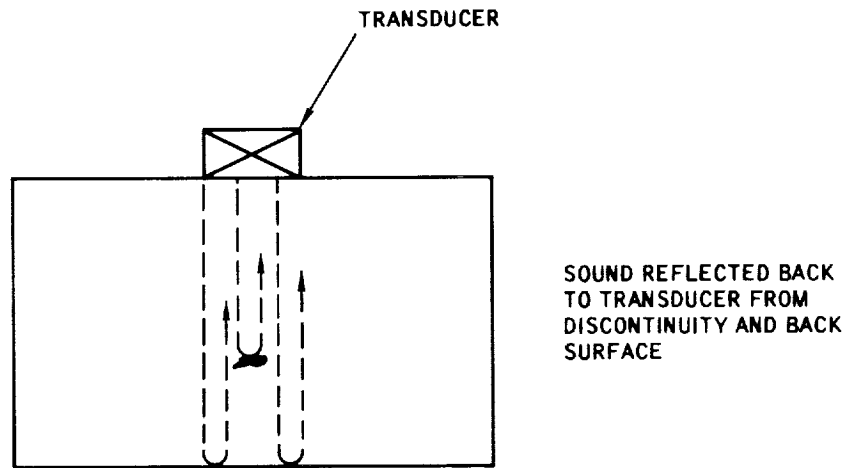
Figure 4-5. Single-Transducer Echo Technique

face is not parallel with the front surface. One transducer transmits and
the other receives, as shown in Figure 4-6. In this case, the receiver unit
is receiving back surface and discontinuity echoes, even though the trans-
mitter unit is not directly over the reflectors.

b. Through-Transmission Techniques. Two transducers are used in the
through-transmission technique, one on each side of the test specimen as
shown in Figure 4-7. One unit acts as a transmitter and the other as a
receiver. The transmitter unit projects a soundbeam into the material;
the beam travels through the material to the opposite surface; and the sound
is picked up at the opposite surface by the receiving unit. Any discontinui-
ties in the path of the soundbeam cause a reduction in the amount of sound
energy reaching the receiving unit. For best results in this technique, the

TRANSMITTING UNIT   RECEIVING UNIT

SOUND REFLECTED TO
RECEIVING UNIT
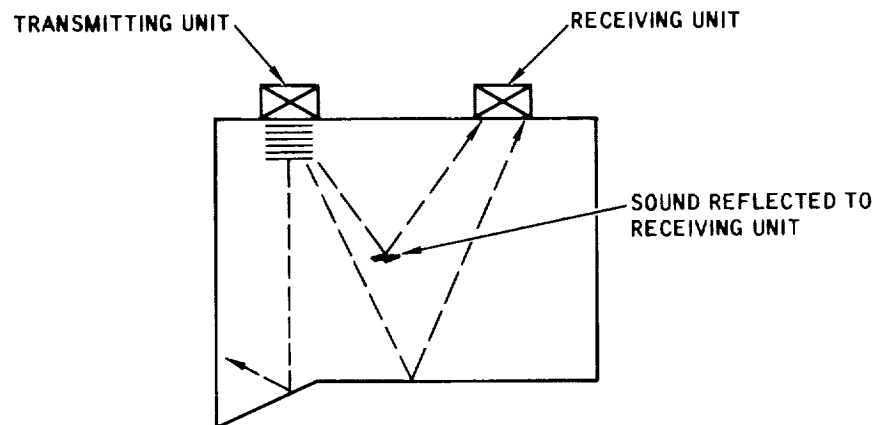
Figure 4-6. Double-Transducer Echo Technique
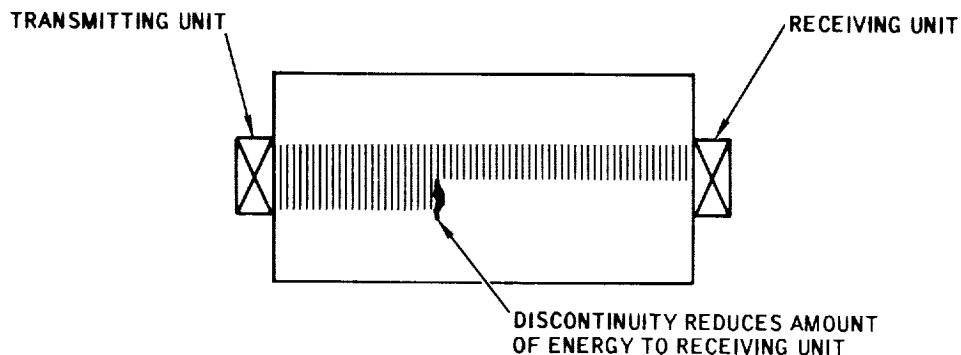
Figure 4-7.   Through-Transmission Technique

transmitter unit selected, is the best available generator of acoustic energy, and the receiver unit selected, is the best available receiver of acoustic energy. For example, a barium titanate transmitter unit is used with a lithium sulfate receiver unit.

3.   ANGLE-BEAM TECHNIQUES

The angle-beam technique is used to transmit sound waves into the test material at a predetermined angle to the test surface. According to the angle selected, the wave modes produced in the test material may be mixed longitudinal and shear, shear only, or surface modes. Usually, shear-wave transducers are used in angle-beam testing. Figure 4-8 shows an angle-beam unit scanning plate and pipe material. To avoid confusion from dead-zone and near-zone effects encountered with straight-beam trans-
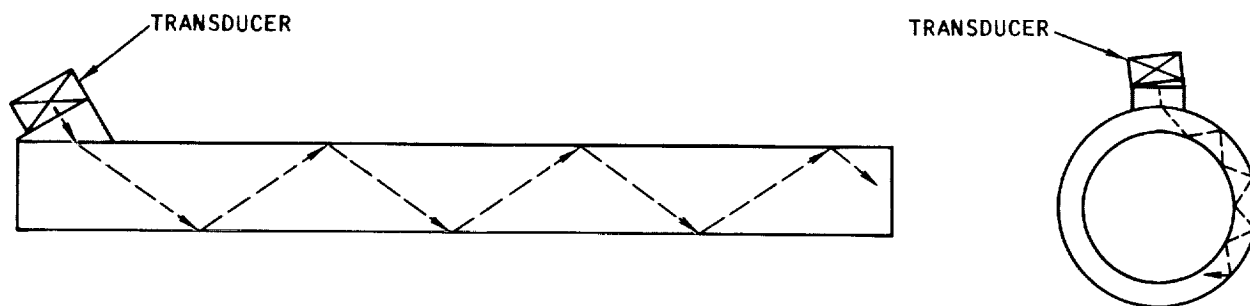
Figure 4-8. Shear-Wave Technique

ducers, parts with a thickness less than 5/8 inch are tested with angle-beam units. In this technique, the soundbeam enters the test material at an acute angle and proceeds by successive zig-zag deflections from the specimen boundaries, until it is interrupted by a discontinuity or boundary where the beam reverses direction and is reflected back to the transducer. Allowances are made when placing the angle-beam unit, to account for the effective length of penetration which is reduced because of the zig-zag path taken by the soundbeam. Angle-beam techniques are used for testing welds, pipe or tubing, sheet and plate material, and for specimens of irregular shape where straight-beam units are unable to contact all of the surface. Angle-beam transducers are identified by case markings that show soundbeam direction by an arrow and indicate the angle of refraction in steel for shear waves.

4. SURFACE-WAVE TECHNIQUES

The surface-wave technique requires special angle-beam transducers that project the soundbeam into the test specimen at a grazing angle where almost all of the beam is reflected. For test specimens where near-surface or surface discontinuities are encountered, surface-wave transducers are used to generate Rayleigh surface waves in the test material. The surface-wave technique is shown in Figure 4-9.

403 PREPARATION FOR TESTING

1. GENERAL

Ultrasonic test preparations begin with an examination of the test specimen to determine the appropriate technique; then, components are selected from available equipment to perform the test. Many variables affect the choice of technique. For example, the test specimen may be too large to fit in the immersion tank. In the case of large, fixed structures, the testing unit is moved to the test site. This may require portable
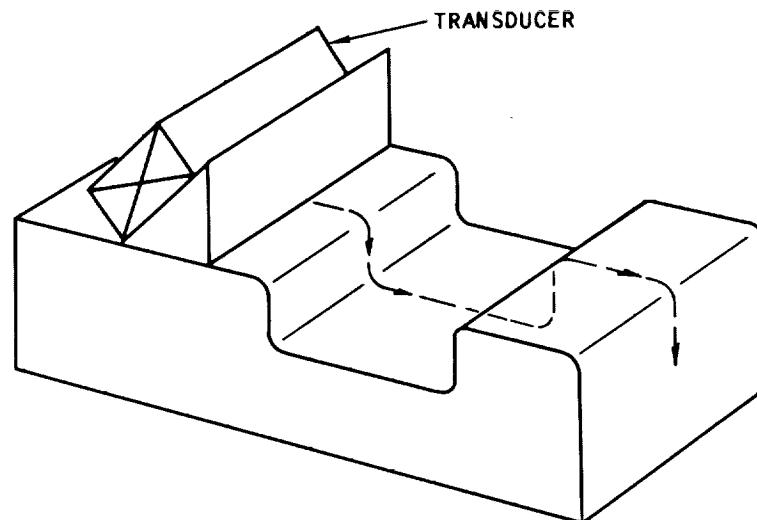
Figure 4-9. Surface-Wave Technique

testing equipment. Other factors are: the number of parts to be tested, the nature of the test material, test surface roughness, methods of joining (welded, bonded, riveted, etc.), and the shape of the specimen. If the testing program covers a large number of identical parts and a permanent test record is desirable, an immersion technique with automatic scanning and recording may be suitable. One-of-a-kind or odd-lot jobs may be tested with portable contact testing units. Each case will require some study as to the most practical, efficient technique.

When setting up any test, an operating frequency is selected, a transducer is chosen, and a reference standard is established. The test specimen is carefully studied to determine its most common or probable discontinuities. For example; in forgings, laminar discontinuities are found parallel to the forging flow lines; discontinuities in plate are usually parallel to the plate surface and elongated in the rolling direction; the common defect in pipe is a longitudinal crack, etc. If possible, a sample specimen is sectioned and subjected to metallurgical analysis.

2. FREQUENCY SELECTION

High test frequencies are an advantage in immersion testing. In contact testing, 10 Mc is usually the maximum frequency. Low frequencies permit penetration of ultrasonic waves to greater depth in the material, but may cause a loss of near-surface resolution and sensitivity. A sample test specimen is used to evaluate soundbeam penetration with a high-frequency transducer (10 to 25 Mc for immersion and 5 to 10 Mc for contact) and observing the total number of back reflections. If there is no back echo, a lower frequency is required. Successively lower frequencies are applied until several back reflections are obtained. If near-surface resolution is required, it may be necessary to turn the part over and retest from the opposite side, or a high-frequency unit may be used, temporarily, following the low-frequency scan.

3. TRANSDUCER SELECTION

The transducer selection is largely governed by the optimum frequency as determined in the previous paragraph.

In immersion testing, other considerations include the possibility of using a paintbrush transducer for high-speed scanning to detect gross discontinuities; or, using a focused transducer for greater sensitivity in detecting small discontinuities in near-surface areas (no deeper than 2 inches). Note that with a given transducer diameter, beam-spreading decreases as the frequency is raised. For example, of two 3/8-inch diameter transducers, one 10 Mc and the other 15 Mc frequency, the 15 Mc unit is more directive. In contact testing, angle-beam units are used for testing welds and relatively thin test material.

4. REFERENCE STANDARDS

Commercial ultrasonic reference standards are described in detail in Chapter 3: Equipment. These standards are adequate for many test situations, provided the acoustic properties are matched or nearly matched in the test specimen and the test block. In most cases, responses from discontinuities in the test specimen are likely to differ from the indications received from the test block hole. For this reason, a sample test specimen is sectioned, subjected to metallurgical analysis, and studied to determine the nature of the material and its probable discontinuities. In some cases, artificial discontinuities in the form of holes or notches are introduced into the sample to serve as a basis for comparison with discontinuities found in other specimens. From these studies, an acceptance level is determined which establishes the number and magnitude of discontinuities allowed in the test specimen. In all cases, the true nature of the test material is determined by careful study of the sample specimen and a sensible testing program is established by an intelligent application of basic theory.

404 TESTING PROCEDURES

1. GENERAL

The following procedures for immersion and contact testing are intended to familiarize the operator with basic operating procedures used in ultrasonic testing. Reference to specific manufacturer's operating manuals is recommended to clarify variations in equipment nomenclature and design.

2. TYPICAL IMMERSION TESTING PROCEDURE

The following immersion testing procedure begins with the assumption that all of the required components of equipment for the immersion testing system are assembled at the immersion tank. Refer to Chapter 3: Equipment, for equipment requirements. Figure 4-10 shows a typical immersion system.

A test block with a 3-inch metal distance is adequate for use in this procedure as a simulated test specimen. Until the new operator is familiar with the operating characteristics of the system, it is recommended that these procedures be repeated several times.

    a. Install the transducer on the lower end of the scanner tube. Make sure the O-ring is in place for a watertight connection between the tube and transducer.

    b. Connect the coaxial cable to the upper end of the scanner tube.

    c. Connect the other end of the coaxial cable to the "R" receptacle on the instrument panel.

    d. Turn instrument on and allow it to warm up for a few minutes.

e. Place test block in tank on underwater support.

f. Lower scanner tube, by adjusting the manipulator, into the water so that the transducer face is about 2 inches above the test block surface.

g. Position instrument panel controls as follows:

(1) Frequency - Set to transducer frequency.

(2) Sensitivity - Low, 20% of range.

(3) Pulse Length - Minimum.

(4) Pulse Tuning - Tune for maximum signal amplitude.

(5) Sweep - Adjust for 2-inch division.

(6) Reject - Off.

(7) Sweep Delay - Set initial pulse at first index mark on left side of screen.

(8) Markers - Off.

(9) Test (Normal or Through Transmission) - Normal.

(10) If required, screwdriver controls on the display unit may be adjusted. These controls do not require frequent adjustment.

(a) Intensity. Adjust for minimum visible trace with no bright spot at left end of trace. Use care in adjusting, as it is possible to permanently burn a line or spot on the inner face of the cathode-ray tube if a high level of brilliant intensity is allowed to remain on the screen for long periods.

TANK WITH MOTORIZED BRIDGE

SCANNER TUBE

MANIPULATOR

TRANSDUCER

CARRIAGE OR BRIDGE

TEST SPECIMEN

SUPPORT FOR TEST SPECIMEN
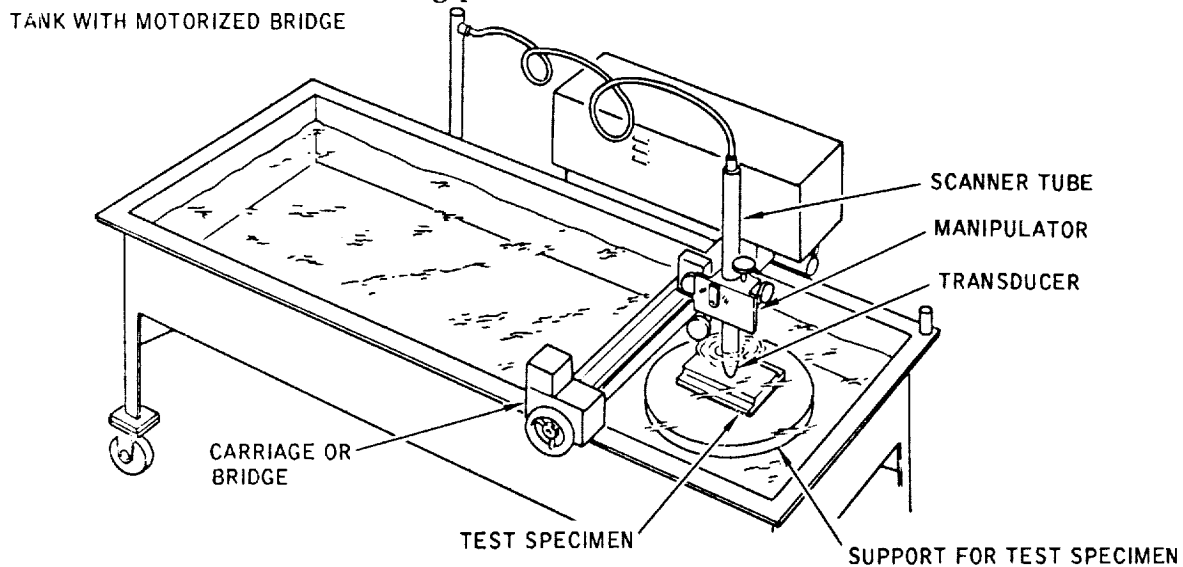
Figure 4-10. Typical Immersion System

(b) <u>Horizontal Positioning</u>. Place sweep start at the left edge of the screen.

(c) <u>Vertical Positioning</u>. Place trace line at zero scribe line.

(d) <u>Focus and Astigmatism</u>. Adjust each for sharpest trace on both vertical and horizontal lines.

h. Move the transducer over an area of the test block so that the soundbeam is not interrupted by the flat-bottomed hole (FBH). Adjust the transducer perpendicular (normal) to the surface to obtain maximum amplitude signals from the top and bottom surfaces of the test block, as shown in Figure 4-11.

i. Observe the pip at the left side of the oscilloscope screen. This is the indication from the initial pulse which is always visible unless more sweep delay is used to move it to the left and off the screen. As shown in Figure 4-11, the next large pip to the right of the initial pulse is the first front-surface reflection. The distance between the two pips is the water-travel distance. Adjust sweep (where applicable, switch dial to Preset) so that the measured distance (2 inches) on the screen is the same as the measured distance of 2 inches between the transducer face and the top surface of the test block.

j. Observe the pips to the right of the first front-surface reflection. Using the manipulator, move the scanner tube slightly up and down over the test block. Note that the distance between the first front-surface reflection and the first back reflection remains constant. Some of the observed pips will move across the screen at a rate twice as fast as the other indications. These fast-moving pips are called water multiples (second and subsequent front-surface reflections). Adjust the water-travel distance by vertical movement
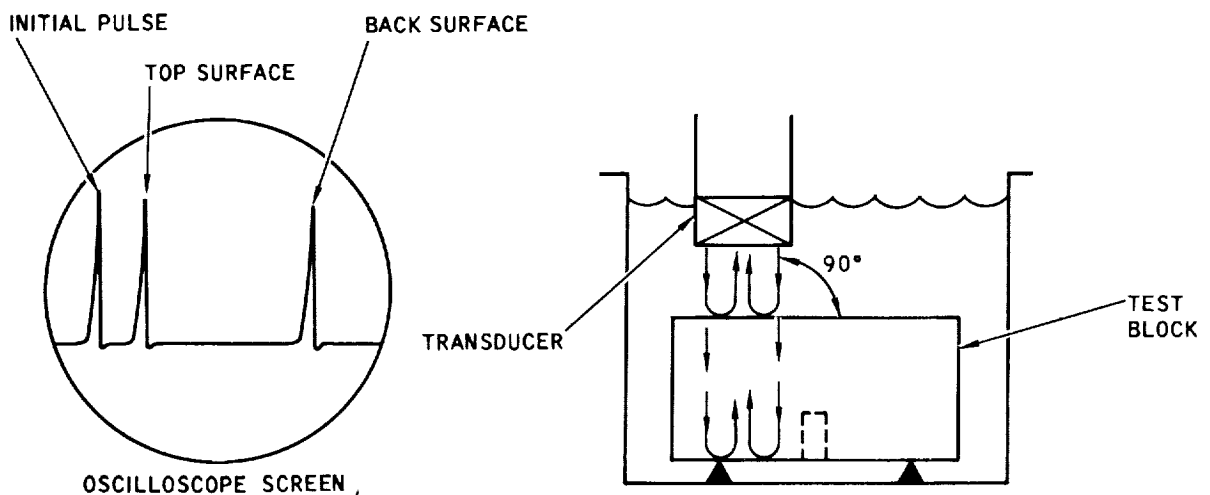
Figure 4-11. Transducer Adjustment, Normal to Test Surface

of the scanner tube so that the water multiple does not appear between the first front and first back-surface reflections.

k. Adjust SWEEP DELAY to move the initial pulse and the water path to the left and off the oscilloscope screen. The first front-surface reflection is positioned under the first vertical grid line at the left side of the screen, as shown in Figure 4-12.
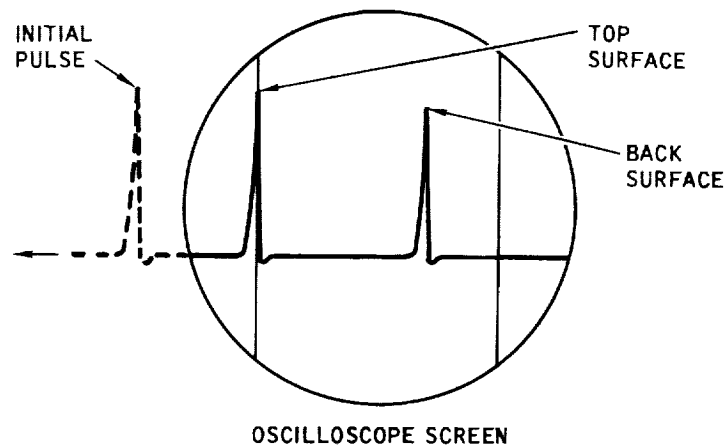
Figure 4-12. Sweep Delay Adjustment

l. Adjust SWEEP to move the first back reflection to the right. Position the first back reflection under the last vertical grid line at the right side of the screen, as shown in Figure 4-13. The material depth is presented across the entire width of the screen. If measurement of depth is desired, turn on MARKERS. Align the square wave markers with the leading edge of the first front-surface reflection. The markers may be expanded or contracted as
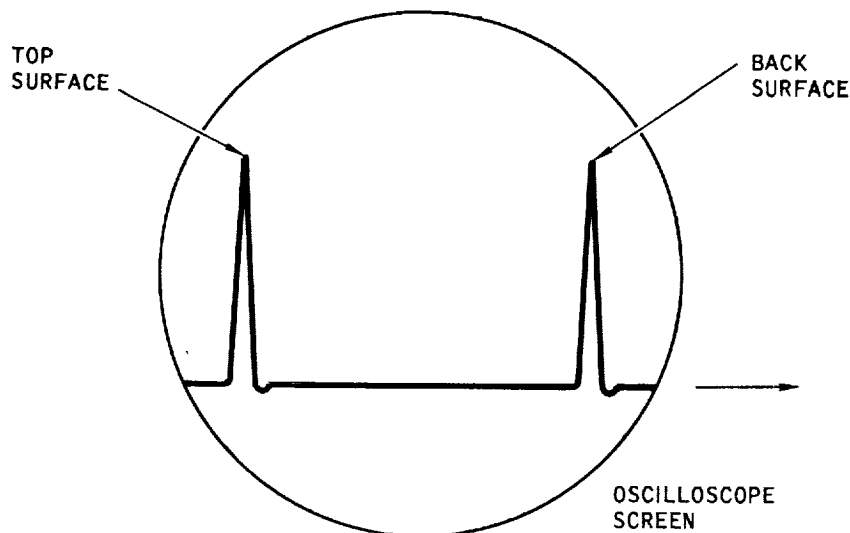
Figure 4-13. Sweep Adjustment

desired to represent inches or centimeters depth in the material.

m. Move the transducer laterally until the maximum response is received from the test block flat bottom hole (FBH). Increase the sensitivity for the desired signal amplitude. Move the transducer back and forth over the FBH and observe the indications on the oscilloscope screen.

3. STANDARDIZING THE IMMERSION TESTING SYSTEM

Standardizing is defined as the matching of responses from standard reference test block with the responses from the test specimen. In this case, the test block has acoustic properties which match those of the test specimen. Once the system is standardized, and the gain or sensitivity is set properly, the actual testing may begin.

a. Select a suitable transducer and frequency for the type of material being tested. Set up equipment, turn on instrument, and allow the equipment to warm up.

b. Place two Hitt (distance/amplitude) test blocks in the immersion tank. Select blocks of the same material as the material in the test specimen. One block should have a metal distance nearest to the thickness of the material being tested and a 3/64-inch diameter flat-bottomed hole (FBH). (Note: If the metal distance of the longest available test block is shorter than the thickness of the test specimen, refer to step f.) The second block should match the first block, including the No. 3 FBH, except that the metal distance should be 1/2 inch.

c. Position the transducer over the upper surface of the longest block, slightly off-center, and normal to the surface. Adjust the water-travel distance from the front face of the transducer to the block surface so that the water multiple (second front-surface reflection) indication or pip does not appear between the first front and the first back-surface reflections. Water multiple pips are identified by moving the transducer up and down and observing the oscilloscope screen. The water multiple pips move across the screen at a rate twice as fast as the other reflections. Manipulate the transducer to produce the maximum height front-surface pip. This indication assures that the soundbeam is normal to the top surface of the block. A maximum number of back-surface pips will serve the same purpose. Move the transducer laterally until the maximum response is received from the FBH.

d. Adjust instrument gain or sensitivity to produce a minimum signal strength of one full-height pip from the FBH, plus at least one half-height second pip from the FBH. For example: if the measured height of the first FBH pip is 2 inches, the second FBH pip is 1 inch, for a combined pip height of 3 inches, as shown in Figure 4-14.

e. Without changing the instrument settings, check the second test block (which has 1/2-inch metal distance), and observe whether the minimum display of one and one-half FBH pips is produced, as in the previous step. (Note: Due to the near-zone effect, the first FBH pip may not reach full height. Measure actual height of first and second FBH pips and compare the combined height of these pips with the combined height of the pips produced in the previous step.) If the combined height of both pips is less than the combined height of the FBH pips displayed in the previous step (for example: less than 3 inches), increase the gain or sensitivity to obtain a matching combined height. When the proper signals are received from both blocks, the instrument setting assures the operator that he will be able to detect discontinuities, both in the near-zone and in the thickest area of the test specimen, which are equal to the size of the flat-bottomed hole in the test blocks. Disregard the following step (f.), and proceed with testing.

f. This step is not required unless the metal distance of the longest available test block (referred to in step b.) is shorter than the thickness of the material being tested. To remedy this, a special test block is manufactured of matching material to the required length. The block dimensions, and the 3/64-inch diameter flat-bottomed hole drilled in the base, are machined in accordance with ASTM Recommended Practice E 127-64. With this block, continue with steps c. through e. If it is not considered worthwhile, to make the special test block, set up the equipment over the longest available block with material the same as the material being tested. Perform steps c. and d. and observe the height and number of back-surface pips. Move the transducer over the test specimen and observe the back-surface pips for evidence of attenuation. If there is a loss of back reflection, either increase the gain or sensitivity, lower the frequency, or lengthen the pulse duration, until

A   FRONT-SURFACE PIP
B   FLAT-BOTTOM HOLE PIP
C   BACK-SURFACE PIP
D   FLAT-BOTTOM HOLE PIP
E   WATER-MULTIPLE PIP

OSCILLOSCOPE SCREEN
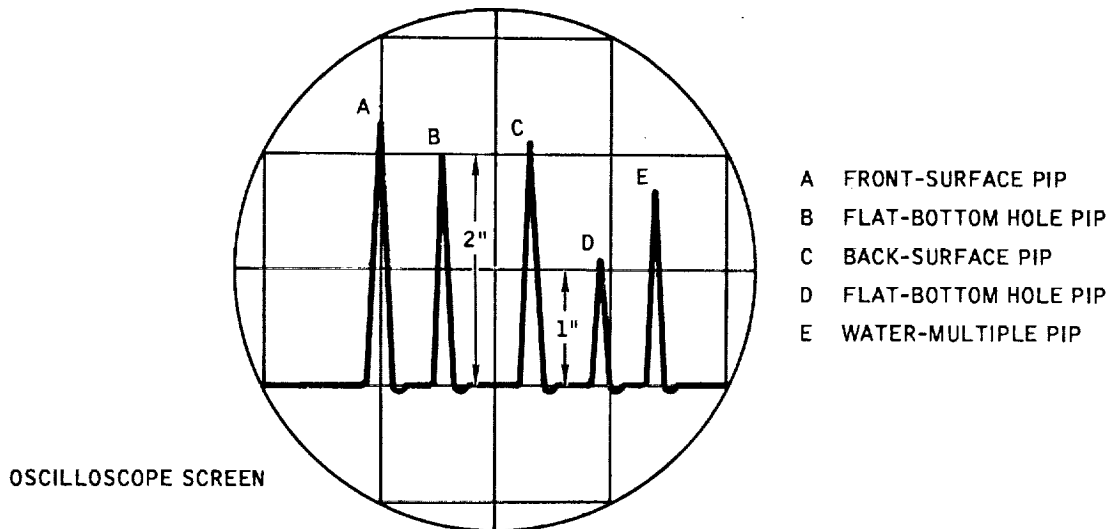
Figure 4-14.   Standardizing Indications

several back-surface pips are obtained. Proceed with testing.

4. TYPICAL CONTACT TESTING PROCEDURE

The following contact testing procedure begins with the assumption that all the required components of equipment for the contact testing system are assembled in the test area. Figure 4-15 shows a typical contact system. An ASME Standard Ultrasonic Reference Plate is adequate for use in this procedure as a simulated test specimen. Until the new operator is familiar with the operating characteristics of the system, it is recommended that these procedures be repeated several times.

    a. Connect the coaxial cable to the "R" receptacle on the instrument panel.

    b. Install a 5 Mc straight-beam, contact transducer on the opposite end of the coaxial cable.

    c. Turn the instrument on and allow it to warm up for a few minutes.

    d. Position instrument panel controls as follows:

        (1) Frequency – Set to transducer frequency (5 Mc).

        (2) Sensitivity – Low, 10% of range.

        (3) Pulse Length – Quarter turn from minimum.

        (4) Pulse Tuning – Tune for maximum signal amplitude.

        (5) Sweep – Adjust for 1-inch division.

        (6) Reject – Off.

        (7) Sweep Delay – Set initial pulse at first index mark on left side of screen.
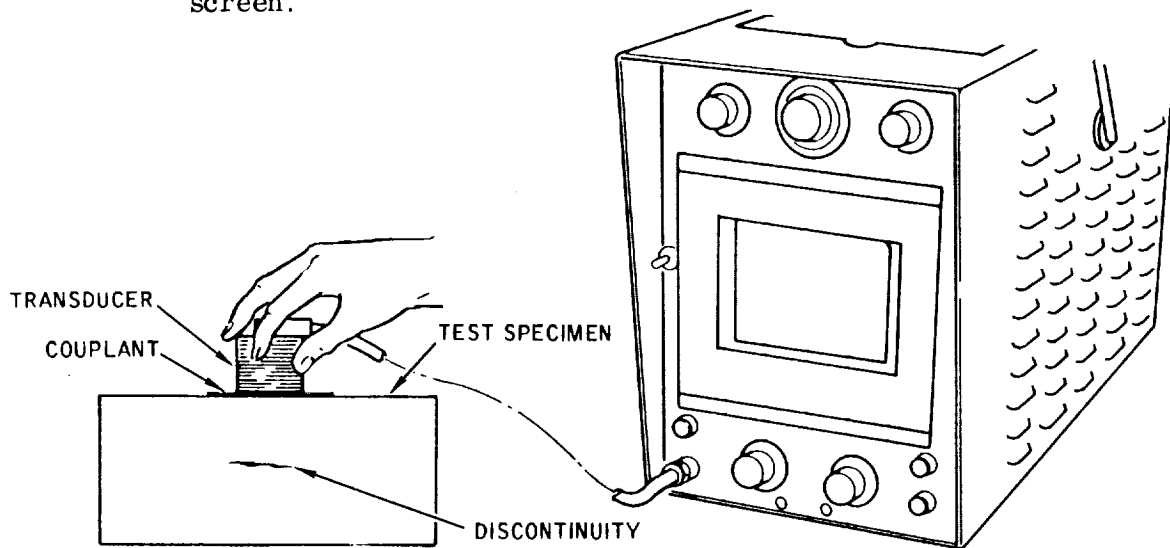
Figure 4-15. Typical Contact System

(8) Markers - Off.

(9) Test (Normal or Through Transmission) - Normal.

e. Place a few drops of couplant (oil) on edge surface of test plate opposite large test hole. Hold transducer in contact with test block at oiled surface as shown in Figure 4-16. Observe indications or pips appearing on the oscilloscope screen. Move the transducer back and forth over the oiled surface and observe the changes shown on the screen.

f. Position the transducer over the large hole in the test block and vary the amplitude of the indications by adjusting the SENSITIVITY control. Set control so that the back-surface pip is 3 inches high.

g. Vary the PULSE LENGTH control and study the action displayed on the screen. Short pulse increases resolution, and long pulse increases penetration.

h. Turn on the REJECT control and observe the effects on the display. Note that the smallest pips disappear completely when enough reject is applied. REJECT is used to clip off "grass" or unwanted signals as shown in Figure 4-17. Turn REJECT OFF for remainder of test.

i. Move transducer to area of test block where hole reflection pips are eliminated. Only the initial pulse and the back reflection are shown on the screen. Vary SWEEP controls to cause the back reflection to move to the left toward the initial pulse. Observe that more pips appear and move in from the right side of the screen, as shown in Figure 4-18. The new pips are multiples of the first back reflection and are equally spaced on the trace. The SWEEP controls may be adjusted to enable the operator to see more time, or more depth in the material. In other words, if the metal distance from top to
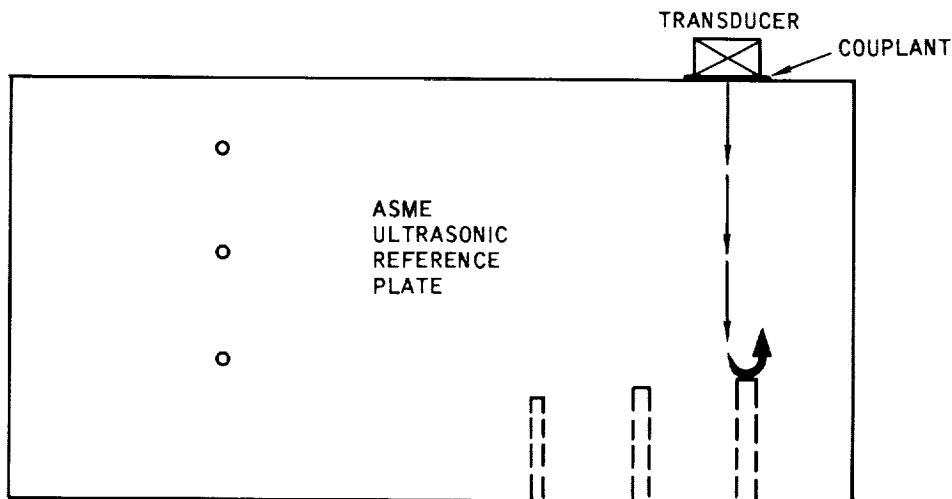
Figure 4-16. Contact Testing Reference Plate

REJECT OFF

REJECT ON

GRASS
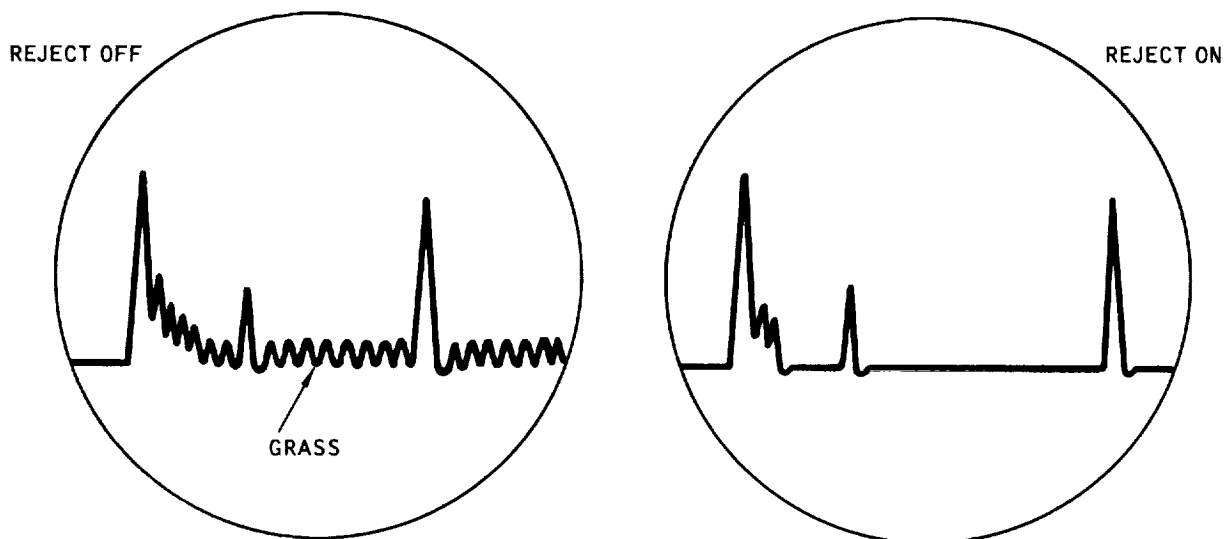
Figure 4-17. Reject Control Effects

bottom is 6 inches, ten multiples of the back reflection represents 60 inches of soundbeam travel as the beam is reflected back and forth.

j. Remove the transducer from the test block and turn on the MARKER. Observe the appearance of square-wave markers on the alternate trace, below the main trace line. Adjust markers as follows:

(1) Turn MARKER FINE and VERNIER controls clockwise and observe marker widening.

(2) Adjust the ALTERNATE DISPLAY SHIFT VERTICAL control, with a screwdriver, to position the marker trace just below the main trace line.

INITIAL PULSE

BACK SURFACE PIP

INITIAL PULSE

FIRST BACK SURFACE PIP

MULTIPLES

NORMAL SWEEP

INCREASED SWEEP
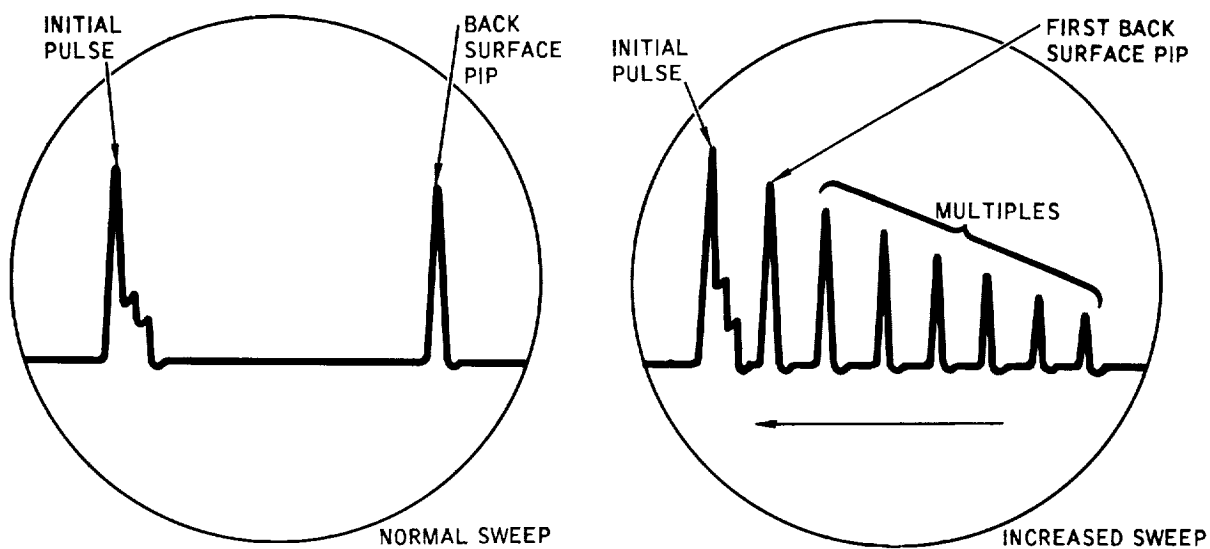
Figure 4-18. Back-Reflection Multiples

(3) Adjust the ALTERNATE DISPLAY SHIFT HORIZONTAL control, with a screwdriver, to set the start of the first marker to coincide with the start of the initial pulse.

(4) Replace the transducer on the test block at an area where only the initial pulse and the back reflection are shown on the screen. Adjust SWEEP to position first back reflection at last index mark on the right side of screen, with initial pulse at first index mark on left side. Adjust marker controls until three full square waves, as shown in Figure 4-19, appear between the leading edge of the initial pulse and the leading edge of the back reflection.

(5) Move transducer over test block hole and measure depth of hole by counting the number of markers. Try several other measurement combinations; two or more full square waves to the inch, for example, until the use of scale index marks, square waves, and the test block, for measuring distance is fully understood. Turn MARKER switch OFF.

k. Vary SWEEP DELAY controls to move the first back reflection to the left side of the screen. Observe that the initial pulse reflection has moved off the screen as shown in Figure 4-20. Only a small area of the material at the back of the block is visible. It is important to become familiar with sweep delay and sweep length to understand the display on the screen. As discussed in previous step "i.", sweep length enables the operator to see more or less time or material. Sweep delay permits the area viewed to be limited to a specific area of the material. Move the initial pulse back onto the screen.

l. Position the transducer over the largest hole in the test block, and set the SENSITIVITY to obtain a 2 1/2-inch hole signal, as shown in Figure 4-21.
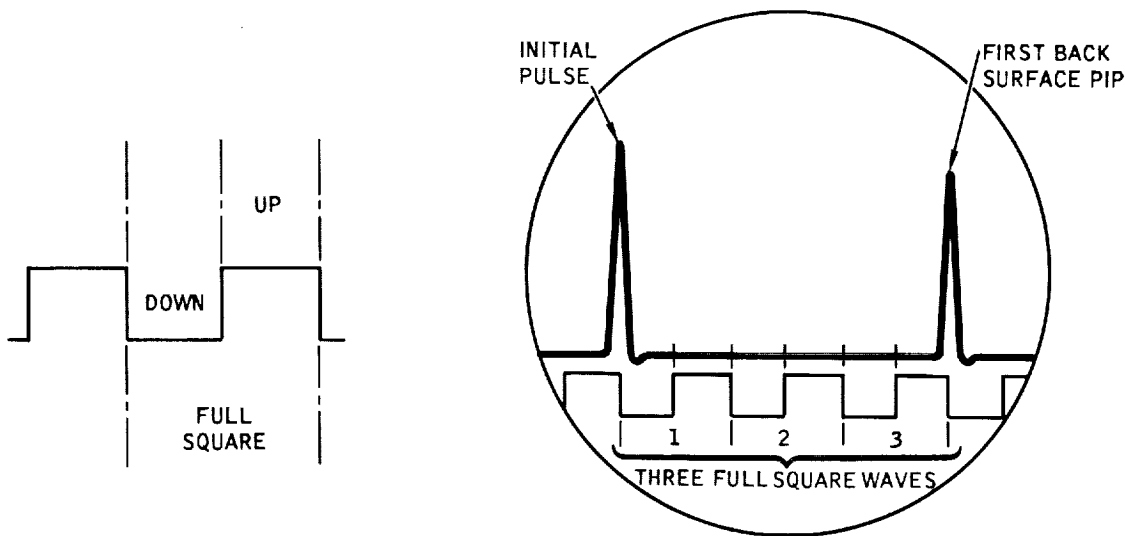
Figure 4-19. Marker Adjustment
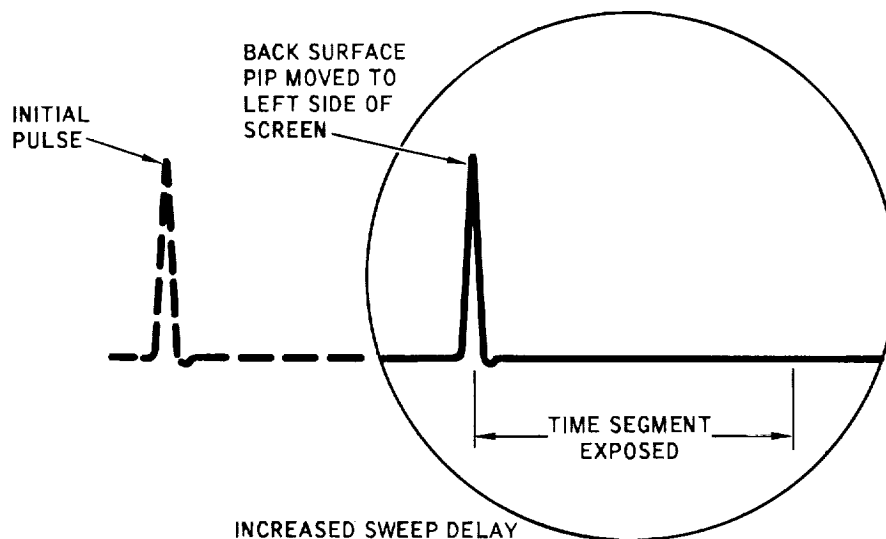
Figure 4-20. Sweep Delay Effect

Move the transducer over the smallest hole and observe the difference in the height of the hole signals, as shown in Figure 4-21. Observe that the height of signal amplitude is related to the size of the discontinuity.

m.   Turn on the REJECT control and repeat step "1." Observe that use of reject may affect signal amplitude linearity. The reject control is used with discretion; its use may make evaluation of the size of a discontinuity difficult or impossible. If reject is used, it is best to leave it on while checking the responses from both the test block and the test specimen.

5.   ANGLE-BEAM CONTACT TESTING PROCEDURE

The angle-beam contact testing procedure is similar to the previous procedure used
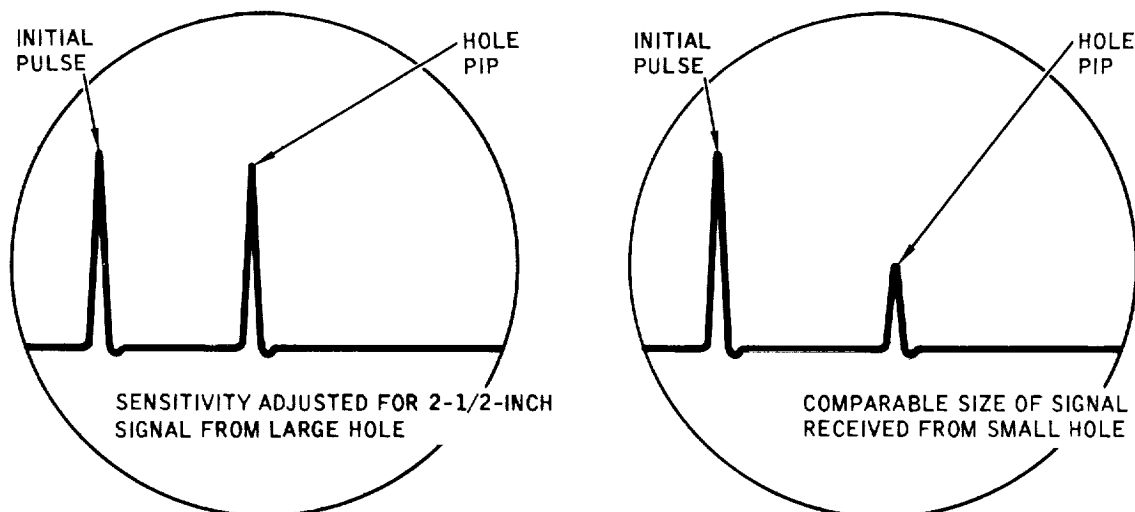
Figure 4-21. Test Hole Size Comparision

for straight-beam testing, except that the soundbeam enters the test material at an angle to the surface contacted. An I.I.W. (International Institute of Welding) test block is recommended for use in this procedure as a simulated test specimen.

a. Select a 5 Mc straight-beam transducer and connect it to the instrument coaxial cable.

b. Turn on instrument and allow it to warm up for a few minutes. Set the instrument controls as follows:

    (1) Frequency – Set to transducer frequency (5 Mc).

    (2) Sensitivity – Low, 20% of range.

    (3) Pulse Length – Quarter turn from minimum.

    (4) Pulse Tuning – Tune for maximum signal amplitude.

    (5) Sweep – Adjust for 2-inch division.

    (6) Reject – Off.

    (7) Sweep Delay – Set initial pulse at first index mark on left side of screen.

    (8) Markers – Off.

    (9) Test (Normal or Through Transmission) – Normal.

c. Place a few drops of couplant (oil) on edge surface of test block. Hold the straight-beam transducer on the oiled surface as shown in Figure 4-22.

d. Adjust SWEEP LENGTH so that five reflections appear at equal intervals across the screen as shown in Figure 4-22.
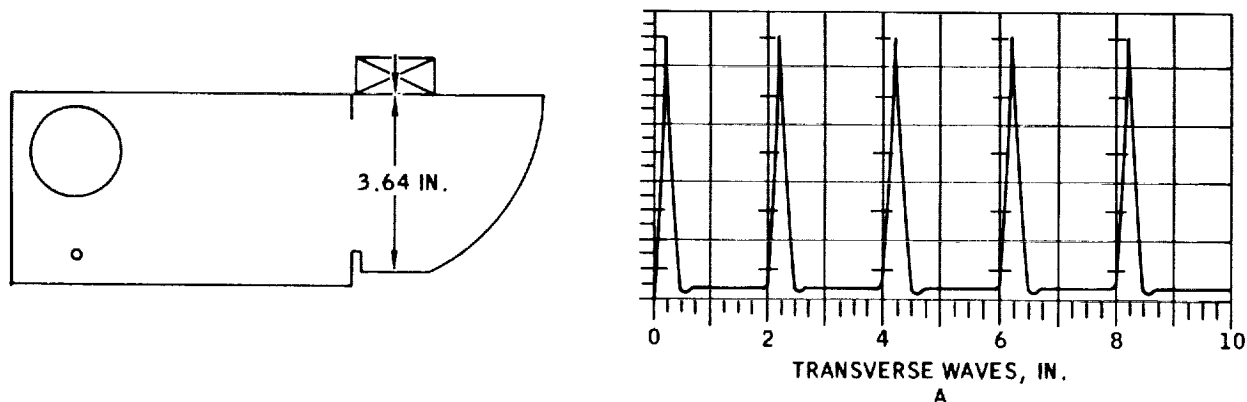
Figure 4-22. IIW Test Block, Basic Sweep Length Adjustment

e. Remove the straight-beam transducer and replace it with a 2.25 Mc angle-beam transducer. Reset frequency control on instrument panel.

f. Place the angle-beam transducer on the test block as shown in Figure 4-23. Note that with the angle-beam unit, the initial pulse is broadened and small signals appear close behind it. This is a result of reverberations within the plastic wedge on the transducer. These signals are normal and should not be confused with signals from discontinuities or the back reflection.

g. Observe the location of the back reflection received from the test block arc. Note the distance between the 4-inch mark and the back reflection pip. This is the distance represented by sound travel in the Lucite wedge on the transducer.

h. Adjust SWEEP LENGTH so that the reflection from the arc occurs at the 4-inch mark. Distance on the screen now accurately represents distance of sound travel in the test block.

i. Increase the instrument sensitivity to such a level that reflections from the 0.060-inch hole and the 90° groove in the test block can be recognized. These reflections occur near the 8- and 9-inch marks on the screen. Readjust instrument as necessary to obtain indications similar to those shown in Figure 4-24.

j. Place the angle-beam transducer in each of the positions indicated on the test block in Figure 4-25. Move the transducer, at each position, until the maximum reflection is obtained for each indication shown. When working to a test specification, adjust the sensitivity control until the amplitude of the reflection is exactly that given in the specification.

k. Now that the sweep and the sensitivity of the instrument is standardized to

A = SOUND PATH LENGTH IN LUCITE
B
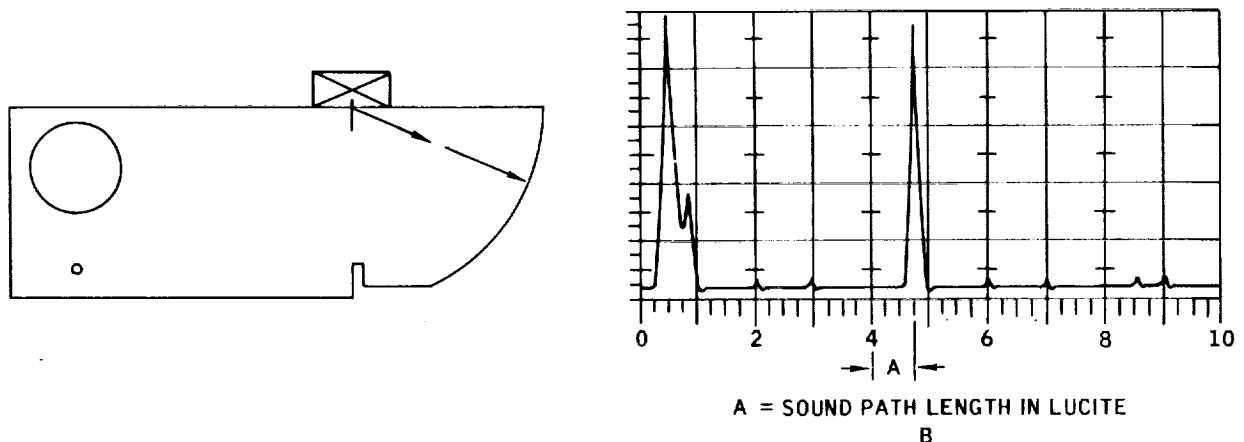
Figure 4-23. IIW Test Block, Lucite Wedge Sound-Path Measurement
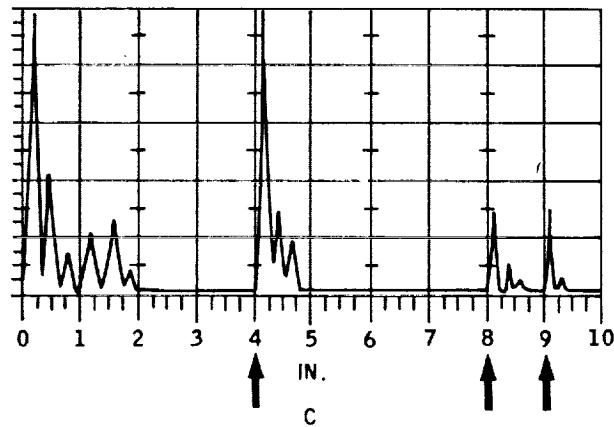
Figure 4-24. IIW Test Block, Indications from Increased Sensitivity

the acoustic properties of the steel test block, a butt-weld in a steel plate may be tested. Place the angle-beam unit on the butt-welded steel plate alongside the weld. Determine the skip distance of the soundbeam by touching a finger on the plate and observing the reduced indications on the screen. Draw 2 chalk marks parallel to the weld seam, one at 1/2 the skip distance and one at the full skip distance from the center of the seam. With the aid of the centerline on the transducer, move the unit in a zig-zag path from one chalk mark to the other, as shown in Figure 4-26, progressing along the test specimen to completely scan the weld. Contact, with a good couplant, between the transducer and the test surface must remain uniform along the scanning path. Continue scanning until a discontinuity is located.
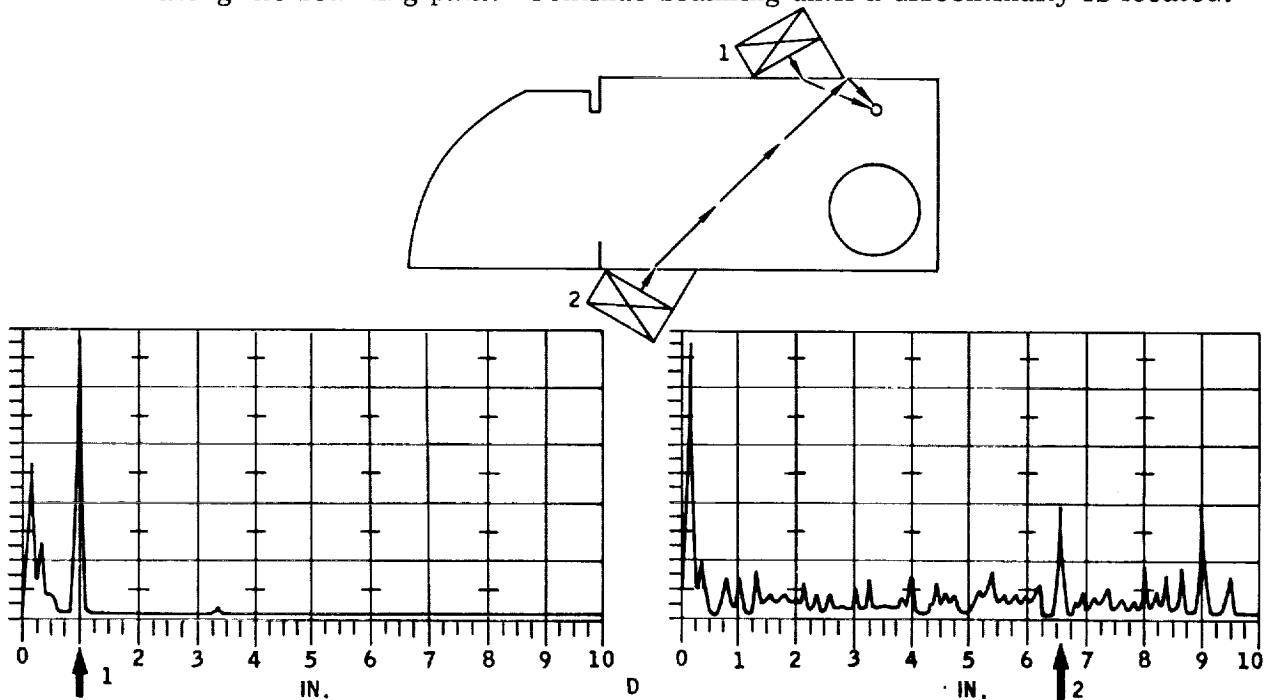
Figure 4-25. IIW Test Block, Checking Sensitivity
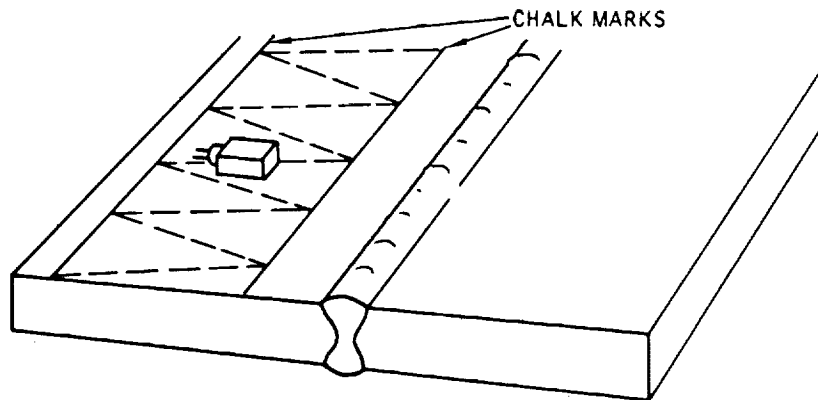
Figure 4-26. Weld Test Scanning Path

l.   The soundbeam path in butt-weld testing is shown in Figure 4-27. To accurately locate the discontinuity in the weld, by making a scale sketch or by using trigonometry, would require considerable time and unnecessary effort. This is avoided by using a sliding calculator that is mounted over the transducer.

m.   Figure 4-28 shows how the calculator works. The bottom part of the illustration shows a section of the weld area and the position of the soundbeam. The center area shows a plan view of the calculator. The instrument screen is shown at the top. The calculator has been adjusted so that the entry point of the soundbeam, under the transducer, coincides with the 0 point on the rule. The slider has been adjusted for the exact thickness of the plate

E - THE ENTRY POINT OF THE SOUND BEAM.

ϕ - THE EXACT ANGLE OF THE BEAM.

T - THE THICKNESS OF THE PLATE.
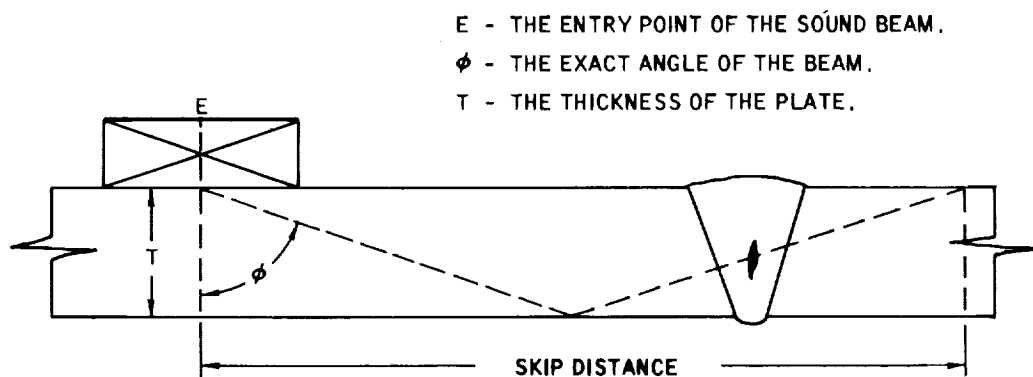
Figure 4-27. Butt-Weld Testing with Angle-Beam Transducer
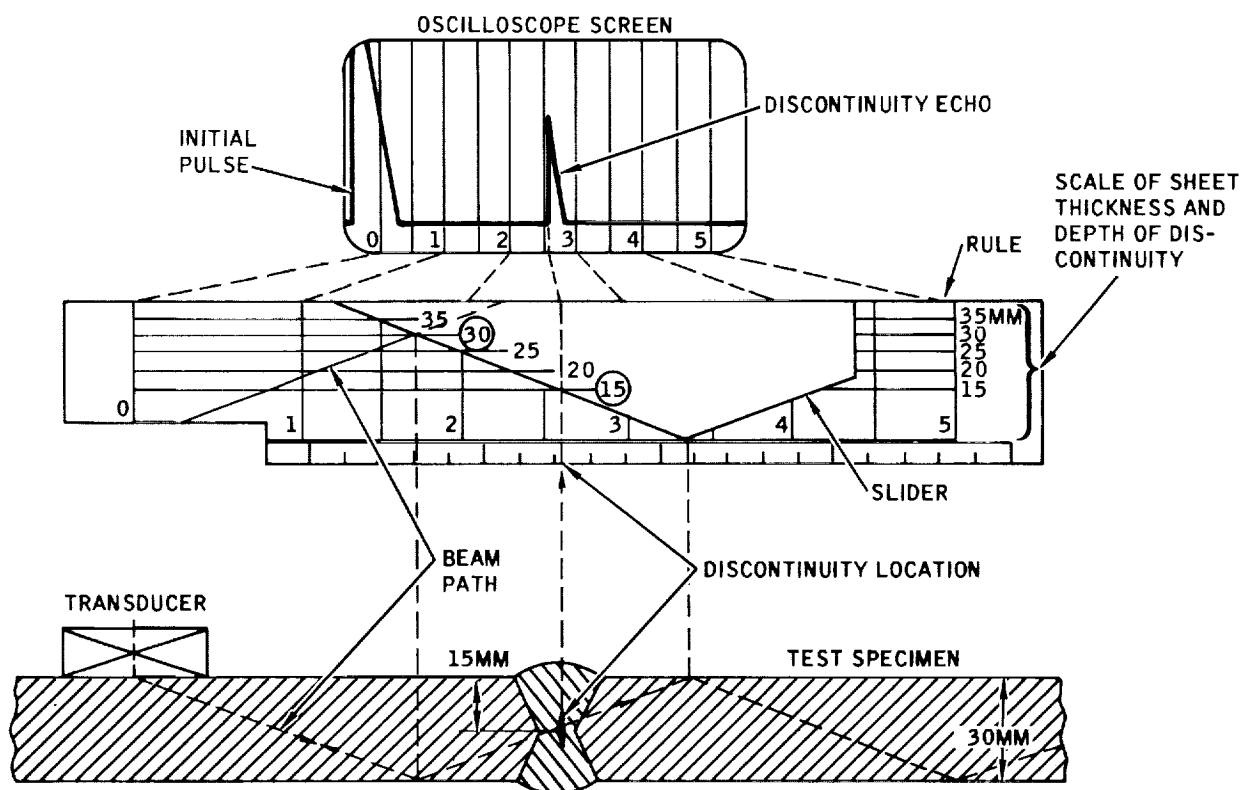
Figure 4-28. Weld Inspection Calculator

(30mm) at its intersection with the sloping line, representing the beam path, on the rule. The position of the discontinuity is read off the screen, and at the same point on the rule, the depth of the discontinuity is read on the thickness scale. These calculators are available for each of the various re-fracted angles in standard angle-beam transducers. They are not inter-changeable, e.g., a 45° angle-beam transducer requires a 45° calculator.

405 INTERPRETATION OF TEST RESULTS

1. GENERAL

Ultrasonic test indications from subsurface discontinuities within the test specimen are usually related or compared to those from standard test blocks having flat-bottomed holes of varying depths or diameters. These comparisons are fairly accu-rate for evaluating the size, shape, position, orientation, and impedance of disconti-nuities. Test conditions, such as contact used in the field, and the discontinuities themselves, are sometimes the cause of ultrasonic phenomena which are difficult to interpret. This difficulty may be resolved by experience in relating the ultrasonic indications to the probable type of discontinuity with reference to the test conditions. Impedance of the material, surface roughness, surface contour, attenuation, and angle of incidence are all considered when evaluating the size and location of an unknown

discontinuity by its echo amplitude. The simplest method is to compare the discontinuity with a test block similar in alloy, shape, and back reflections, to the test specimen. The experienced operator also learns to discriminate between the indications from actual defects and those of no interest, which are called false or irrelevant indications.

2. TYPICAL IMMERSION TEST INDICATIONS

Immersion test indications, generally displayed on A-scan pulse-echo units, are interpreted by analysis of three factors: amplitude of reflection from a discontinuity, loss of back reflection, and distance of discontinuity from the surfaces of the article. Individual discontinuities that are small, compared with the transducer crystal diameter, are usually evaluated by comparing the amplitudes of the test-specimen echoes with the test-block echoes. As the surface of the test specimen and the surface of a discontinuity within it are not as smooth as the surface of the test block and the flat-bottom hole in the test block, the estimated size of the discontinuity is generally a bit smaller than the actual size. Discontinuities that are larger than the crystal diameter, are evaluated by the distance the crystal is moved over the test specimen while an indication is still maintained. In this case, the amplitude has no quantitative meaning; the length of time the amplitude is maintained does indicate the extent of the discontinuity in one plane. A loss or absence of back reflection is evidence that the transmitted sound is absorbed, refracted, or reflected so that the energy is not returned to the crystal. Evaluating this loss does not determine the size of the discontinuity as well as the comparison method used with small discontinuities.

With relatively large discontinuities, the indication from the discontinuity may saturate the display with no back reflection, since the soundbeam is not transmitted through the discontinuity.

a. Small Discontinuity Indications. A significant number of the discontinuities encountered in ultrasonic testing of wrought aluminum are relatively small. Foreign materials or porosity in the cast ingot are rolled, forged, or extruded into wafer-thin discontinuities during fabrication. The forces used in fabricating tend to orient the flat plane of the discontinuity parallel to the surface of the part. Such a discontinuity and its ultrasonic indication are shown in Figure 4-29. The relationship of the discontinuity indication and its amplitude to the test block indications is determined by comparison with a range of test block flat-bottomed hole reflections, as shown in Figure 4-30.

b. Large Discontinuity Indications. Discontinuities that are large, when compared with the crystal size, usually produce an indication that saturates the display, as shown in Figure 4-31. Since the discontinuity reflects nearly all of the sound energy, the partial or total loss of back reflection is typical. The dimensions of the discontinuity may be determined by measuring the distance the transducer is moved while still receiving an indication. If the discontinuity is not flat, but is three-
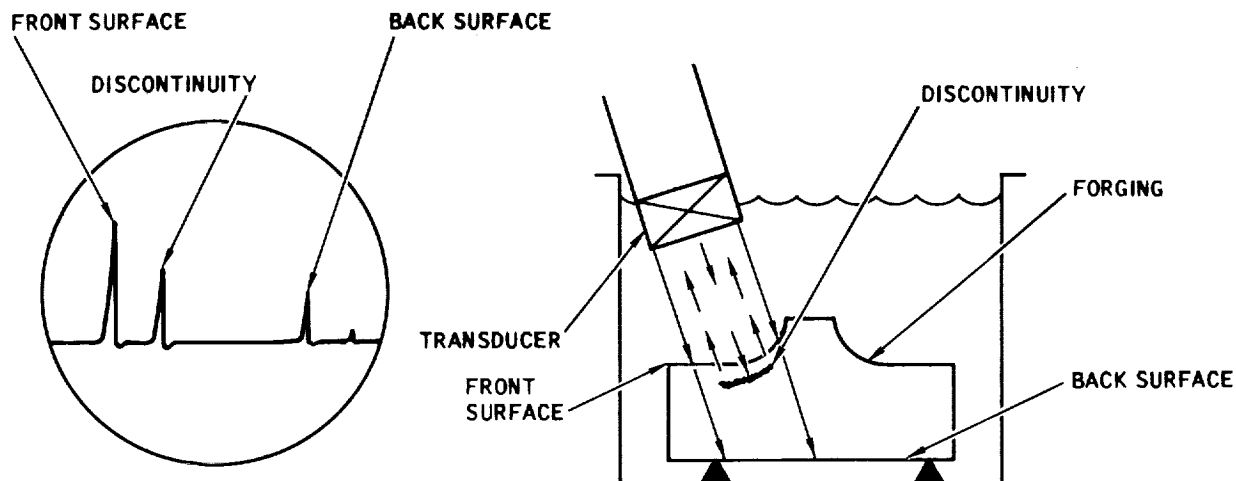
Figure 4-29. Force-Oriented Discontinuity Indication

dimensional, the extent of the third dimension may be determined by turning the article over and scanning from the back side. If the possibility of two discontinuities, lying close together, is suspected, the article may be tested from all four sides.
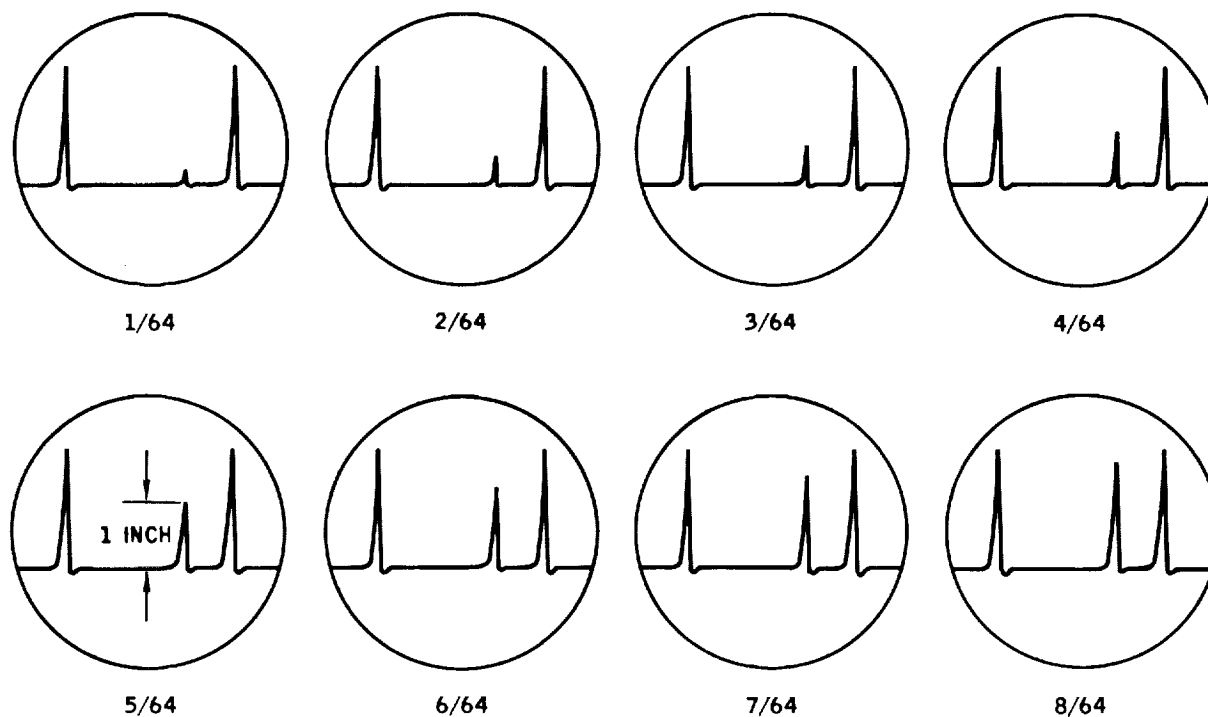
Figure 4-30. Amplitude Range of 1/64 to 8/64 Flat-Bottomed Holes
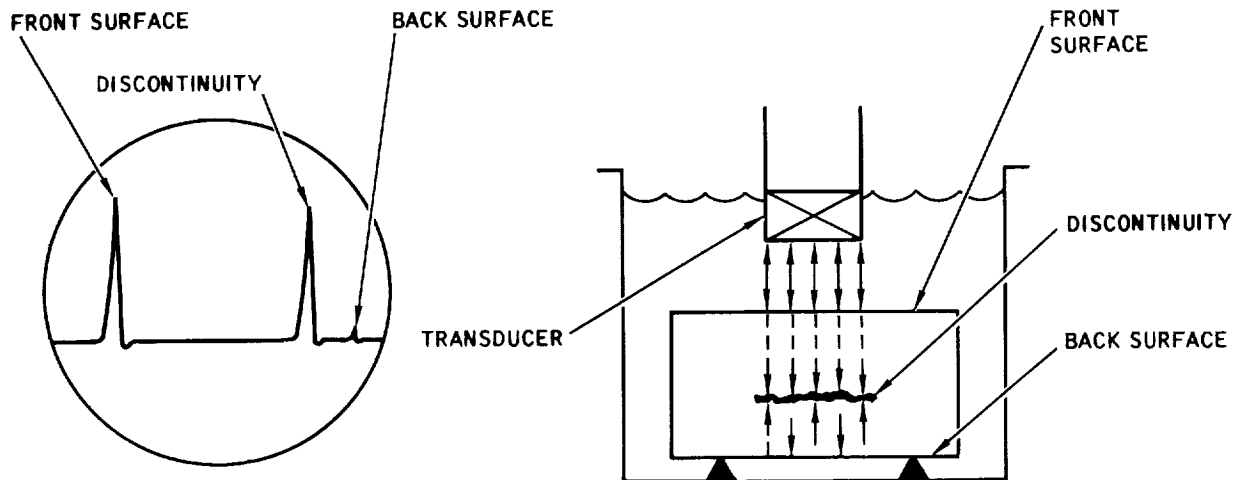
Figure 4-31. Large Discontinuity Indication

c. <u>Loss of Back Reflection</u>. Evaluating loss of back reflection is most important when it occurs in the absence of significant individual discontinuities. In this case, among the causes of reduction or loss of back reflection, are: large grain size, porosity, and a dispersion of very fine precipitate particles. Figure 4-32 shows the indications received from a sound test specimen, and the indications displayed from a
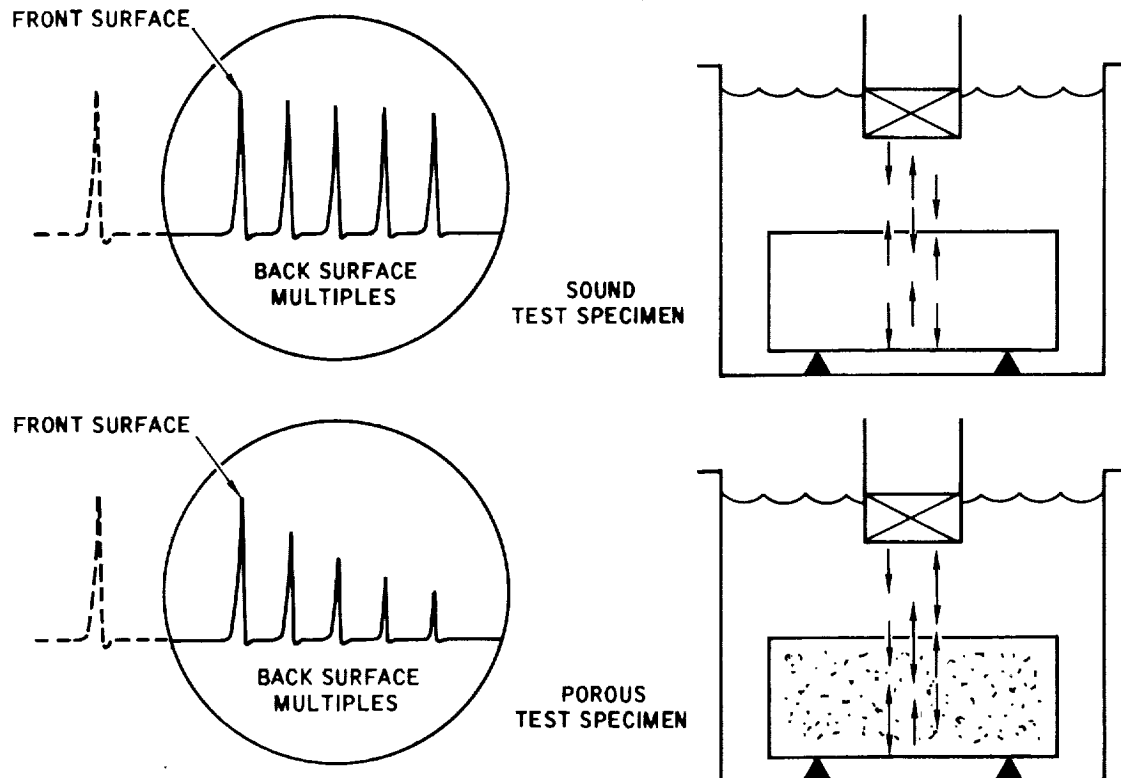
Figure 4-32. Reduced Back Reflection from Porosity

similar specimen with porosity. Note that the back reflections from the porous plate are reduced considerably.

   d. **Irrelevant Indications**. When considering indications that may be irrelevant, it is a good rule to be suspicious of all indications that are unusually consistent in amplitude and appearance while the transducer is passing over the test specimen. Reflections from fillets and concave surfaces may result in responses displayed between the front and back surfaces which are sometimes mistaken for reflections from discontinuities. These spurious indications result from sound received at a time which is the same as the time required for the sound to return from a discontinuity at a given distance within the test specimen. If a suspected indication results from a contoured surface, the amplitude of the indication will diminish as the transducer is moved over the flat area of the front surface. At the same time, the amplitude of the indication from the flat area will increase. Moving the transducer back over the contoured surface will cause the flat-area indication to decrease as the amplitude of the suspected signal increases. Where a reflection from an actual discontinuity is strong in localized areas, an irrelevant or false indication will tend to be consistent as the transducer is moved along the contoured surface. Reflections around a contoured surface may be shielded off by interrupting the soundbeam with a foreign object such as a piece of sheet metal, as shown in Figure 4-33. Broad-based pips, as contrasted to a sharp spike or pip, are likely to be reflections from a contoured surface. Near the edges of rectangular shapes, edge reflections, with no loss of back reflection, are sometimes observed. This type of indication usually occurs when the transducer is within 1/2-inch of the edge of the part. Articles with smooth, shiny surfaces will sometimes give rise to false indications. For example, with a thick aluminum plate machined to a smooth finish, spurious indications which appeared to be reflections from a discontinuity, located about 1/3 of the article depth, were received. As the transducer was moved over the surface of the plate, the indication remained rela-
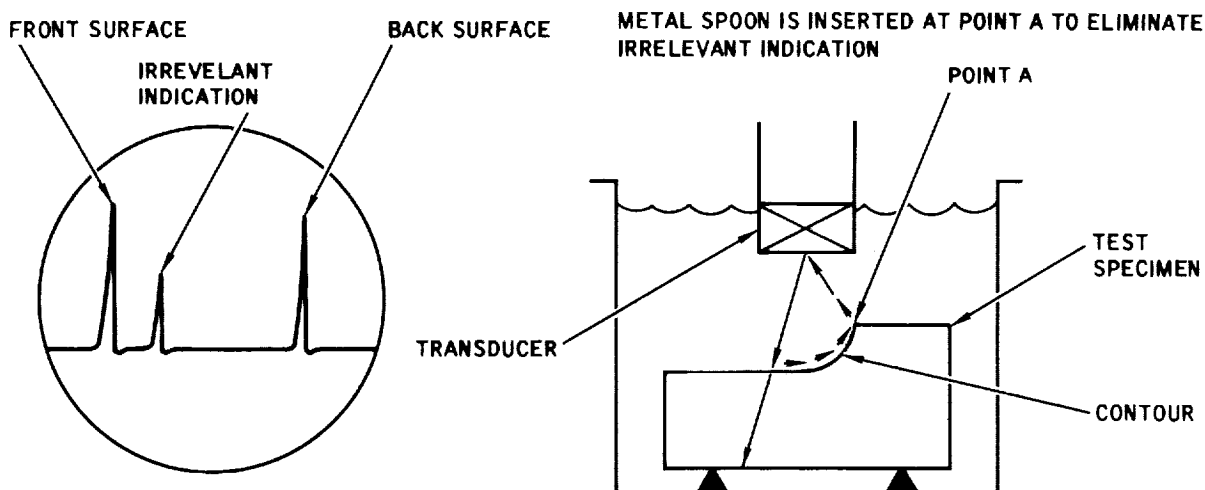
Figure 4-33. Irrelevant Indication from Contoured Surface

4-32

tively uniform in shape and magnitude. Apparently this type of indication results from surface waves generated on the extremely smooth surface, possibly reflecting from a nearby edge. They are eliminated by coating the surface with wax crayon or a very thin film of petroleum jelly.

e. Angled-Plane Discontinuity Indications. Discontinuities oriented with their principal plane at an angle to the front surface are sometimes difficult to detect and evaluate. Usually, it is best to scan initially at a comparatively high gain setting (high sensitivity), to detect angled-plane discontinuities. The transducer is manipulated, later, around the area of the discontinuity, to evaluate its magnitude. In this case, the manipulation is intended to cause the soundbeam to strike the discontinuity at right angles to the principal plane. With large discontinuities that have a relatively flat, smooth surface but lie at an angle to the surface, the indication moves along the base line of the display as the transducer is moved because of the change in distance of sound travel. Bursts in large forgings fit this category, and tend to lie at an angle of 45° to the surface.

f. Grain Size Indications. Unusually large grain size in the test specimen may produce "hash" or noise indications, as shown in Figure 4-34. In the same illustration, note the clear indications received from the same type of material with fine grain. In some cases, abnormally large grain-size results in a total loss of back
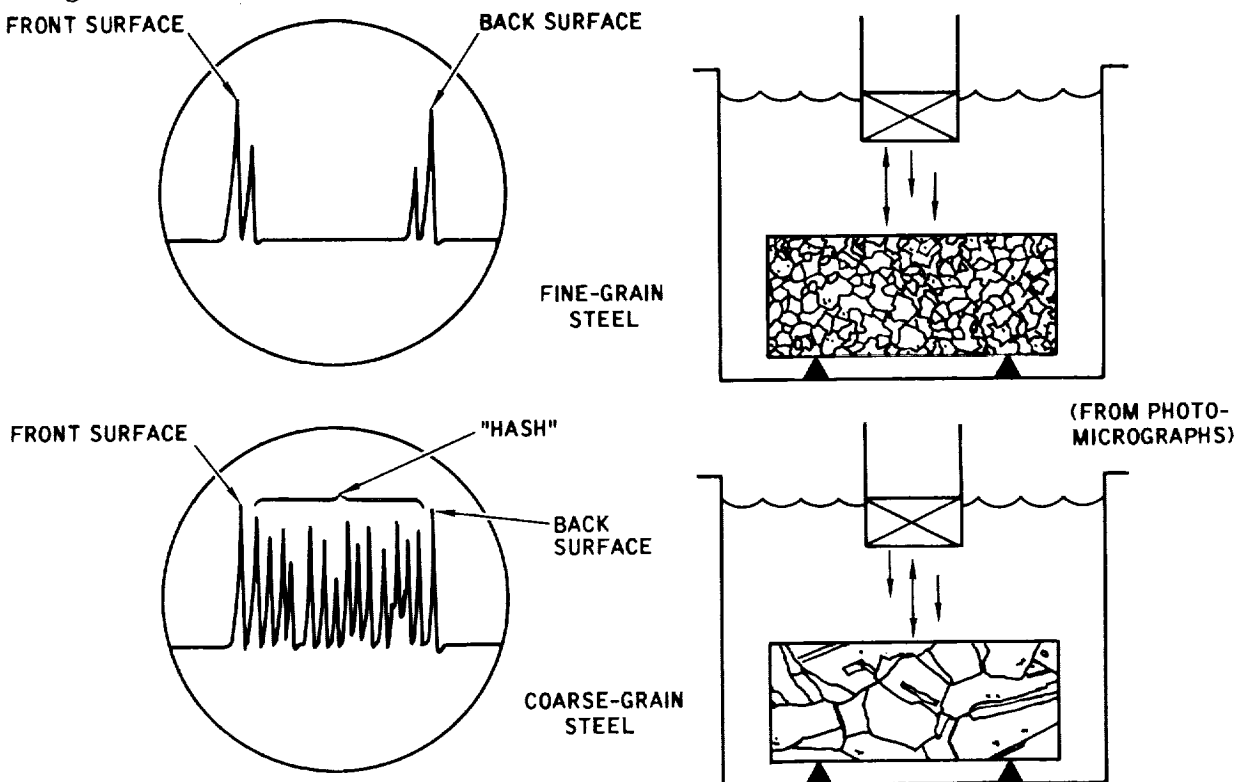
Figure 4-34. Grain Size Indications

reflection. These conditions are usually brought about by prolonged or improper forging temperatures, or high temperature during hot working and subsequent improper annealing of the test specimen.

3. TYPICAL CONTACT TEST INDICATIONS

Contact test indications, in many instances, are similar or identical to those discussed in the previous paragraphs on immersion test indications. Little additional discussion will be given when contact indications are similar to immersion indications. Interference from the initial pulse at the front surface of the test specimen and variations in efficiency of coupling, produce irrelevant effects that are sometimes difficult to recognize in contact testing. As in immersion testing, signal amplitude, loss of back reflection, and distance of the discontinuity from the surfaces of the article are all major factors used in evaluation of the display.

    a. Dead-Zone Indications. The dead zone is the length of the soundbeam path, after entering the test material, during which no reflections are displayed because of obstruction by the initial pulse. In immersion testing, the initial pulse is separated from the front-surface pip by the water path. Only by inserting a standoff, such as a plastic block, can separation of these responses be achieved in contact testing. In most contact testing, the initial pulse obscures the front surface indications, as shown in Figure 4-35. With straight-beam transducers, near-surface discontinuities may be difficult to detect, because of the initial-pulse interference. Shortening the initial pulse may be effective when near-surface discontinuities are obscured by the ringing "tail" of the initial pulse. Figure 4-36 shows a comparison of long and short pulses applied to the test specimen where the discontinuity is near the surface.

    b. Typical Discontinuity Indications. Typical indications encountered in ultra-
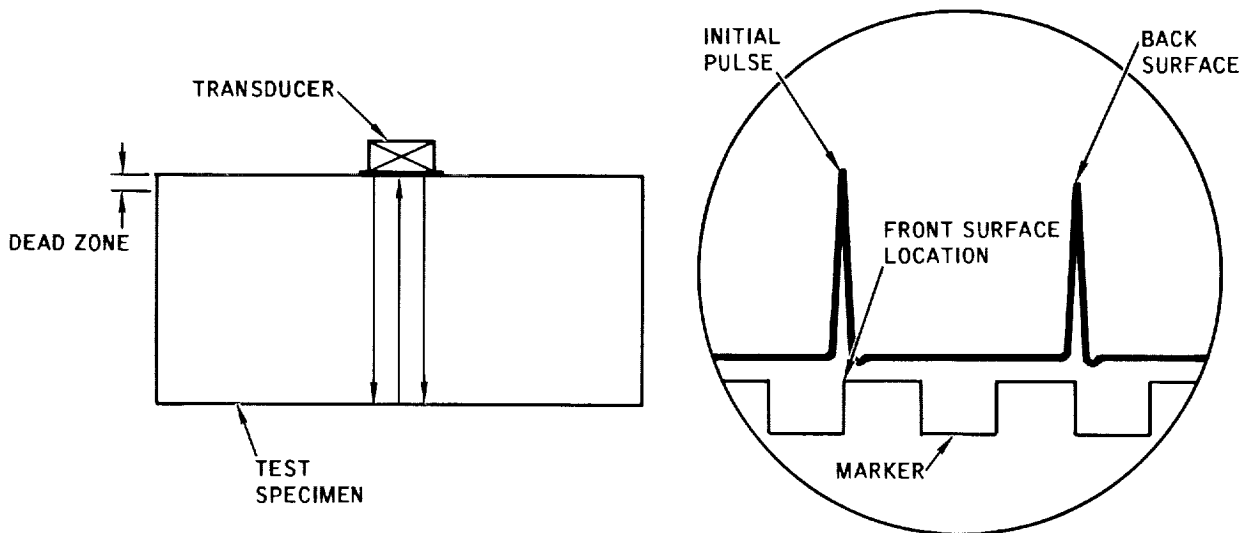
Figure 4-35. Dead-Zone Interference
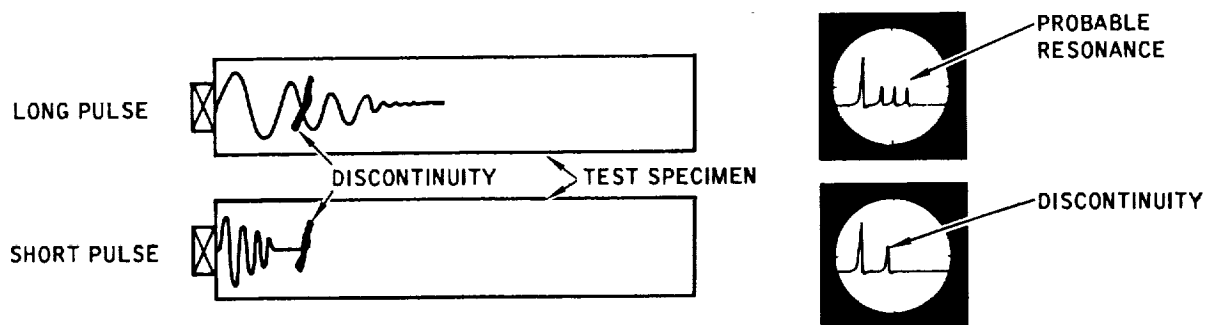
Figure 4-36. Long and Short Pulse Effects on Display

sonic testing include those from discontinuities found in forgings, as shown in Figure 4-37, such as nonmetallic inclusions, seams, forging bursts, cracks, and flaking. Laminations in rolled sheet and plate are shown by a reduction in back reflection multiples as shown in Figure 4-38. View A illustrates the display received from a normal plate and view B shows a reduction in the distance between the back reflections received when the transducer is moved over the lamination. In angle-beam testing of welds, a satisfactory weld area is shown with the weld fusion zones clearly indicated, as shown in view A of Figure 4-39. View B shows the same reflections for the fusion zones, but in this case, a discontinuity is located in the center of the weld. The weld seam commonly has discontinuities such as porosity and slag which produce indications as shown in Figure 4-40. Surface cracks are sometimes detected when using a shear wave with an angle-beam transducer. Figure 4-41 shows a surface-wave indi-
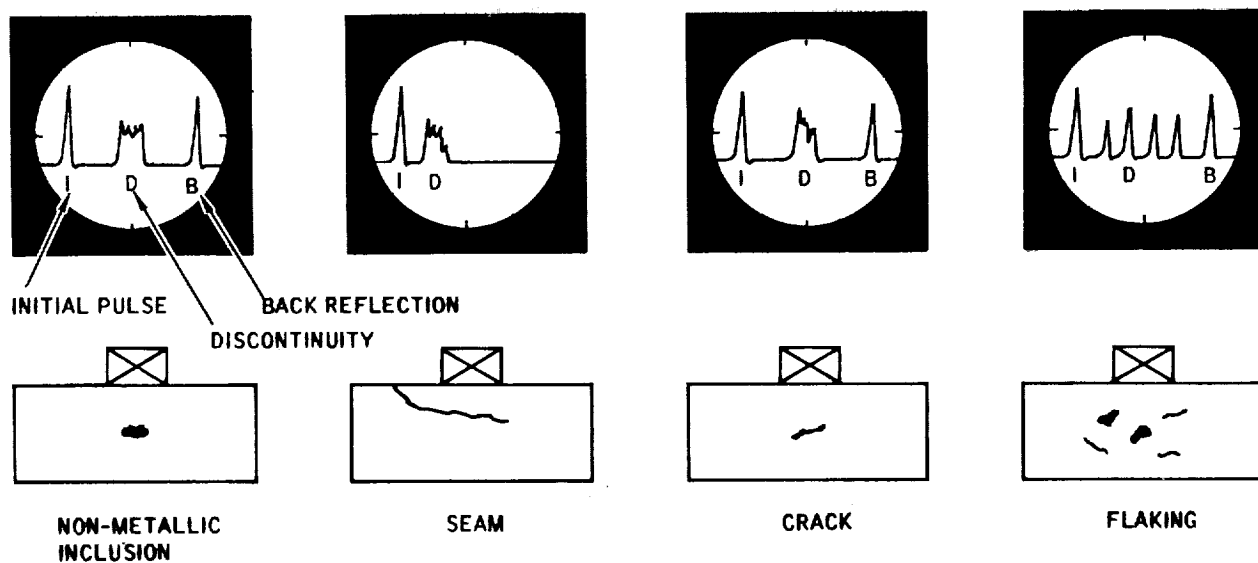
Figure 4-37. Typical Contact Test Discontinuity Indications

VIEW A   VIEW B
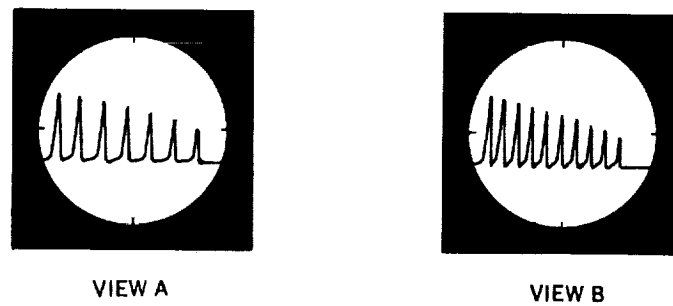
Figure 4-38. Effect of Lamination on Back-Reflection Multiples

WELD   NEAR EDGE

DISCONTINUITY

FAR EDGE

A   B
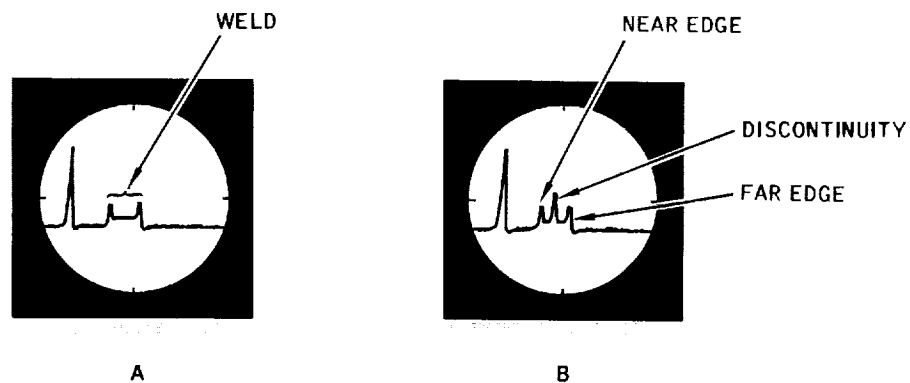
Figure 4-39. Weld Indications Using Angle-Beam Contact Techniques

SEAM   POROSITY   SLAG
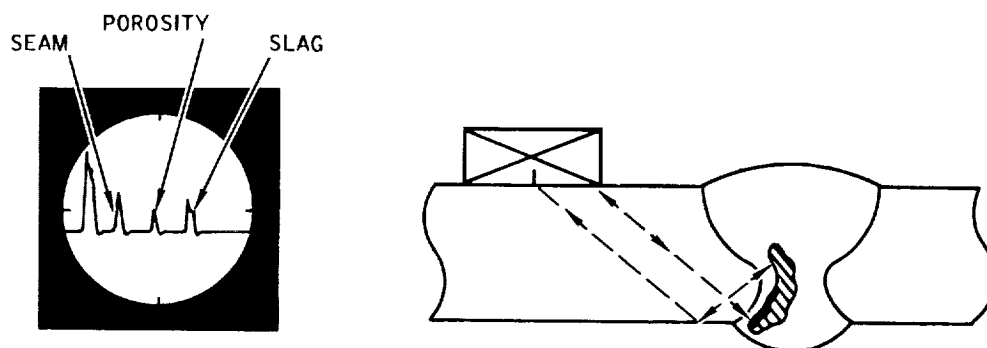
Figure 4-40. Porosity and Slag Indications in Weld Seam

cation from a crack in the surface of the test specimen. With pitch-and-catch testing, using two transducers, the initial or transmitted pulse does not interfere with reception, as with the single transducer. Figure 4-42 shows the indications received from a relatively thin test specimen, using two transducers. Paired angle-beam transducers are used to improve near-surface resolution. The transit time of the sound-beam when passing through the Lucite wedge gives an additional advantage in that the initial pulse is moved to the left in the same way the water-path separation occurs in immersion testing. Figure 4-43 shows an indication from a discontinuity only 0.02 inch below the surface of the material.

    c. <u>Irrelevant Indications</u>. Coarse-grain material causes reflections or "hash" across the width of the display, as shown in Figure 4-44, when the test is attempted
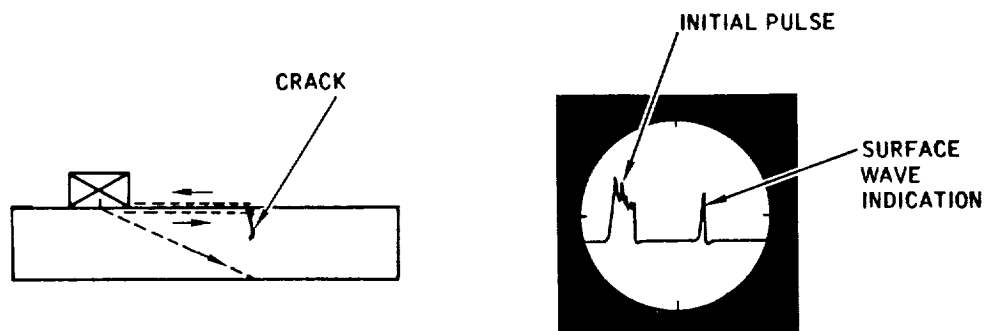
Figure 4-41. Surface Crack Indication Using Angle-Beam Technique
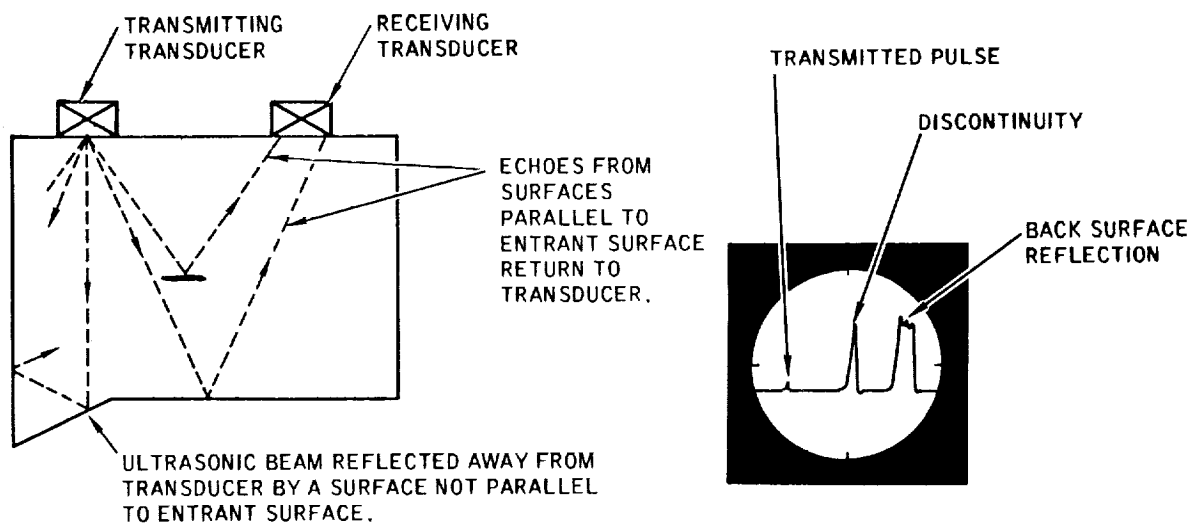
Figure 4-42. Two-Transducer Indications
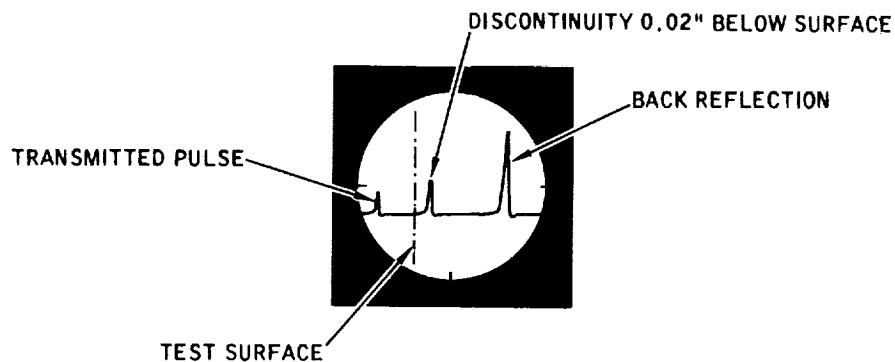
Figure 4-43. Indication of Near-Surface Discontinuity

Figure 4-44. Coarse Grain Indications

at a high frequency. To eliminate or reduce the effect of these unwanted reflections, lower the frequency and change the direction of the soundbeam by using an angle-beam transducer. When testing cylindrical specimens, especially when the face of the transducer is not curved to fit the test surface, additional pips following the back-surface echo will appear as shown in Figure 4-45. In testing long specimens, mode conversion occurs from the soundbeam striking the sides of the test specimen and returning as reflected shear waves, as shown in Figure 4-46. A more directive, straight soundbeam will lessen this problem by changing to a larger diameter transducer. Surface waves generated during straight-beam testing also cause unwanted
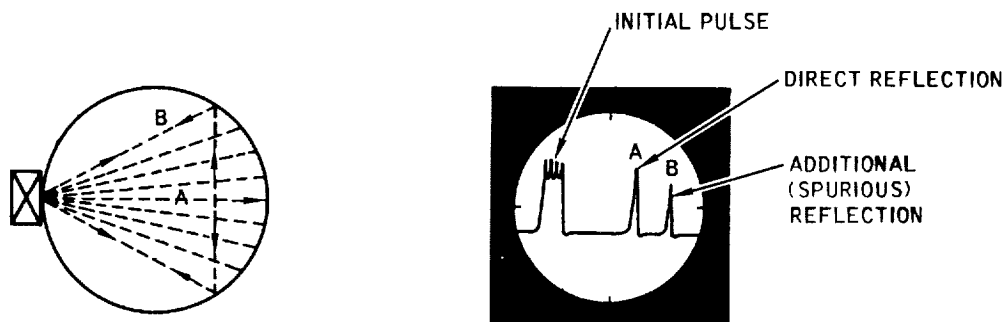
Figure 4-45. Irrelevant Indication from Cylindrical Specimen
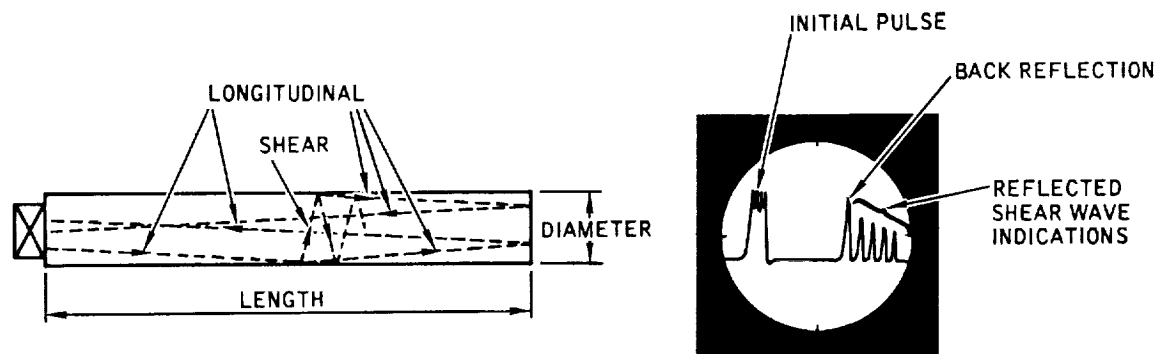
Figure 4-46. Irrelevant Indication from Long Bar Specimen

irrelevant indications when they reflect from the edge of the test specimen as shown in Figure 4-47. Movement of the transducer will cause the indication caused by the surface wave to move across the display with the movement of the transducer. When testing with two straight-beam transducers, it is possible to have a small surface-wave component of the soundbeam transmitted to the receiving unit as shown in Figure 4-48. This type of unwanted reflection is easily recognized by varying the dis-
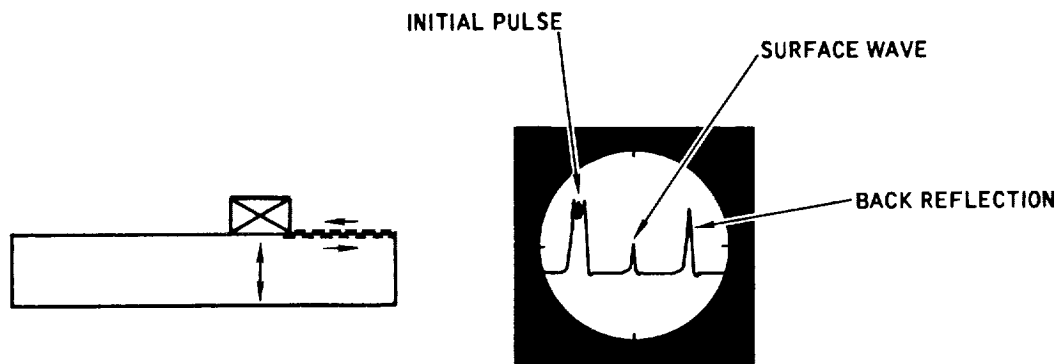
Figure 4-47. Irrelevant Surface-Wave Edge Reflection
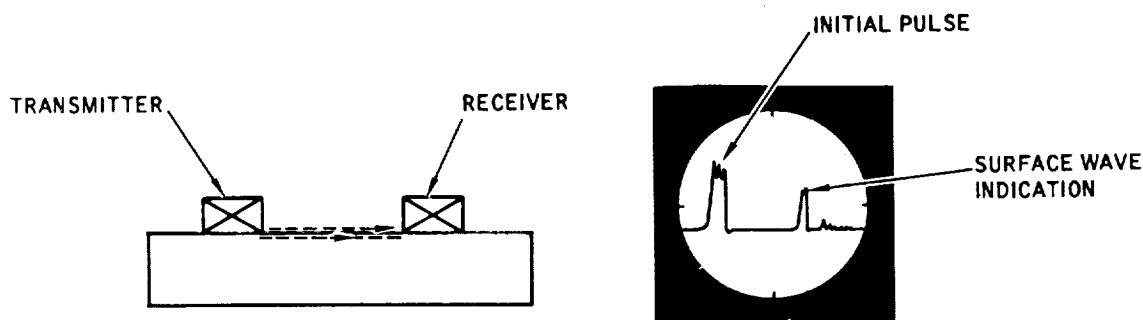
Figure 4-48. Irrelevant Surface-Wave Indication with Two Transducers

tance between the transducers and watching the indication; when the distance is increased, the apparent discontinuity indication moves away from the initial pulse. Using angle-beam transducers, a certain amount of unwanted reflections are received from the wedge. These indications are shown immediately following the initial pulse in Figure 4-49. When the transducer is lifted off the test specimen, the reflections from within the wedge are identified because they are still present on the display. With continued use, the crystal in the transducer may come loose or fracture. When this happens, the indication is characterized by a prolonged ringing which adds a "tail" to the initial pulse as shown in Figure 4-50. As the prolonged ringing effect results in a reduced capability of the system to detect discontinuities, the transducer is discarded or repaired.

INITIAL PULSE
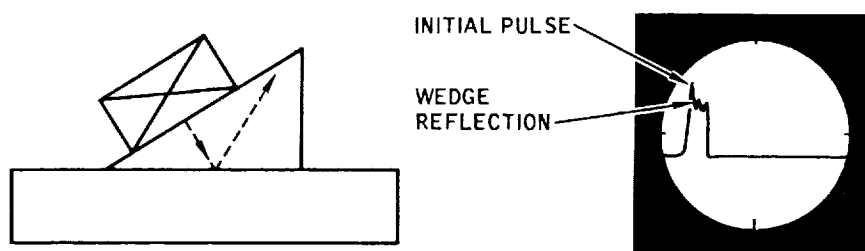
WEDGE
REFLECTION

Figure 4-49. Irrelevant Indication from Plastic Wedge

A

B
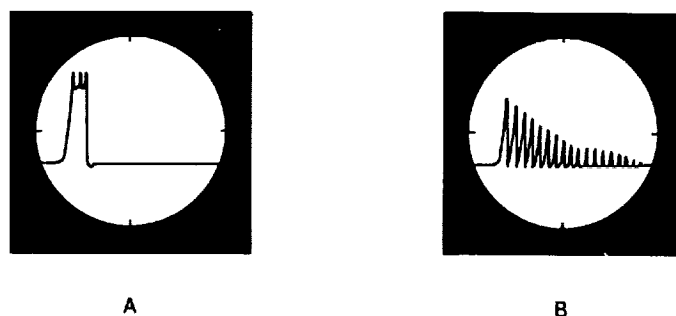
Figure 4-50. Irrelevant Indication from Loose Transducer Crystal

4-40

406 RESONANCE TECHNIQUE

1. GENERAL

The resonance technique is used primarily for thickness measuring of material with two sides smooth and parallel, but it will also detect discontinuities lying in the same plane as the test surface. As each thickness of a given material has a characteristic or fundamental resonant frequency, when this frequency (or its multiples) is applied as a continuous beam of sound energy to the test specimen, standing waves cause a surge of increased amplitude in the received indications. When checking material thickness, a continuous beam of longitudinal waves are transmitted into the test specimen; the wavelength is varied by causing the transducer to vibrate over a range of frequencies; resonance occurs at some point, and standing waves are set up within the specimen. Standing-wave patterns for several frequencies are shown in Figure 4-51. As shown, when the frequency is increased, the wavelength decreases. Since wavelength and frequency are related to the thickness of the material, the fundamental resonant frequency is determined from the formula:
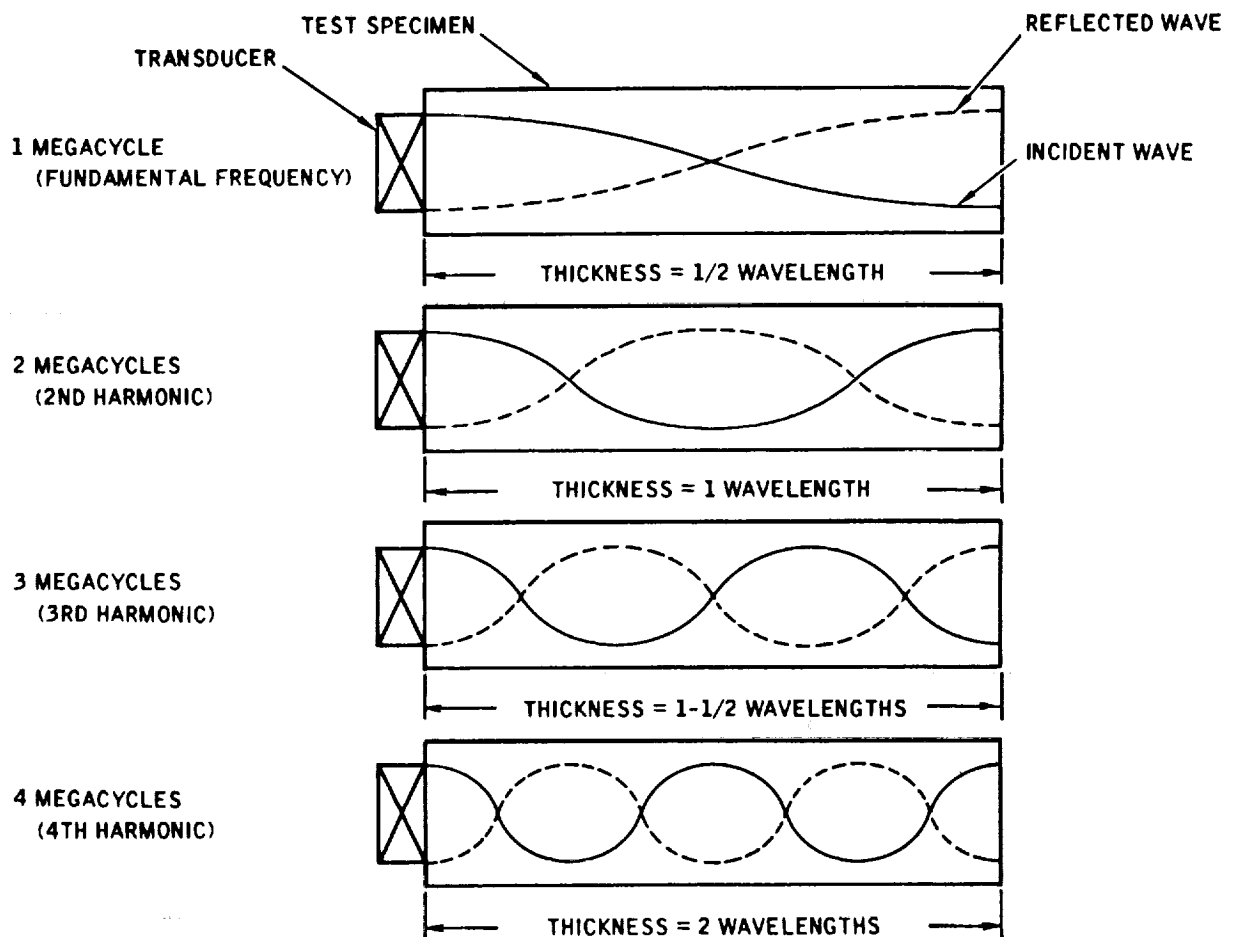
Figure 4-51. Standing Wave Patterns

$$F = \frac{V}{2T}$$

Where: F = fundamental frequency for resonance

V = velocity of longitudinal waves in the given material

T = thickness of the material.

With instruments using an oscilloscope (CRT) display, the fundamental frequency and its harmonics appear on the screen as pips. The fundamental resonant frequency is always the difference between any two adjacent harmonics or pips. On most instruments, the actual thickness measurements are a direct readout from a scale over the CRT display, a meter, or a scale over a stroboscopic light display. Other instruments require the use of charts or tables to compute the thicknesses. To use these charts or tables, the frequency difference between any two adjacent harmonics is determined; the frequency is located on the chart or table; and the corresponding thickness is read off. A constants or K table is also used for frequency-thickness conversion by dividing the frequency into the constant K factor to obtain the thickness of the material in inches. The K factors in the table are derived by dividing the longitudinal wave velocity of each given type of material, in million inches per second, by 2.

2.   TYPICAL RESONANCE TESTING PROCEDURE

In the following resonance testing procedure, the assumption is made that the operator has assembled the necessary equipment at the test area. Refer to Chapter 3: Equipment, for requirements and description of the equipment.

   a.   Turn on instrument and allow it to warm up a few minutes. Connect the coaxial cable to the oscillator and install the transducer on the opposite end of the cable.

   b.   Using a suitable couplant, place transducer on test block and observe display. Figure 4-52 shows typical reference test blocks.

   c.   Adjust instrument until the thickness indications match the known thicknesses marked on the test block.

   d.   Place transducer on a section of sheet or plate selected for this exercise. For example, a standard 1/4-inch thickness of steel plate.

   e.   Observe the display, and determine the fundamental resonant frequency (the difference between any two adjacent harmonics).

   f.   Assuming the fundamental resonant frequency to be 0.461 megacycles, compute the thickness by using the formula $T = \frac{K}{F}$ and substituting the following values for K and F:

STEPPED REFERENCE BLOCK

TAPERED REFERENCE BLOCK
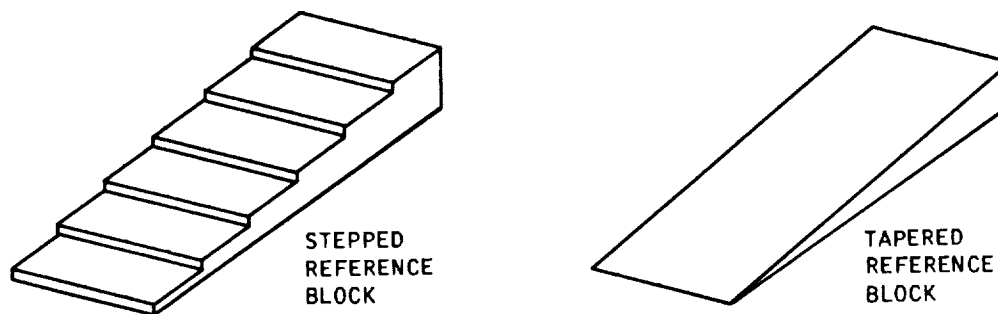
Figure 4-52. Resonance Test Blocks

K = 0.116 (steel constant obtained from K table)

F = 0.461 megacycles (fundamental resonant frequency)

$$T \text{ (thickness)} = \frac{0.116 \text{ (constant K)}}{0.461 \text{ (fundamental resonant frequency)}}$$

T = 0.25

3.   TYPICAL RESONANCE TEST RESULTS

Resonance instruments using an oscilloscope (CRT) display, show the fundamental frequency and its harmonics on the screen as pips. Figure 4-53 shows a typical CRT display. Two resonance indications are shown projecting above the horizontal sweep

CRT SCREEN

RESONANCE INDICATIONS

HORIZONTAL SWEEP
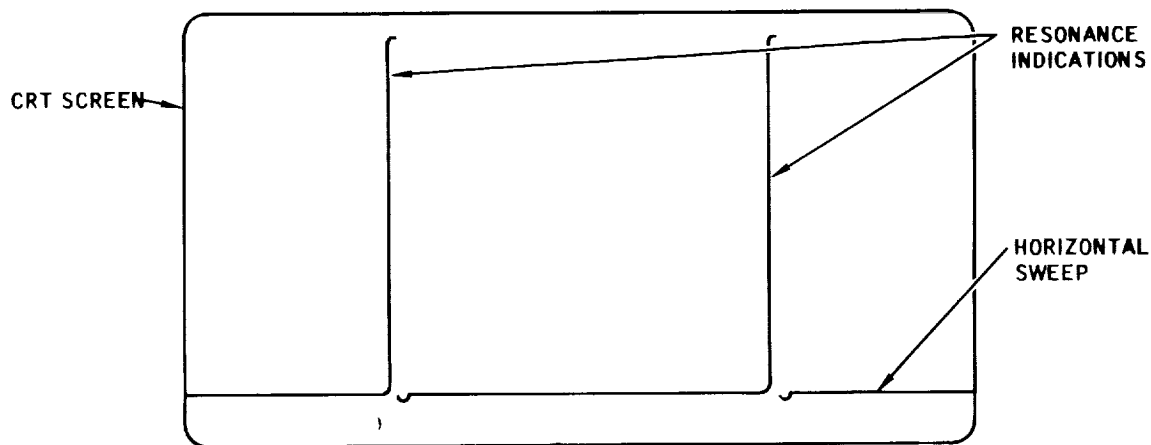
Figure 4-53. Typical Resonsnce CRT Display

line. Their height represents signal strength or amplitude, and their position along the base line is a function of frequency. By placing a transparent thickness scale, designed for the material under test, over the face of the CRT, a direct thickness readout is obtained. The scale shown superimposed over the CRT in Figure 4-54, is made for aluminum and covers a range of 0.090 to 0.180 inch. The 2nd, 3rd, and
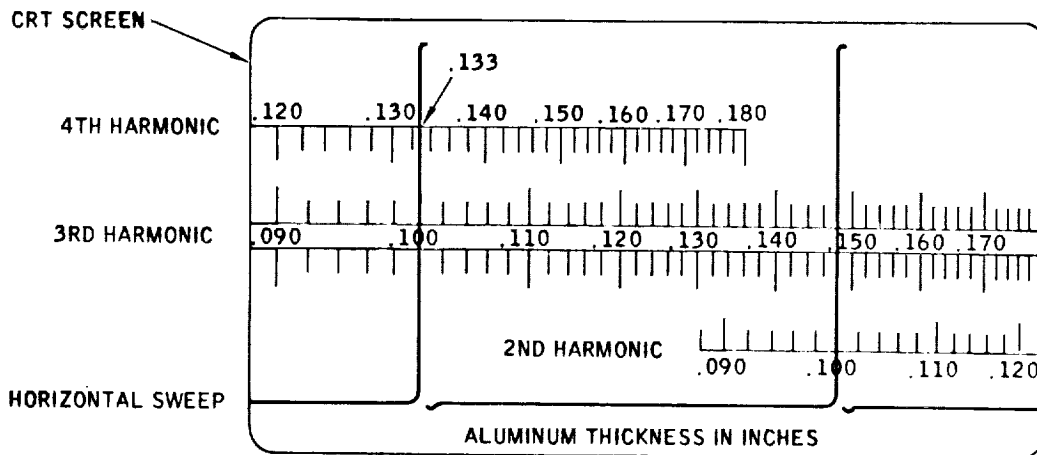
Figure 4-54.   Transparent Thickness Scale

4th harmonics are shown. The left indication is read as 0.100 or 0.133 inch, and the right indication is read as 0.100 or 0.148 inch. The correct thickness is 0.100 inch, since it appears once for each indication. Resonance thickness testers are also used for detecting corrosion, which is indicated by a decrease in signal amplitude caused by reduced material thickness. Figure 4-55 shows three different CRT displays from various back-surface conditions. Where smooth surface produce sharp, strong indi-
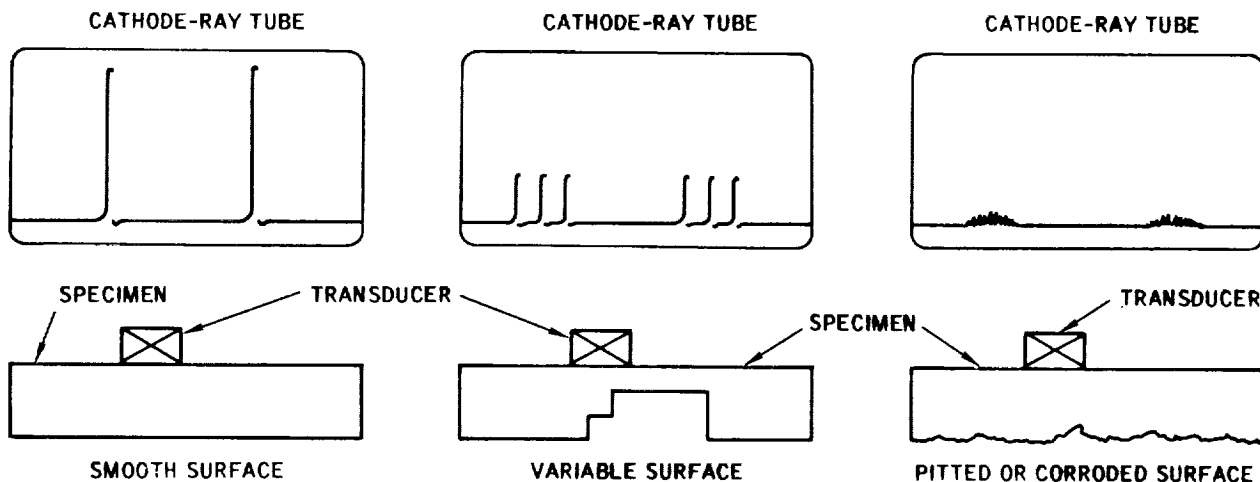
Figure 4-55.   CRT Display of Back-Surface Variables

cations, variable surfaces produce several indications of varying frequency and re-
duced amplitude. Corroded surfaces produce weak signals over a wide range of
resonant frequencies. Gross discontinuities are also detected with ultrasonic
resonance instruments by observing changes in the strength or locations of the
resonance indications. Figure 4-56 shows several resonance indications obtained
from a plate containing various types of discontinuities. The instrument is set up for
direct thickness measuring with three or four resonance indications appearing on the
CRT screen. Discontinuities are indicated, as the transducer is moved along the test
specimen, by a sudden shifting of the indications or by the appearance or disappearance
of all or some of the indications. For detecting voids or substandard bond areas in
honeycomb or bonded structures, bond testers are used for indicating the quality or
soundness of the material. Lack of bond is similar to a laminar discontinuity.
Usually it is a void or empty space and has a very high impedance mismatch. A typ-
ical CRT pattern from an ultrasonic bond tester is shown in Figure 4-57. By adjust-
ing the size of the resonance pattern, to represent a void of known size, the pattern
is then compared with the responses obtained from a bonded specimen under test. The
bond tester function is similar to a "GO-NO-GO" gage. Indications within a given
size are considered good. Indications over a given size, mean the material being
tested is below minimum requirements. The reference standards, made up for each
test, must simulate as closely as possible the physical characteristics of the bonded
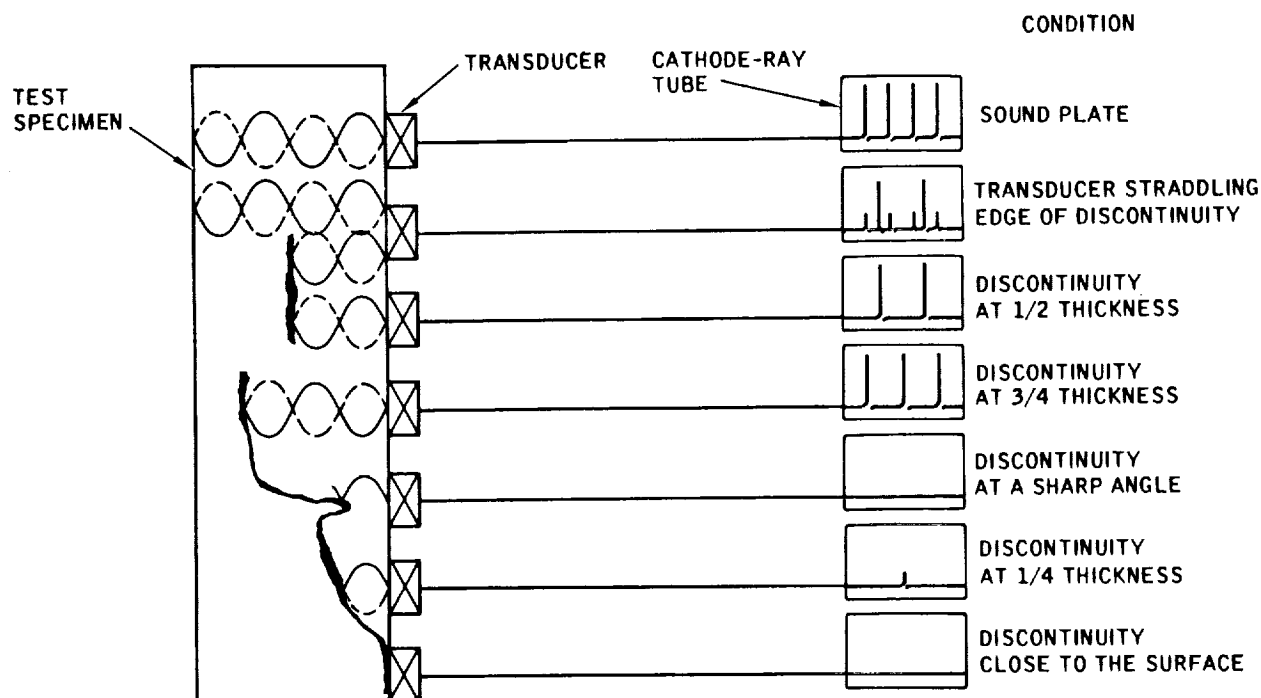
Figure 4-56. CRT Displays of Discontinuities
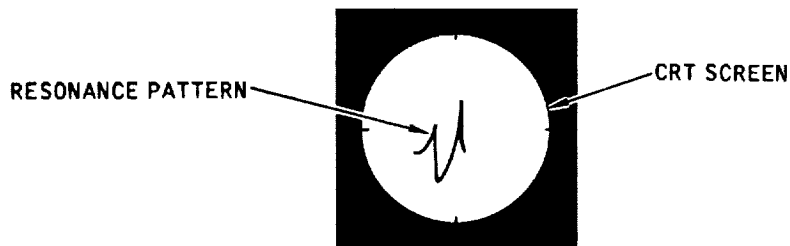
Figure 4-57. Bond Tester Display

specimens being tested and also must have clearly marked "void" and "non-void" areas.

407   REFERENCE TABLES

In the following reference tables, a high percentage of acoustic reflection, Table 4-1, is an indication of high impedance mismatch. Longitudinal and shear wave velocities, density, and acoustic impedance are given in Table 4-2 for a number of materials. Constant K values of various materials are given in Table 4-3, for resonance testing.

Table 4-1.   Percentage of Reflection

FIRST MEDIUM	ALUMINUM	STEEL	NICKEL	COPPER	BRASS	LEAD	MERCURY	GLASS	QUARTZ	POLYSTYRENE	BAKELITE	WATER	OIL
ALUMINUM	0	21	24	18	14	3	1	2	0.3	50	42	72	74
STEEL		0	0.2	0.3	1	9	16	31	27	77	76	88	89
NICKEL			0	0.8	2	12	19	34	29	79	75	89	90
COPPER				0	0.2	7	13	19	22	75	71	87	88
BRASS					0	5	10	23	16	73	68	86	87
LEAD						0	1	9	8	62	55	79	80
MERCURY							0	4	1	8	6	75	76
GLASS								0	0.8	40	32	65	67
QUARTZ									0	46	17	68	71
POLYSTYRENE										0	1	12	17
BAKELITE											0	18	23
WATER												0	0.6
OIL (TRANSFORMER)													0

Table 4-2. Acoustic Properties of Materials

MATERIAL	DENSITY P=GM/CM^3	LONGITUDINAL WAVES		SHEAR WAVES		SURFACE WAVES	
		VELOCITY V_L=CM/μ SEC.	IMPEDANCE Z_L=GM X 1000/ CM^2 - SEC.	VELOCITY V_T=CM/μ SEC.	IMPEDANCE Z_T=GM X 1000/ CM^2 - SEC.	VELOCITY V_R=CM/μ SEC.	IMPEDANCE Z_R=GM X 1000/ CM^2 - SEC.
AIR	.001	.033	.033	-	-	-	-
ALUMINUM 2SO	2.71	.635	1,720	.310	840	.290	788
ALUMINUM 17ST	2.80	.625	1,750	.310	868	.279	780
BARIUM TITANATE	.56	.550	310	-	-	-	-
BERYLLIUM	1.82	1.280	2,330	.871	1,600	.787	1,420
BRASS (NAVAL)	8.1	.443	3,610	.212	1,720	.195	1,580
BRONZE (P-5%)	8.86	.353	3,120	.223	1,980	.201	1,780
CAST IRON	7.7	.450	2,960	.240	1,850	-	-
COPPER	8.9	.466	4,180	.226	2,010	.193	1,720
CORK	.24	.051	12	-	-	-	-
GLASS, PLATE	2.51	.577	1,450	.343	865	.314	765
GLASS, PYREX	2.23	.557	1,240	.344	765	.313	698
GLYCERINE	1.261	.192	242	-	-	-	-
GOLD	19.3	.324	6,260	.120	2,320	-	-
ICE	1.00	.398	400	.199	199	-	-
LEAD, PURE	11.4	.216	2,460	.070	798	.063	717
MAGNESIUM, AM 35	1.74	.579	1,010	.310	539	.287	499
MOLYBDENUM	10.09	.629	6,350	.335	3,650	.311	339
NICKEL	8.3	.563	4,950	.296	2,610	.264	2,320
OIL, TRANSFORMER	.92	.138	127	-	-	-	-
PLASTIC (ACRYLIC RESIN-PLEXIGLASS)	1.18	.267	320	.112	132	-	-
POLYETHYLENE	-	.153	-	-	-	-	-
QUARTZ, FUSED	2.20	.593	1,300	.375	825	.339	745
SILVER	10.5	.360	3,800	.159	1,670	-	-
STEEL	7.8	.585	4,560	.323	2,530	.279	2,180
STAINLESS 302	8.03	.566	4,550	.312	2,500	.312	2,500
STAINLESS 410	7.67	.739	5,670	.299	2,290	.216	2,290
TIN	7.3	.332	2,420	.167	1,235	-	-
TITANIUM (TI 150A)	4.54	.610	2,770	.312	1,420	.279	1,420
TUNGSTEN	19.25	.518	9,980	.287	5,520	.265	5,100
WATER	1.00	.149	149	-	-	-	-
ZINC	7.1	.417	2,960	.241	1,710	-	-

Table 4-3. Resonance Testing, Constant K Table

MATERIAL	CONSTANT K (1,000,000 IN./SEC.)
ALUMINUM	0.121 - 0.131
ALUMINUM OXIDE	0.188 - 0.193
BERYLLIUM	0.252
BRASS	0.086 - 0.092
BRONZE (P-5%)	0.0695
CAST IRON	0.087 - 0.110
COPPER	0.092 - 0.093
CORK	0.010
GLASS, PLATE	0.114
GLASS, PYREX	0.111
GOLD	0.064
ICE	0.078
LEAD	0.047 - 0.049
MAGNESIUM	0.114 - 0.116
MOLYBDENUM	0.124
MONEL	0.106 - 0.108
NICKEL	0.113 - 0.115
PETROLEUM	0.026 (APPROXIMATELY)
PLASTIC (ACRYLIC RESIN, PLEXIGLASS)	0.0525
POLYETHYLENE	0.036
PHENOLIC LAMINATE (PAPER BASE)	0.052
RUBBER	0.0205
QUARTZ	0.114
SILVER	0.071
STEEL, CAST	0.110 - 0.116
STEEL, STAINLESS	0.112 - 0.114
STEEL	0.115 - 0.118
TEFLON	0.0245 - 0.0335
TIN	0.065
TITANIUM	0.121 - 0.126
TUNGSTEN	0.102
TUNGSTEN-SILVER	0.076 (APPROXIMATELY)
URANIUM	0.066 - 0.070
WATER (FRESH)	0.028 (APPROXIMATELY)
ZINC	0.082
ZIRCONIUM	0.093 - 0.102

CHAPTER 5: CALIBRATING TESTING UNITS
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CHAPTER 5: CALIBRATING TESTING UNITS

500 GENERAL

Periodic calibration of ultrasonic testing units is frequently required to establish linearity of displayed indications and to ensure proper instrument performance. Irrelevant effects within the testing unit are eliminated by calibrating the instrument system to reference standards. Once the equipment is calibrated to known standards, the operator may confidently adjust or standardize the unit to the values of the test material and expect an accurate display of discontinuities within the test sample. Standardizing the calibrated instrument to values of the test sample is done (refer to Chapter 4: Techniques) with special reference blocks, made in a specific shape and size of material which matches the dimensions and physical properties of the test sample as nearly as possible. When acceptance of the test sample is based on a rigid testing standard, considerable attention is given to calibration of the instrument system and to standardizing of the instrument to sample variables.

501 STANDARD REFERENCE BLOCKS (Figure 5-1)

1. GENERAL

For the purpose of equipment calibration, ultrasonic standard reference blocks are
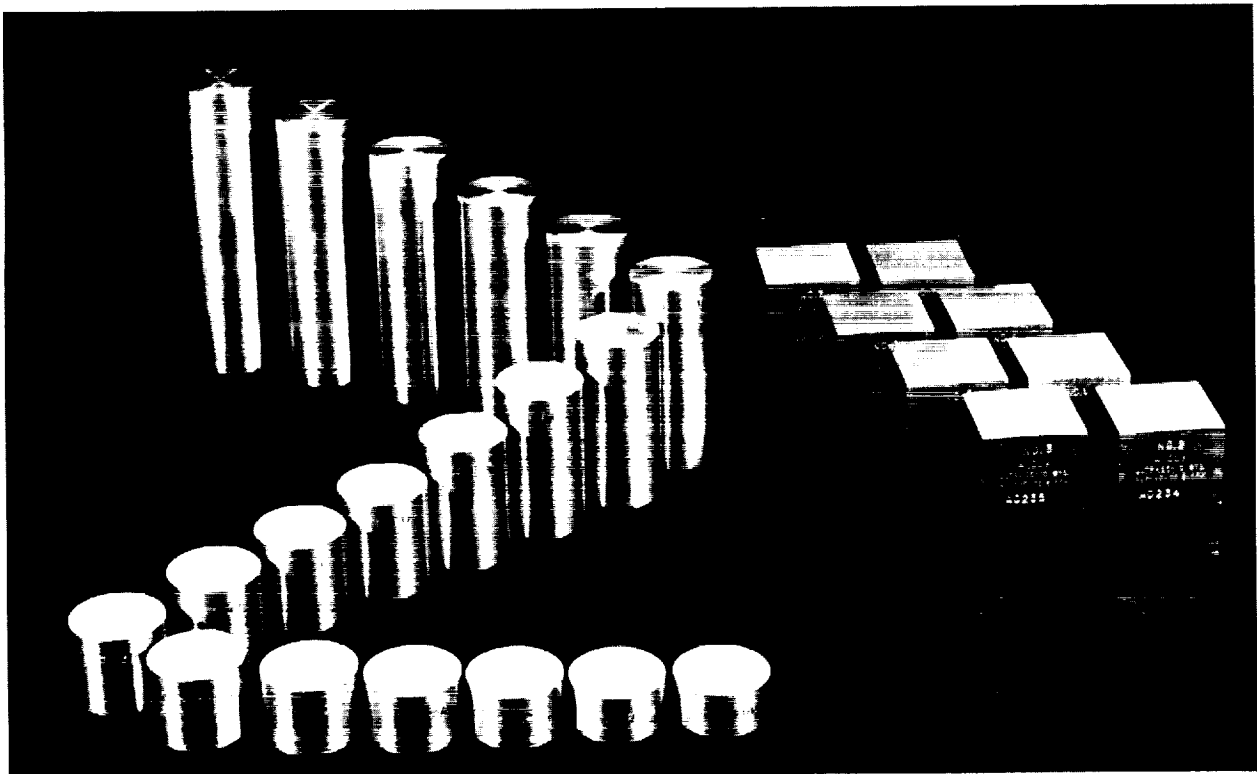
Figure 5-1. Standard Reference Blocks

manufactured in various shapes and sizes, each with a standard size flat-bottomed hole drilled into one end. These blocks are readily available from sources such as Alcoa, Automation Industries, Inc., etc, and are referred to as off-the-shelf standards. A fundamental reference standard, used for checking instrument performance and for checking reference blocks, consists of a series of varying-diameter steel balls, mounted on steel pins and immersed in couplant when calibrating. Area/amplitude reference blocks consist of a series of eight blocks of the same size, shape, and length, with flat-bottomed holes of varying diameter in the bottom of each block. Distance/amplitude blocks are made in a series of blocks of the same shape, same diameter flat-bottomed holes, but with varying lengths. For further information, refer to ASTM Recommended Practice E127-64.

2. MATERIALS

Ultrasonic standard reference blocks are made of carefully selected aluminum alloy bar stock (refer to ASTM Recommended Practice E127-64). Various other types of blocks are made from plastic, steel, magnesium, carbon, etc.

When testing materials, sensitivity corrections and adjustments for metal distance are most reliable when made on special reference blocks of a material which most nearly matches the material of the test specimen. When calibrating, the material of the reference block used for checking performance of the equipment may be different than the material found in subsequent test samples. In such cases, the equipment is standardized to the variables of the material under test, as described in Chapter 4, Techniques.

3. SHAPES (Figure 5-2)

Standard reference blocks are usually manufactured in rectangular or cylindrical shapes. Commonly, two sets of blocks are used; one set for area/amplitude correction and one set for distance/amplitude correction. A basic set which combines both area and distance responses may be used. Reference blocks are checked for accuracy by using a fundamental reference standard, which consists of a series of steel balls, of varying diameter, which are mounted on steel pins and immersed in the couplant.

    a.   Shapes for Area/Amplitude Standards. Area/amplitude standard reference blocks are usually made in sets of rectangular or cylindrical blocks with each block as nearly the same size and shape as the others in the set. The only variable is the size of the one hole drilled in the bottom center of each block to a depth of 3/4 inch, perpendicular to the longitudinal axis of the block. The hole diameters in each set vary in a progression of 1/64th inch increments; for example: 1/64, 2/64, 3/64, etc., to 8/64 inch. The hole bottom in each block is made flat by final drilling with a flat-end drill or cutter. The finished hole bottom is made as smooth as possible and is

HOLE PERPENDICULAR TO
TOP SURFACE (A). HOLE
BOTTOM (C) PARALLEL
WITH TOP SURFACE (A).

A = ULTRASONIC ENTRY SURFACE.
B = METAL DISTANCE. 3 INCHES FOR
AREA/AMPLITUDE BLOCKS, VARYING
DIMENSION FOR DISTANCE/AMPLITUDE
BLOCKS.
C = FLAT-BOTTOM HOLE SURFACE.
D = BACK SURFACE. PARALLEL WITH TOP
SURFACE.
E = HOLE DIAMETER. VARYING DIMENSION
FOR AREA/AMPLITUDE BLOCKS IN
1/64-INCH INCREMENTS, 5/64-INCH
DIAMETER FOR ALL DISTANCE/AMPLI-
TUDE BLOCKS. 1/4-INCH FLAT COUN-
TERBORE FOR PLUGGING HOLE.

Figure 5-2. Standard Reference Block Design

parallel to the top surface of the block. As will be seen later, the area of
the hole bottom, when reflected and displayed on the oscilloscope, is re-
lated to the height of the pip or amplitude, As each hole bottom is located
at a constant distance, pip size is directly related to area size of the hole
bottom. Steel balls, of varying diameters, are also used as an area/ampli-
tude standard. Various corporations use an unusual area/amplitude standard
which consists of a long steel block, pierced by eight press-fit pins with
flat ends which protrude 2 inches from one side of the block. The pins are
made of standard diameter drill rod, 1/16 to 1/2 inch diameter, installed
perpendicular to the surface of the block, with the tops of the pins parallel
to the surface of the block. With the block immersed, the instrument is
calibrated by centering the transducer over each of the eight pin tops.

b. Shapes for Distance/Amplitude Standards. Rectangular or cylindrical blocks,
similar to area/amplitude blocks, are made in sets with each block as nearly
the same shape as the others in the set, except that block height is varied.
The holes drilled in the bottom center of each block are usually 5/64 inch
diameter, flat-bottomed, and 3/4 inch in depth. As each hole bottom is
sized to a constant diameter, oscilloscope pip size is directly related to the
distance of the hole bottom from the top surface.

502 TYPICAL CALIBRATION PROCEDURE

1. GENERAL

In the following paragraphs, a typical calibration procedure will be covered, assuming conditions and equipment as follows:

a. Test Instrument. Any of several commercially available pulse-echo ultrasonic testing instruments.

b. Test Frequency. The test frequency shall be 15 Mc.

c. Transducer. An immersion transducer of 3/8 inch diameter quartz; with an operational frequency of 15 Mc.

d. Power Source. Line voltage with regulation ensured by a voltage regulating transformer.

e. Immersion Tank. Any container is satisfactory that will hold couplant and is large enough to allow accurate positioning of the transducer and the reference block.

f. Couplant. Clean deaerated water is used as a couplant. The same water, at the same temperature, is used when comparing the responses from differing reference blocks.

g. Bridge and Manipulator. The bridge is strong enough to support the manipulator and rigid enough to allow smooth, accurate positioning of the transducer. The manipulator adequately supports the transducer and provides fine angular adjustment in two vertical planes that are normal to each other.

h. Reference Blocks. Test sensitivity corrections for metal distance and discontinuity area responses are accomplished by using an area/amplitude set of blocks and a distance/amplitude set. A basic set which combines both area and distance responses may be used; for example, the ASTM basic set consisting of ten reference blocks. Area/amplitude relations are compared between blocks containing a 3 inch metal distance and 3/64 -, 5/64 -, and 8/64-inch diameter holes. Distance/amplitude relations are compared between blocks of varying length which contain 5/64 inch diameter holes.

i. Fundamental Reference Standard. When calibrating area/amplitude responses, an alternate to the reference blocks described is the ASTM set of 15 steel balls, free of corrosion and surface marks and of ball-bearing quality, ranging in size from 1/8 to 1 inch diameter in 1/16 inch increments. A suitable device, such as a tee pin, is necessary to hold each ball in the immersion tank.

2. AREA/AMPLITUDE CHECK

The linear range of the instrument is determined by obtaining the ultrasonic responses from each of the area/amplitude-type reference blocks (steel balls may be used as an alternate for the reference blocks) as follows:

a. Place a No. 5 area/amplitude reference block (a block containing a 5/64 inch diameter hole) in the immersion tank. Position the transducer over the upper surface of the block, slightly off-center, at a water distance of 3 inches between the face of the crystal and the surface of the block. This distance is adjusted accurately, within a + or - tolerance of 1/32 inch, by using a gage between the block and the crystal.

b. Manipulate the transducer, normal to the surface of the block, to obtain a maximum pip height from the front surface reflection of the block. This indication proves that the soundbeam is perpendicular to the top surface of the block. A maximum number of back surface reflection pips serves the same purpose.

c. Move the transducer laterally until the maximum response is received from the hole bottom.

d. Adjust the instrument gain control until the pip height is 31% of the maximum obtainable on the cathode ray tube screen. Do not repeat this step for the remaining blocks in the set.

e. Replace the reference block with each of the other blocks in the set. Repeat steps b. and c. for each block and record the indications. Maintain a water distance of 3 inches for each block, except for the No. 7 and No. 8 blocks which require a water distance of 6 inches.

f. Plot a curve of the recorded indications as shown in Figure 5-3. In the example shown, the point where the curve of responses deviates from a straight line defines the limit of linearity in the instrument. Amplitudes plotted below the limit of linear response (in this example) are in the linear range of the instrument and no correction is required. Amplitudes of indication above the limiting point are in the non-linear range and are increased to the ideal linearity curve. This is done by projecting a vertical line upward from the actual height of indication until the ideal curve is intercepted. The point of interception defines the corrected height of indication (CH) in per cent of maximum amplitude of indication that the instrument can display. The difference between the corrected height (CH) and the actual height (AH) is the correction factor (CF). For each different amplitude indication in the non-linear range, the correction factor (CF) is plotted in the same way, because the curve deviation is not constant. When the actual indication height is displayed, the corrected indication height is computed
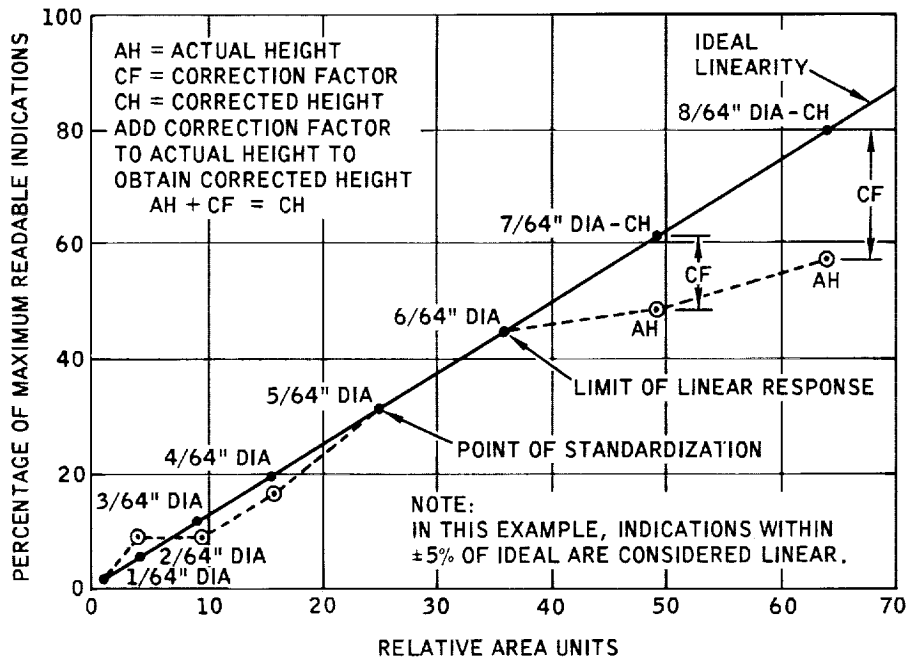
Figure 5-3. Typical Area/Amplitude Response Curve

by adding the correction factor directly to the actual indication height, as follows:

$$AH + CF = CH$$

g. The linear range of the instrument may also be determined by recording the ultrasonic responses from each of fifteen steel balls, ranging in size from 1/8 to 1.0 inch in diameter in 1/16 inch increments. The immersion method is used, following previous steps a. through f., except that in step d. the instrument gain control is adjusted until the pip height is 50% of the maximum obtainable on the oscilloscope screen with the transducer positioned over the 1/2 inch diameter steel ball. For each ball, the water distance is maintained constant at 3 ± 1/32 inch and the transducer is positioned for maximum response from each ball. The recorded indications are plotted on a curve as shown in Figure 5-4.

3. DISTANCE/AMPLITUDE CHECK

The distance/amplitude characteristics of the instrument are determined by obtaining the ultrasonic responses from each of the reference blocks in a set of blocks of varying metal distance with a 5/64 inch diameter hole in each block. The resultant indications are recorded on a curve, in the following procedure:
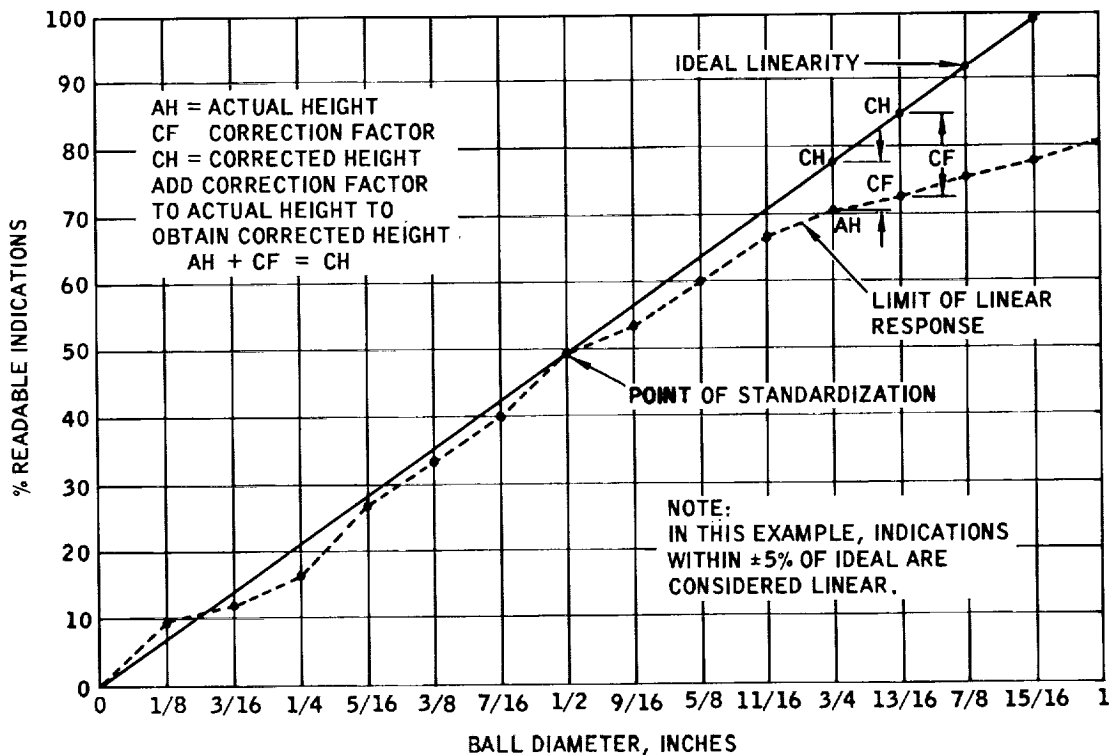
Figure 5-4. Steel Ball Area/Amplitude Response Curve

a. Place a reference block, containing a 5/64 inch flat-bottomed hole with a metal distance of 3.000 inches from the top surface to the hole bottom, in the immersion tank. Position the transducer over the upper surface of the block, slightly off-center, at a water distance of 3 inches between the face of the crystal and the surface of the block. Adjust this distance accurately, within a + or - tolerance of 1/32 inch, by using a gage between the block and the crystal.

b. Manipulate the transducer, normal to the surface of the block, to obtain a maximum pip height from the front surface reflection of the block. This indication proves that the soundbeam is perpendicular to the top surface of the block. A maximum number of back surface reflections serves the same purpose.

c. Move the transducer laterally until the maximum response is received from the hole bottom. Adjust the instrument gain control until the pip height is 25% of the maximum obtainable on the cathode ray tube screen.

d. Replace the reference block with each of the other blocks in the set. Repeat steps b. and c. for each block and record the indications. Maintain water distance of 3 inches for each block, except when the basic set is used, which

requires a water distance of 6 inches for one block containing an 8/64 inch diameter hole with a metal distance of 3.000 inches.

e. Plot a curve of the recorded indications as shown in Figure 5-5. In the example shown, the near field (fresnel) zone extends from the 0.5 inch indication to the 2.0 inch indication. As the distance beyond 2.0 inches increases, the indications attenuate or decrease in height.

4. TRANSDUCER CHECK

To improve accuracy during ultrasonic test equipment calibration, the characteristics of the transducer, as modified or distorted by the test instrument, are determined by recording a distance/amplitude curve from a 1/2 inch diameter steel ball immersed in water. A beam pattern or plot can also be obtained from the same steel ball at a fixed water distance of 3 inches. It is well to remember that the curve and beam plot recorded in this procedure are not valid if the transducer is subsequently used with any test instrument other than the one used in this procedure. A complete analysis of transducer characteristics cannot be accomplished with the commercial ultrasonic testing equipment used in this procedure. To ensure maximum accuracy, the transducer may be calibrated with the special equipment called for in Chapter 6: Calibrating Transducers. In the following procedure, the apparatus used for checking the

TEST FREQUENCY: 15 MC
TRANSDUCER: 3/8-INCH DIAMETER QUARTZ
WATER DISTANCE: 3 ±1/32 INCH

POINT OF STANDARDIZATION

METAL DISTANCE, INCHES
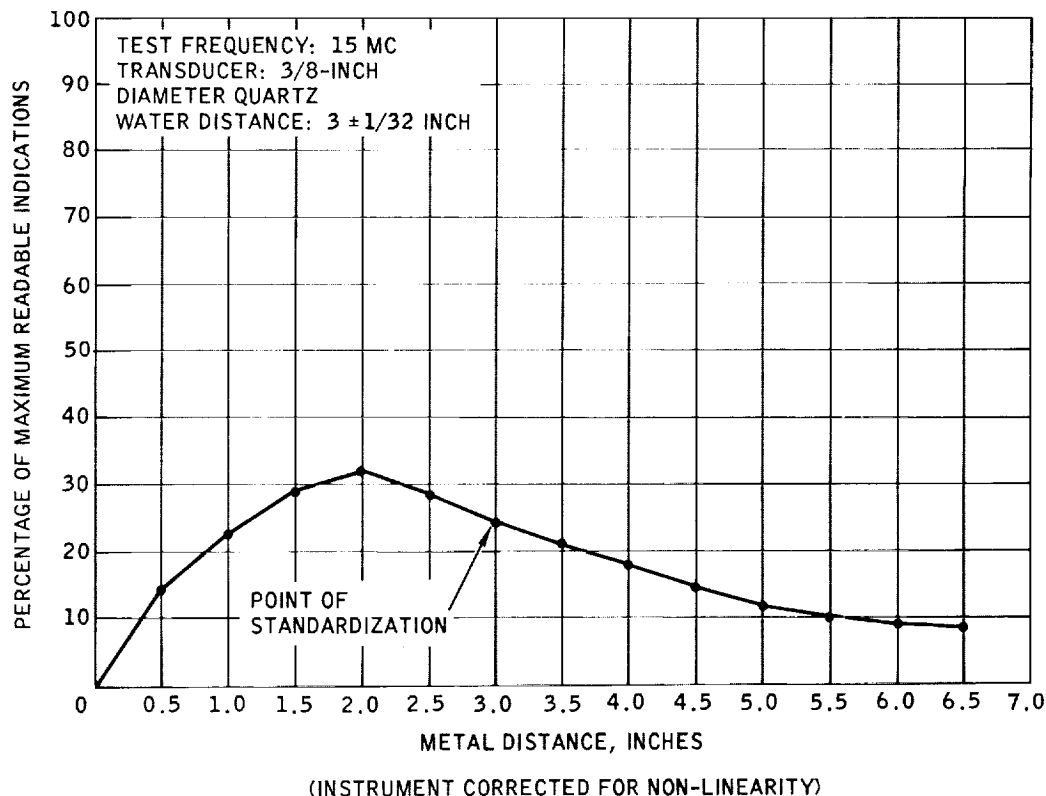
(INSTRUMENT CORRECTED FOR NON-LINEARITY)

Figure 5-5. Typical Distance/Amplitude Response Curve

transducer is the same as that prescribed in the previous paragraphs for calibrating the instrument with reference blocks. The maniuplator is set to allow a range in water distance of 0 to at least 6 inches from the face of the transducer to the ball surface.

a. Adjust the instrument gain control until the pip height is 50% of the maximum obtainable on the oscilloscope screen with the transducer positioned at a water distance of 3 ± 1/32 inch from the face of the transducer to the top surface of the ball. Exercise care in producing a true maximum indication by locating the transducer beam center on the center of the ball. Record this point of standardization.

b. After standardizing the instrument, set the water distance at 1/4 inch. Again, exercise care in using the manipulator to locate the transducer beam center on the center of the ball. Record the maximum indication. Do not readjust the instrument gain control in this or succeeding steps of the procedure.

c. Vary the water distance in 1/8 inch increments through a range of 1/4 to 6 inches. Record the maximum indication for each increment of water distance, using care each time the transducer is moved back that the beam center remains centered on the ball.

d. As shown in Figure 5-6, plot the recorded indications (corrected for any non-linearity) on a curve to demonstrate the axial distance/amplitude response of the transducer and the particular test instrument used in the test. The curve for an acceptable transducer is similar to the curve shown in Figure 5-6. It is important that the peaks in the curve occur at water distances of 1.25, 1.75, and 3 inches as shown. The allowable deviation in water distance for the occurence of these peaks is 1/16 inch.

e. Determine the transducer beam pattern by relocating the manipulator to obtain a 3 ± 1/32 inch water distance from the 1/2 inch diameter steel ball to the face of the transducer. While scanning laterally, 3/8 inch total travel, the height of the indication from the ball is observed while the transducer passes over the ball. Three distinct lobes or maximums are observed. The symmetry of the beam is checked by making four scans; displacing each scan by rotating the transducer 45 degrees. The magnitude of the side lobes should not vary more than 10 per cent about the entire perimeter of the soundbeam. An acceptable transducer will produce a symmetrical beam profile which has side lobes with magnitudes no less than 20 nor more than 30 per cent of the magnitude of the center lobe. The beam pattern or plot of an acceptable transducer is shown in Figure 5-7.
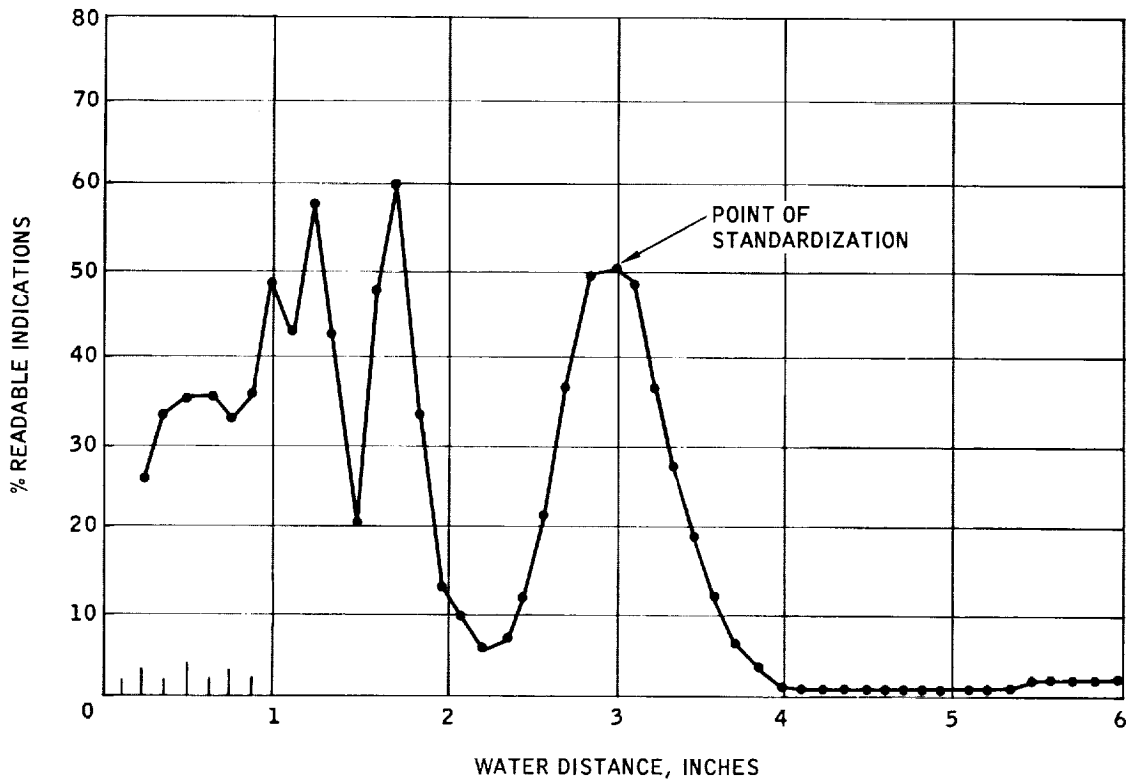
Figure 5-6. Transducer Axial Distance/Amplitude Characteristics

IMERSION TRANSDUCER - 3/8-INCH DIAMETER QUARTZ, WITH OPERA- TIONAL FREQUENCY OF 15 MC.

TARGET - 1/2-INCH DIAMETER STEEL BALL AT A WATER DISTANCE OF 3 ±1/32 INCH.

SIDE LOBE MAGNITUDE SHOULD BE 20% - 30% OF CENTER LOBE.
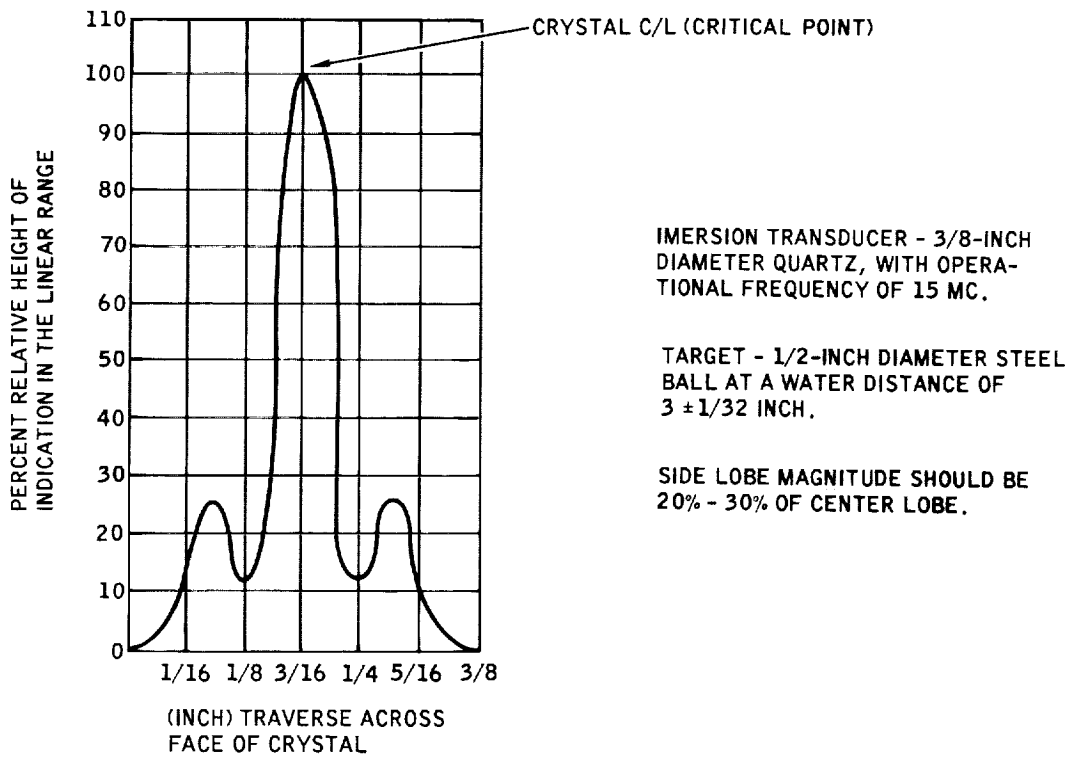
Figure 5-7. Transducer Beam Pattern

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CHAPTER 6: CALIBRATING TRANSDUCERS

600   GENERAL

Ultrasonic transducers, though identical in appearance and manufactured to the same specification, usually have individual characteristics. Acoustic anomalies may exist because of variations in crystal cutting, areas of poor bond to lens or backing, and misalignment of parts in the transducer assembly.

601   GENERAL EQUIPMENT QUALIFICATIONS

Specialized wideband transmitting and receiving equipment is required for accurately measuring transducer variables. To analyze transducer characteristics, the crystal is excited by a voltage spike in a fashion that will not distort the natural mode of operation. The signals received by the transducer are amplified without distortion, and the information received is displayed in some manner which will provide a permanent photographic record. The following pages describe the special instrumentation equipment and techniques for measuring, or calibrating and recording transducer characteristics such as frequency, sensitivity, damping factor, beam size, beam symmetry, and beam focal distance.

602   GENERAL CALIBRATING TECHNIQUE

In general, the calibrating technique consists of using a small reflector in the immersion tank; a ball bearing, a flat post, or a thin wire is scanned by the ultrasonic beam. As the transducer is moved over the reflector, a changing response is produced on the oscilloscope as a distance/amplitude plot of the beam in profile. At the highest amplitude portion of the beam, the RF return signal waveform is photographically recorded with the transducer held stationary. The unrectified RF waveform is analyzed for information relating to the frequency, damping, and sensitivity of the unit. With the transducer moving over the target, using precision manipulative equipment, data potentiometers, and related delay circuits, a dynamic recording of the beam symmetry is produced by use of an open-shutter camera. More uniform test results may be expected when these recorded measurements are used in specifying or selecting transducers to be used for inspecting materials or articles.

603   TRANSDUCER CALIBRATING EQUIPMENT

1.   GENERAL

Equipment used to accurately measure the send-receive characteristics of an ultrasonic transducer is capable of reproducing an exact indication, on the oscilloscope screen, of the signals sent and received by the transducer. The system also moves the transducer over the reflector. With potentiometers coupled to the motion, a distance/amplitude plot of the soundbeam is produced on the oscilloscope screen. An open-shutter camera is then used to record the beam profile on Polaroid film.

2.   TEST SETUP

The transducer is placed in a couplant tank (similar to a small aquarium) made of Lucite or glass so the immersed transducer and reflector are viewed through the couplant. A reflector is placed in the soundbeam with accurate motion of the scanning transducer ensured by the use of milling table crossfeeds. Potentiometers on the crossfeeds convert motion data into electrical signals which are fed into the horizontal position controls of the oscilloscope. The horizontal oscilloscope display shows distance of transducer traverse in inches. Either X or Y directions of crystal movement are produced by simply switching potentiometers.

3.   FUNCTION

Figure 6-1 shows a functional diagram of the instrumentation equipment, which consists of a timer, delay unit, pulser, and wideband receiver. The unit repeatedly pulses the transducer with a sharp spike and then amplifies return signals fed back through the crystal. In operation, the timer triggers both the delay unit and the pulser tube which, at an adjustable time, later triggers the oscilloscope.

4.   RECORDING METHOD

Figure 6-2 shows how the response curve is recorded with an open-shutter camera.
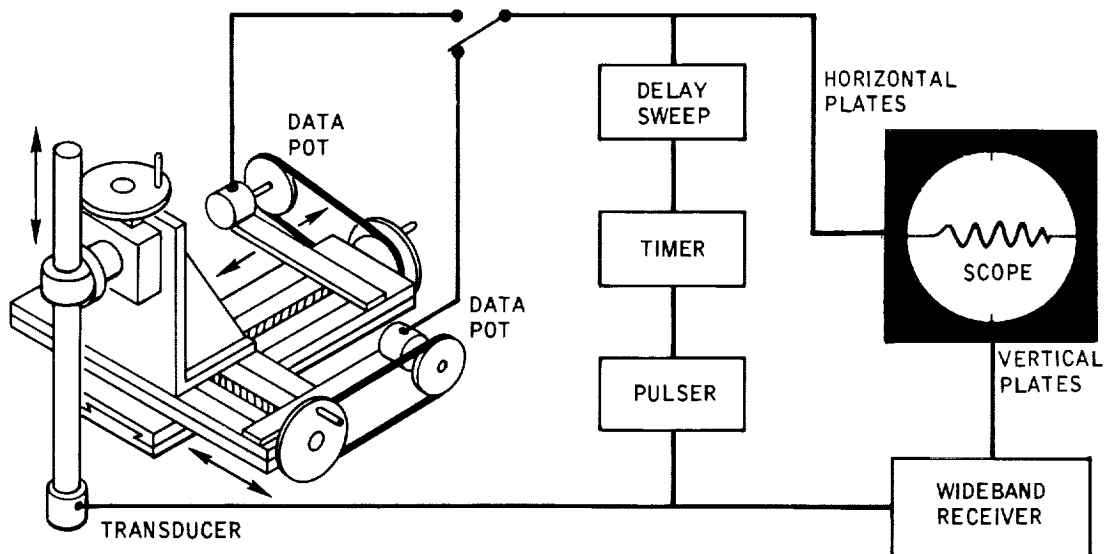
Figure 6-1.   Equipment Functional Diagram

The data potentiometers, as shown, are used to delay the RF presentation across the oscilloscope screen. By this method, a permanent record of the response curve is produced, calibrated in thousandths of an inch describing the uniformity of the soundbeam. This information is related to specific abnormalities in the transducer, such as variations in damping, crystal thickness, lens composition, and dimensional nonuniformity. A recommended camera for this system is a scope-mounted Polaroid, featuring a lock-open shutter and a viewing port for use while photographing.

5. MANIPULATIVE EQUIPMENT

Precision elevating and transversing mechanisms are required for precise soundbeam and focal length measurements. Milling table crossfeeds are used, which consist of heavy micrometer screw slides, calibrated in thousandths of an inch. Two of the slide screws are fitted with sprocket and chain drives that develop the delay sweep by the use of data potentiometers. By relating the micrometer reading to the distance the trace has moved across the oscilloscope screen; the recording is calibrated in inches per division on the bezel of the oscilloscope. The two data potentiometers, one on the transverse and one on the longitudinal movements, are mounted so that one plot is made across the target and then, by switching to the other one, a plot rotated 90° from the first plot, is obtained. Two recordings of the beam profile are made without turning or disturbing the mounting of the transducer.
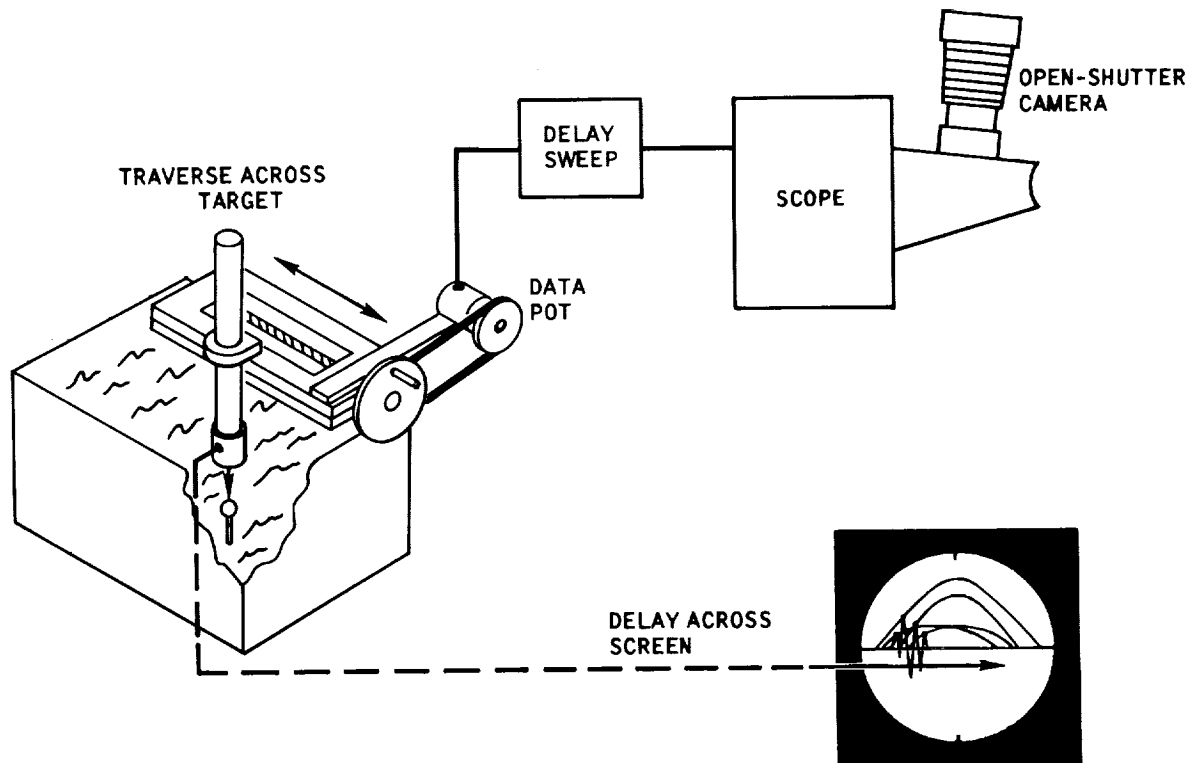
Figure 6-2. Camera Recording Method

6. REFLECTOR TARGETS

Unless reflector targets are carefully chosen, a bad target can seriously distort the signal and will produce invalid information. In most cases, precision steel balls are used, particularly when calibrating focused transducers. The diameter of the ball selected is maintained as small as possible. The size of the effective reflecting surface of the ball is held to less than one-quarter wavelength of the transducer frequency. This will prevent frequency distortion and undue influence of the target on the measurement of the beam. When analyzing larger diameter flat transducers, a ball target may not offer adequate signal amplitude for profile recording. In this case, a flat-topped post, as small in diameter as possible, is used, provided the transducer is held perpendicular to the post surface while testing. Best results are obtained from the use of ball reflectors in that they eliminate the difficulty experienced with flat reflectors in holding the transducer normal to the flat surface. Selection of ultrasonic reflectors varies with the geometry of each crystal and lens. Reflectors are small compared with the beam size measured, or about equal in size to actual discontinuities the transducer is expected to detect. For example, a flat, circular reflector of one-eighth the crystal diameter is adequate for testing flat-disc transducers used to detect fairly large imperfections. Spherically-focused transducers, used to detect very small areas, produce soundbeams much smaller than those produced by unfocused transducers. In proportion, reflector size is small. In one experiment, performed by the AEC Hanford Laboratories, the soundbeam traversed a 29-mil diameter ball from a fine-line ball-point pen.

7. PULSER

This test requires a pulser with short pulse capability. To analyze the natural frequency of the transducer and the damping characteristics, the transducer is excited with a voltage pulse that will not drive the crystal into abnormal oscillation. This demands a pulse duration as short as possible, much less than one period of the natural resonant frequency of the crystal. For analysis of high-frequency (5 to 25 Mc) transducers, the recommended pulse duration is 0.025 microseconds with a rise time of 10 nanoseconds. (A microsecond is one-millionth second and a nanosecond is one-billionth second.)

8. WIDEBAND RECEIVER

To prevent the received signal from becoming distorted, a receiver with a wideband RF amplifier is used. A recommended receiver is one with a bandwidth of 1.5 to 60 Mc, rise time response of 10 nanoseconds, and a gain of about 40 db.

9. DISPLAY SYSTEM

An effective system has sufficient bandwidth and rise time to present the information without distortion. A recommended oscilloscope is the Tektronix Type 547 with a Type L vertical amplifier plug-in. Bandwidth is dc to 30 Mc with a rise time

capability of 0.010 microsecond. This scope combination offers delay and time base expansion features that are desirable for recording transducer beam profiles.

604 RECORDING OF TRANSDUCER BEAM PROFILES

1. GENERAL

Transducer data sheets are prepared, as shown in Figure 6-3, for mounting of photographic records and recording of transducer analysis. The following paragraphs describe various methods used to obtain transducer beam profiles.

2. FLAT-DISC TRANSDUCER MEASUREMENTS

Figure 6-4 shows a beam profile plot of responses picked up by a flat-disc transducer positioned in water over a reflector made from the butt end of a metal drill which has been cut and polished flat. The flat end of the drill and the crystal face are held parallel while the transducer scans over the reflector along the four parallel paths shown. These four-beam amplitude profiles, taken with a moving transducer, plus a return signal waveform taken from a stationary transducer, are recorded on a photograph to provide a permanent record of individual transducer characteristics.

3. FOCUSED TRANSDUCER MEASUREMENTS

Figure 6-5 shows the basic transducer measurements for a focused transducer. With the reflector stationary, a waveform is obtained and two beam amplitude profile plots are taken with the transducer traversed in the X-axis and the Y-axis. If the depth of field for a focused transducer is required, the beam profile may be taken at points inside and outside the focal point.

4. CYLINDRICALLY-FOCUSED TRANSDUCER MEASUREMENTS

A wedge-shaped soundbeam, focused in width and unfocused along the length, is produced by the cylindrically-focused transducer which has a concave lens. A steel ball is used for measuring beam width by traversing the immersed transducer over the reflector across the length of the beam as shown in Figure 6-6. Correct ball diameter depends on the frequency, crystal size, and lens radii of the transducer being tested. A rule of thumb is to select as small a reflector as possible which will still produce adequate signal levels for profiling.

Since beam width is usually narrow, the problem of maintaining ball alignment while traversing along the beam length, may be avoided by substituting a piece of wire for the ball, and wire diameter depends on the same factors that determine ball diameter selection, i.e., frequency, crystal size, and lens radii.

Two beam amplitude profiles are produced by translating along the beam length over the wire, and then translating across the beam width over the ball reflector.

FREQUENCY DAMPING FACTOR, BEAM WIDTH/DIAMETER, FOCAL LENGTH, BEAM SYMMETRY

SERIAL NO._____ DATE _____

TYPE_____FOCUSED_____ HOUSING STYLE _____

FREQUENCY _____15 MC_____ CRYSTAL SIZE_____3/16_____

CRYSTAL _____LITHIUM SULFATE_____ LENS_____1/4 RAD._____

REFLECTORS USED: INSPECTOR_____

A.____0.039 DIA. STEEL BALL_____ DRIVER PULSE:

B.____0.039 DIA. STEEL BALL_____ DURATION_____0.065_____MICROSECONDS

C.____0.039 DIA. STEEL BALL_____ AMPLITUDE_____150_____VOLTS

CONNECTING CABLES:

	LENGTH	TYPE
PULSER TO CRYSTAL	5'	RG 62
RECEIVER TO SCOPE	5'	RG 62

DRIVER PULSE: RECEIVED SIGNAL TRACE A
: _____ DB DOWN

TIME ———▶

TRACE

    A. (WAVEFORM)

      .1 MICROSEC/CM

      2.0 VOLTS/CM

    B. (Y DIRECTION)

      2 MICROSEC/CM

      .5 VOLTS/CM

      .004 INCH/DIV

    C. (X DIRECTION)

      2 MICROSEC/CM

      .5 VOLTS/CM

      .004 INCH/DIV
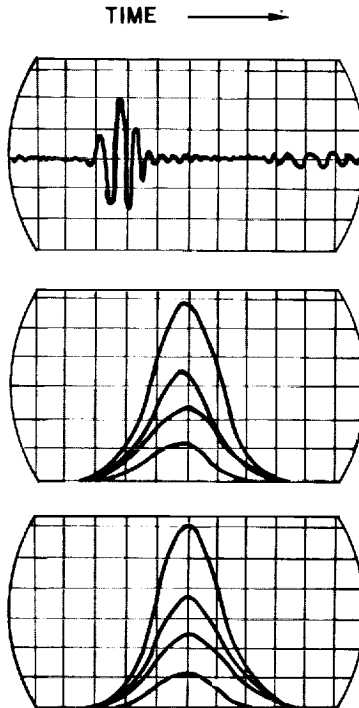
MEASURED FREQUENCY 17.5 MCS
TRACE A

FOCAL LENGTH 0.558 INCHES

____20____ MICROSEC WATER PATH
(ROUND TRIP TIME)

DAMPING FACTOR ____3.0____
TRACE A

BEAM WIDTH OR DIA.____0.007____
INCHES 3DB AMP. POINTS
TRACE B

BEAM SYMMETRY:

    LENGTH VS AMP._____

    270° - 90° ____X____
    TRACE B

    180° - 360°____X____
    TRACE C

Figure 6-3. Typical Transducer Data Sheet
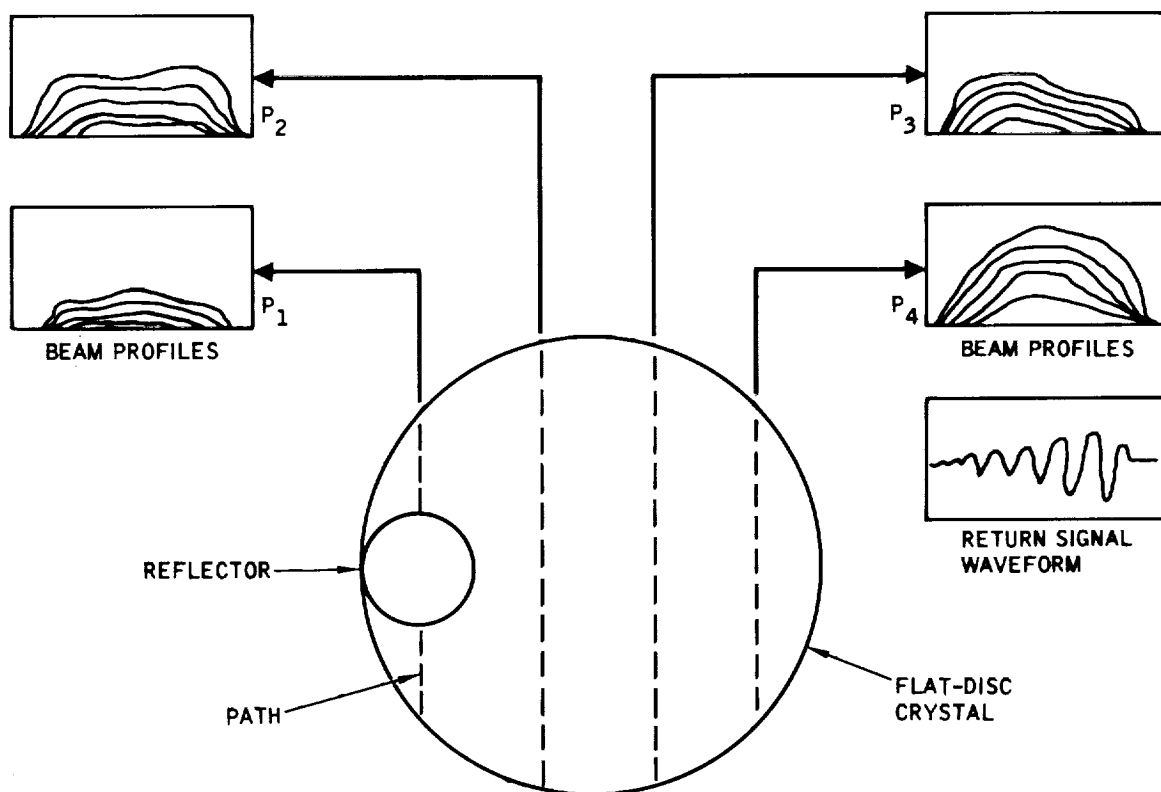
Figure 6-4. Flat-Disc Transducer Measurements
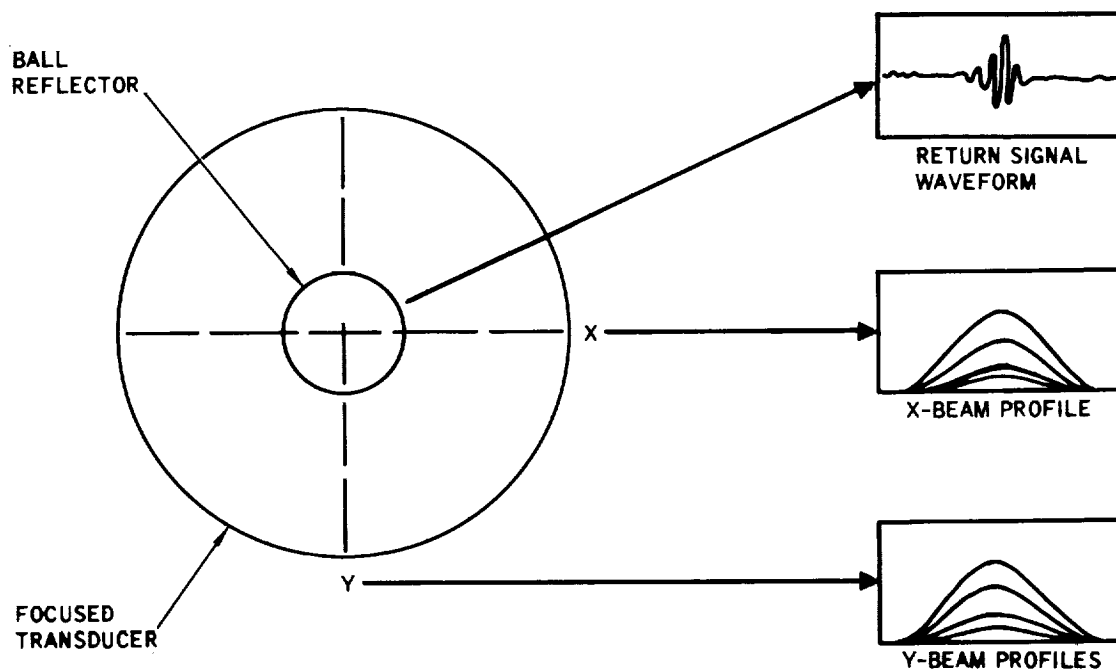
Figure 6-5. Focused Transducer Measurements
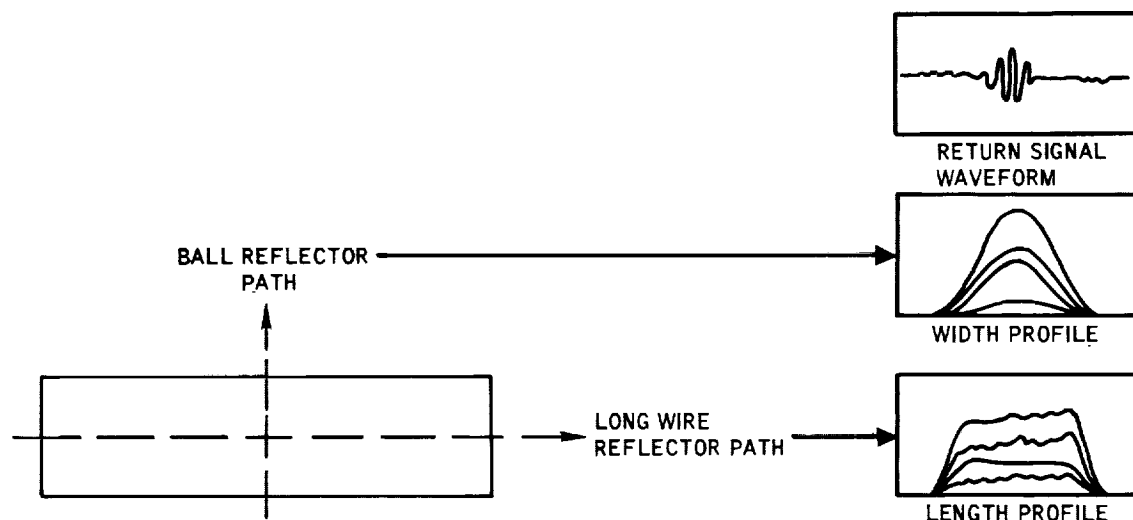
Figure 6-6. Cylindrically-Focused Transducer Measurements

The point selected for the beam-width measurement is determined by the beam-length measurement at the point of highest amplitude. With the ball stationary in this beam area, the waveform is also recorded. If the depth of field for the focused area of the beam is required, the beam profile is taken with the reflector moved to points in the soundbeam (by moving the transducer, actually) which are nearer than the focal point and beyond the focal point.

605   ANALYSIS OF TRANSDUCER DATA

1.   GENERAL

In the following paragraphs, each of the main headings on the transducer data sheet are discussed. For each transducer tested, the waveform and beam profile plots are analyzed as follows.

2.   WAVEFORM

At the highest amplitude portion of the beam, as determined by the profile shots, the return signal waveform is recorded photographically with the transducer stationary. This record is calibrated in millivolts on the vertical scale and time on the horizontal scale, permitting a determination of crystal frequency, damping factor, and sensitivity.

3.   FREQUENCY

In this test, the actual frequency of transducer operation is measured and compared to the design frequency. The actual frequency measurement is a measure of the acoustic wave in the water medium. As this is the frequency of the energy used when testing material, this is the frequency that is recorded. To record the acoustical frequency of

the transducer, the first reflected signal from the ball target is analyzed. Trace A in Figure 6-3 illustrates this signal. The frequency may be calculated if the period (time-base) is known: number of complete cycles per unit of time equal frequency.

4. DAMPING FACTOR

Extent of crystal damping is measured by the damping factor which is defined as the number of positive half cycles within the RF pulse that are greater than the first half cycle in amplitude. Trace A in Figure 6-3 indicates this measurement. This method produces a damping factor that is a measurement of the time required for the crystal to return to a quiescent state after excitation. By counting the number of cycles generated by the crystal when reacting to the reflected pulse, a measure of damping is reached. The ability of the transducer to resolve is directly related to the damping factor. The smaller the damping factor, the better the ability of the transducer to resolve two signals arriving very close together in a given time.

5. SENSITIVITY

Sensitivity refers to the ability of the transducer to detect the minute amount of sound energy reflected from a relatively small target. The ultrasonic reflectors used, in a test for sensitivity, vary with the geometry of the crystal and lens. In general, the reflector is small, compared to the beam size measured, or roughly equal in size to actual defects the transducer is expected to detect. For flat, straight-beam transducers, a flat, circular reflector of one-eighth the crystal diameter is adequate. Beam sizes of focused transducers, used to detect very small discontinuities, are much smaller than the beam sizes of flat transducers. The reflector is also small. The steel balls from the tips of ballpoint pens, ranging in size from 0.030 to 0.050 inch in diameter, have been used successfully for testing focused units. These tiny balls are also used for measuring the beam width of cylindrically-focused transducers. These units are focused in the width dimension and unfocused along the beam length. If difficulties are experienced in aligning the ball while traversing in the beam length direction, a small diameter fine wire may be laid along the lengthwise path as a substitute for the ball. The vertical amplitude of the signal received, as shown in trace A of Figure 6-3, is calibrated in volts per centimeter to measure sensitivity. With the amplitude and duration of the pulse known, plus the amplification factor of the wideband receiver known and held constant, the measure of sensitivity is recorded in volts peak-to-peak or in decibels down with respect to the pulse voltage.

6. FOCAL LENGTH

The focal length information is not photographed but is recorded as the water path length at which a maximum return signal is obtained on focused transducers. Focal length is recorded manually by the time base measurement on the oscilloscope screen

between the excitation pulse and the water path position at the point of maximum amplitude response. The transducer is held over the center of the ball target and moved toward or away from the ball until the maximum reflected signal is received.

7. BEAM AMPLITUDE PROFILES

The beam amplitude profiles on the photographs show amplitude envelopes of each half cycle with the vertical scale calibrated in millivolts of transducer return signal and the horizontal scale calibrated in mils, or centimeters, of transducer travel. The motion of the transducer across the target drives a data potentiometer which in turn delays the composite RF signal across the oscilloscope screen. With the shutter of the recording camera held open, a distance/amplitude recording for each individual cycle is produced. The highest amplitude cycle records the major envelope, the next highest amplitude cycle records the next lower curve, and so on. This system of recording produces superimposed response curves from each individual cycle with respect to each other. The symmetry of these curves with respect to one another is indicative of uniformity of operation in the send-receive modes of the transducer. The symmetry of these curves is affected by variations in damping, crystal thickness, lens thickness, or bonding of the transducer components.

8. BEAM WIDTH AND SYMMETRY

The beam width is read directly from the width of the profile envelope displayed on the calibrated horizontal axis, or at the 3-db down points on each side of the profile peak. Non-symmetry is recognized as variations in the profile patterns of the propagated soundbeam. And through critical analysis of these beam envelope variations, normal and abnormal conditions can be identified. Non-symmetry may be caused by backing variations, lens centering or misalignment. Porosity in lenses and small imperfections in electrodes and bonding have also been linked to distortion in beam profiles.

CHAPTER 7: COMPARISON AND SELECTION OF NDT PROCESSES
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CHAPTER 7: COMPARISON AND SELECTION OF NDT PROCESSES

700   GENERAL

The purpose of this chapter is to summarize the characteristics of various types of discontinuities, and to list the NDT methods which may be employed to detect each type of discontinuity.

The relationship between the various NDT methods and their capabilities and limitations when applied to the detection of a specific discontinuity will be shown. Such variables as type of discontinuity (inherent, process, or service), manufacturing processes (heat treating, machining, or plating), and limitations (metallurgical, structural, or processing) all will help determine the sequence of testing and the ultimate selection of one test method over another.

701   METHOD IDENTIFICATION

Figures 7-1 through 7-5 illustrate five NDT methods. Each illustration shows the three elements involved in all five tests, the different methods in each test category, and tasks that may be accomplished with a specific method.

702   NDT DISCONTINUITY SELECTION

The discontinuities that will be reviewed in paragraphs 706 through 732 are only a part of the many hundreds that are associated with the various products of the aerospace industry. During the selection of discontinuities for inclusion in this section, only a few of those discontinuities which would not be radically changed under different conditions of design, configuration, standards, and environment were chosen.

703   DISCONTINUITY CATEGORIES

Each of the specific discontinuities are divided into three general categories: inherent, processing, and service. Each of these categories is further classified as to whether the discontinuity is associated with ferrous or nonferrous materials, the specific material configuration, and the manufacturing processes if applicable.

1.   INHERENT DISCONTINUITIES

Inherent discontinuities are those discontinuities that are related to the solidification of the molten metal. There are two types.

    a.   Wrought.   Inherent wrought discontinuities cover those discontinuities which are related to the melting and original solidification of the metal or ingot.

ELEMENT   PROCEDURE   TASK

PERSONNEL — VISIBLE DYE PENETRATE TESTING — DETECT SURFACE DISCONTINUITIES

TECHNIQUES

EQUIPMENT — FLUORESCENT PENETRANT TESTING — SPECIALIZED APPLICATIONS
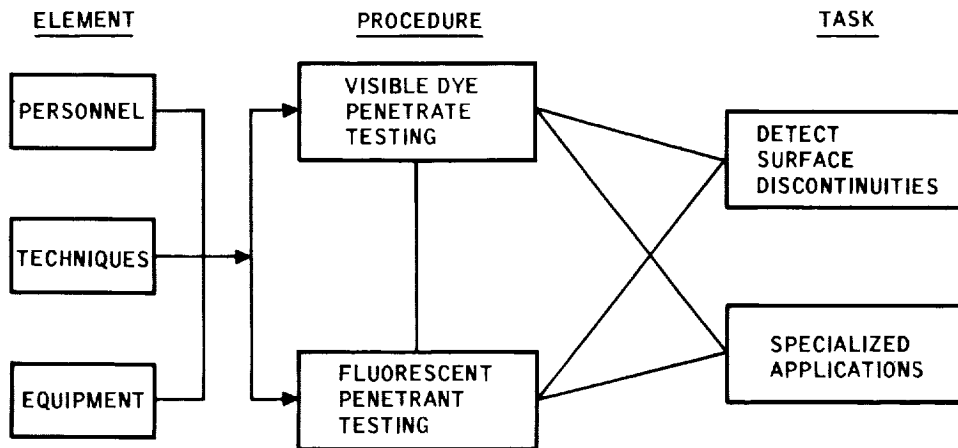
Figure 7-1.   Liquid Penetrant Test

ELEMENT   PROCEDURE   TASK

PERSONNEL — DRY VISIBLE TESTING — LOCATE DISCONTINUITY

TECHNIQUES — WET VISIBLE TESTING

EQUIPMENT — WET FLUORESCENT TESTING — SPECIALIZED APPLICATIONS
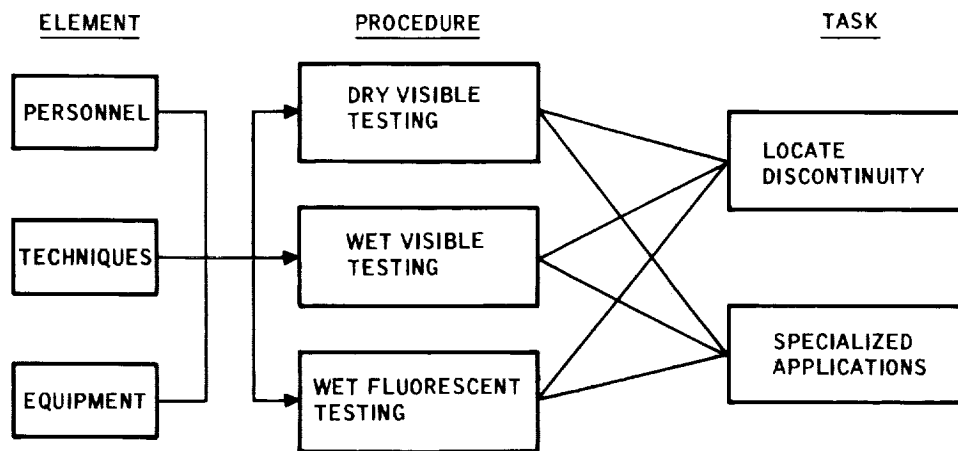
Figure 7-2.   Magnetic Particle Test

ELEMENT   PROCEDURE   TASK

PERSONNEL — PULSE ECHO TESTING — LOCATE DISCONTINUITY

TECHNIQUES — RESONANCE TESTING — DETERMINE BOND

MEASURE THICKNESS

EQUIPMENT — THRU TRANSMISSION TESTING — SPECIALIZED APPLICATIONS
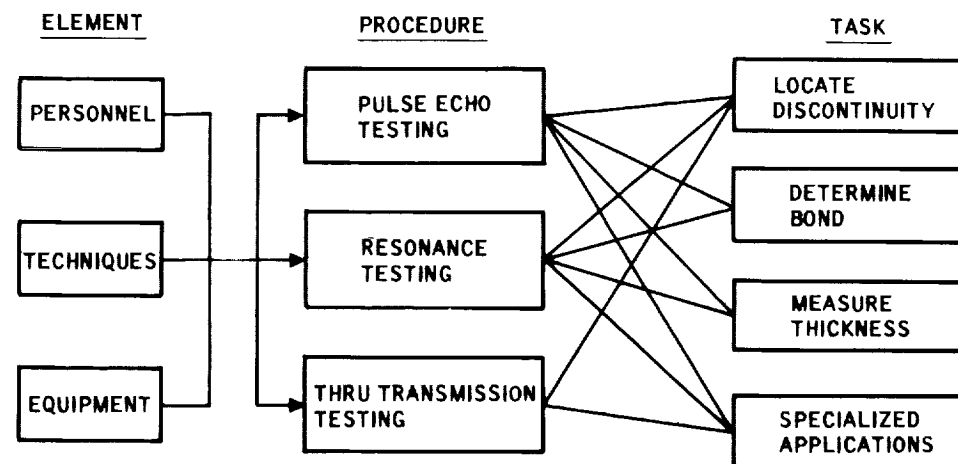
Figure 7-3.   Ultrasonic Test

ELEMENT   PROCEDURE   TASK

```
                    ┌──────────────────────┐          ┌──────────────────┐
                    │ MANUAL CONDUCTIVITY  │          │ MEASURE          │
                    │ TESTING              │          │ CONDUCTIVITY     │
                    └──────────────────────┘          └──────────────────┘

┌──────────────┐    ┌──────────────────────┐          ┌──────────────────┐
│ PERSONNEL    │    │ MANUAL DISCONTINUITY │          │ DETERMINE        │
└──────────────┘    │ TESTING              │          │ HARDNESS         │
                    └──────────────────────┘          └──────────────────┘

                    ┌──────────────────────┐          ┌──────────────────┐
┌──────────────┐    │ MANUAL COATING AND   │          │ DETECT           │
│ TECHNIQUES   │    │ PLATING THICKNESS    │          │ DISCONTINUITIES  │
└──────────────┘    │ TESTING              │          └──────────────────┘
                    └──────────────────────┘          ┌──────────────────┐
                    ┌──────────────────────┐          │ MEASURE          │
┌──────────────┐    │ MANUAL OR AUTOMATIC  │          │ PLATING          │
│ EQUIPMENT    │    │ PHASE ANALYSIS       │          │ THICKNESS        │
└──────────────┘    │ TESTING              │          └──────────────────┘
                    └──────────────────────┘          ┌──────────────────┐
                    ┌──────────────────────┐          │ DETECT           │
                    │ AUTOMATIC MODULATION │          │ DIMENSIONAL      │
                    │ ANALYSIS TESTING     │          │ CHANGES          │
                    └──────────────────────┘          └──────────────────┘
                                                       ┌──────────────────┐
                                                       │ SPECIALIZED      │
                                                       │ APPLICATIONS     │
                                                       └──────────────────┘
```

Figure 7-4.   Eddy Current Test

ELEMENT   PROCEDURE   TASK

```
┌──────────────┐    ┌──────────────────────┐          ┌──────────────────┐
│ PERSONNEL    │    │ FILMLESS             │          │ OBSERVE          │
└──────────────┘    │ TESTING              │          │ FUNCTION         │
                    └──────────────────────┘          └──────────────────┘

                                                       ┌──────────────────┐
┌──────────────┐    ┌──────────────────────┐          │ LOCATE           │
│ TECHNIQUES   │    │ X-RAY FILM           │          │ DISCONTINUITY    │
└──────────────┘    │ TESTING              │          └──────────────────┘
                    └──────────────────────┘          ┌──────────────────┐
                                                       │ DETERMINE        │
┌──────────────┐    ┌──────────────────────┐          │ BOND             │
│ EQUIPMENT    │    │ GAMMA RAY FILM       │          └──────────────────┘
└──────────────┘    │ TESTING              │          ┌──────────────────┐
                    └──────────────────────┘          │ SPECIALIZED      │
                                                       │ APPLICATIONS     │
                                                       └──────────────────┘
```

Figure 7-5.   Radiographic Test

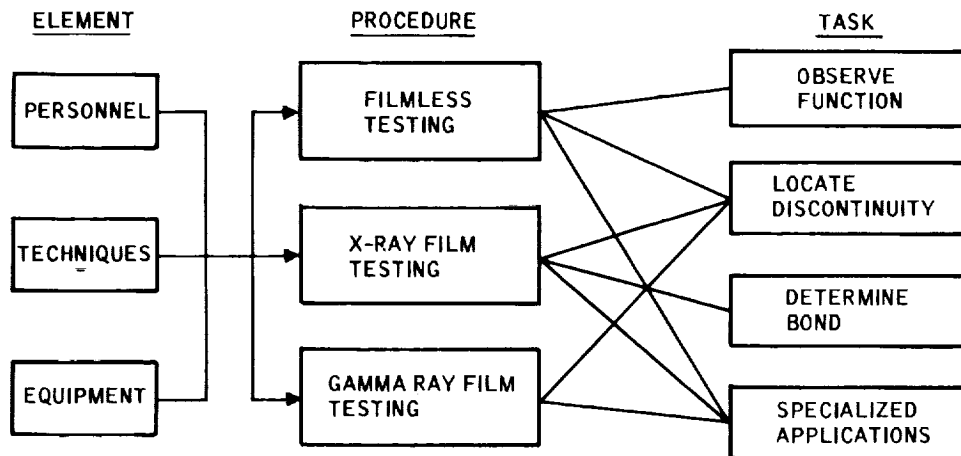b. Cast. Inherent cast discontinuities are those discontinuities which are related to the melting, casting, and solidification of the cast article. It includes those discontinuities that would be inherent to manufacturing variables such as inadequate feeding, gating, excessively high pouring temperature, entrapped gases, handling, and stacking.

2. PROCESSING DISCONTINUITIES

Processing discontinuities are those discontinuities that are related to the various manufacturing processes such as machining, forming, extruding, rolling, welding, heat treating, and plating.

3. SERVICE DISCONTINUITIES

Service discontinuities cover those discontinuities that are related to the various service conditions such as stress corrosion, fatigue, and errosion.

704 DISCONTINUITY CHARACTERISTICS AND METALLURGICAL ANALYSIS

Discontinuity characteristics encompasses an analysis of the specific discontinuity and reference actual photos that illustrate examples of the discontinuity. The discussion will cover:

a. Origin and location of discontinuity (surface, near surface, or internal).

b. Orientation (parallel or normal to the grain).

c. Shape (flat, irregularly shaped, or spiral).

d. Photo (micrograph and/or typical overall view of the discontinuity).

e. Metallurgical analysis (how the discontinuity is produced and at what stage of manufacture).

705 NDT METHODS APPLICATION AND LIMITATIONS

1. GENERAL

The technological accomplishments in the field of nondestructive testing have brought the level of test reliability and reproducibility to a point where the design engineer may now selectively zone the specific article. This zoning is based upon the structural application of the end product and takes into consideration the environment as well as the loading characteristics of the article. Such an evaluation in no way reduces the end reliability of the product, but it does reduce needless rejection of material that otherwise would have been acceptable.

Just as the structural application within the article varies, the allowable discontinuity size will vary depending on the method of manufacture and configuration. For example, a die forging that has large masses of material and extremely thin web sections would not require the same level of acceptance for the whole forging. The forging can be zoned for rigid control where the structural applications are higher, and zoned for less rigid control where the structural requirements permit larger discontinuities.

The nondestructive testing specialist must also select the method which will satisfy the design objective of the specific article and not assume that all NDT methods can produce the same reliability for the same type of discontinuity.

2. SELECTION OF THE NDT METHOD

In selecting the NDT method for the evaluation of a specific discontinuity it should be kept in mind that NDT methods may supplement each other and that several NDT methods may be capable of performing the same task. The selection of one method over another is based upon variables such as:

    a. Type and origin of discontinuity

    b. Material manufacturing processes

    c. Accessibility of article

    d. Level of acceptability desired

    e. Equipment available

    f. Cost

To satisfactorily develop knowledge of the above variables, a planned analysis of the task must be made for each article requiring NDT testing.

The NDT methods listed for each discontinuity in paragraphs 706 through 732 are in order of preference for that particular discontinuity. However, when reviewing that portion of the chapter it should be kept in mind that the rapidly developing NDT field and new techniques may alter the order of test preference.

3. LIMITATIONS

The limitations applicable to the various NDT methods will vary with the applicable standard, the material, and the service environment. Limitations not only affect the NDT test, but in many cases the structural reliability of the test article is affected. For these reasons, limitations that are listed for one discontinuity may also be applicable to other discontinuities under slightly different conditions of material or environment. In addition, the many combinations of environment, location, material, and test capability do not permit mentioning all limitations that may be associated with a specific discontinuity. The intent of this chapter is fulfilled if you are made aware of the many factors that influence the selection of a valid NDT test.

706   BURST

1.   CATEGORY.   Processing

2.   MATERIAL.   Ferrous and Nonferrous Wrought Material

3.   DISCONTINUITY CHARACTERISTICS

Surface or internal.   Straight or irregular cavities varying in size with large inter-
faces or very tight.   Usually parallel with the grain.   Found in wrought material
which required forging, rolling, or extruding.   (See Figure 7-6.)

4.   METALLURGICAL ANALYSIS

   a.   Forging bursts are surface or internal ruptures which are attributed to
        processing at an incorrect temperature, or excessive working or metal move-
        ment during the forging, rolling, or extruding operation.

   b.   A burst does not have a spongy appearance and, therefore, is distinguishable
        from a pipe, even if it should occur at the center.

   c.   Bursts are often large and very seldom healed during subsequent working.

5.   NDT METHODS APPLICATION AND LIMITATIONS

   a.   ULTRASONIC TESTING METHOD

        (1)   Normally used for the detection of internal bursts.

        (2)   Bursts are definite breaks in the material and they resemble a crack,
              producing a very sharp reflection on the scope.

        (3)   Ultrasonic testing is capable of detecting varying degrees of burst which
              could not be detected by other NDT methods.

        (4)   Nicks, gouges, raised areas, tool tears, foreign material, gas bubbles
              on the article may produce adverse ultrasonic test results.

   b.   EDDY CURRENT TESTING METHOD.   Not normally used.   Testing is
        restricted to wire, rod, and other articles under 0.250 inch diameter.

   c.   MAGNETIC PARTICLE TESTING METHOD

        (1)   Usually used on wrought ferrous material that has surface or exposed
              internal burst.

        (2)   Results are limited to surface and near surface evaluation.

   d.   LIQUID PENETRANT TESTING METHOD.   Not normally used.   When
        fluorescent penetrant is to be applied to an article previously dye penetrant
        tested, all traces of dye penetrant should first be removed by prolonged
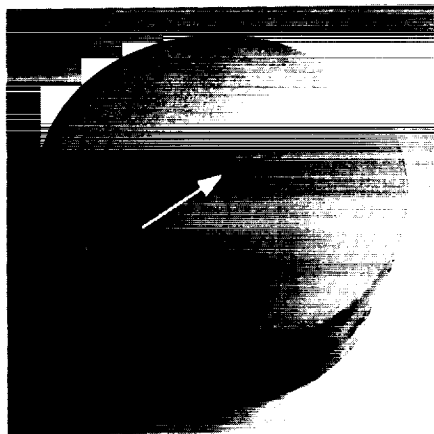   cleaning in applicable solvent.

e. RADIOGRAPHIC TESTING METHOD. Not normally used. Such variables
    as the direction of the burst, close interfaces, wrought material, discontinuity
    size, and material thickness restrict the capability of radiography.
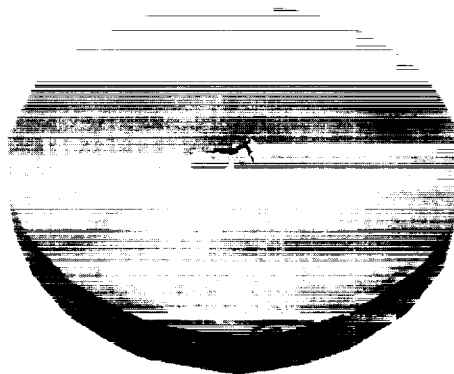
A FORGING EXTERNAL BURST
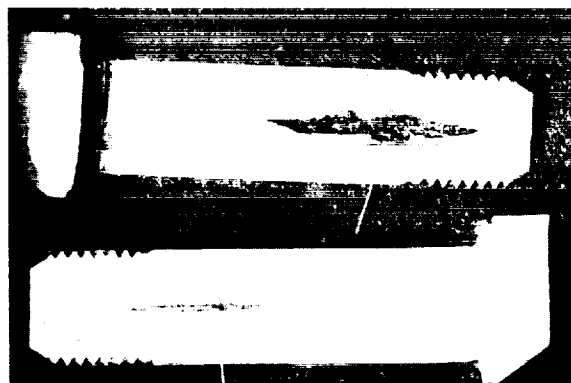
B BOLT INTERNAL BURST

C ROLLED BAR INTERNAL BURST

D FORGED BAR INTERNAL BURST

Figure 7-6. Burst Discontinuities

707   COLD SHUTS

1. CATEGORY. Inherent

2. MATERIAL. Ferrous and Nonferrous Cast Material

3. DISCONTINUITY CHARACTERISTICS

Surface and subsurface. Generally smooth indentations on the cast surface resembling
a forging lap. (See Figure 7-7.)

4. METALLURGICAL ANALYSIS

Cold shuts are produced during casting molten metal. They may result from splashing,
surging, interrupted pouring, or meeting of two streams of metal coming from different
directions. Also, solidification of one surface before the other metal flows over it, the
presence of interposing surface films on cold, sluggish metal, or any factor that will
prevent a fusion where two surfaces meet will produce cold shuts. They are more
prevalent in castings which are formed in a mold with several sprues or gates.

5. NDT METHODS APPLICATION AND LIMITATIONS

   a. LIQUID PENETRANT TESTING METHOD.

      (1) Normally used to evaluate surface cold shuts in both ferrous and non-
           ferrous materials.

      (2) Will appear as a smooth, regular, continuous, or intermittent indication,
           reasonably parallel to the cross section of the area in which it occurs.

      (3) Liquid penetrant used for the testing of nickel base alloys (such as
           Inconel "X," Rene 41) should not exceed 0.5 percent sulfur.

      (4) Certain castings may have surfaces which may be blind and from which
           removal of the excessive penetrants may be difficult.

      (5) Geometric configuration (recesses, orifices, and flanges) may permit
           buildup of wet developer thereby masking any detection of a dis-
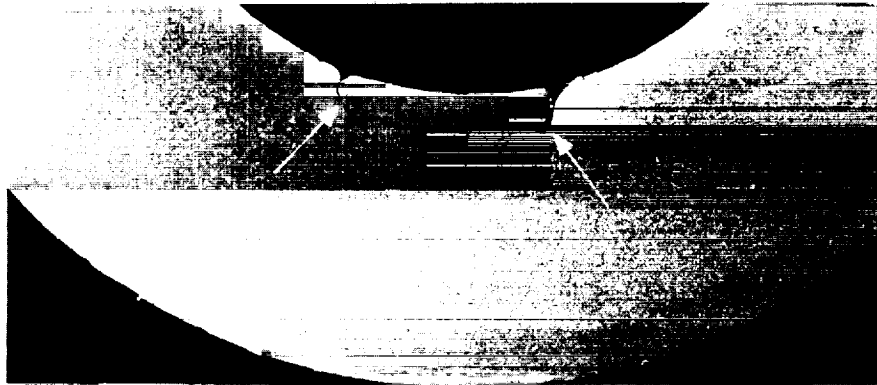   continuity.

   b. MAGNETIC PARTICLE TESTING METHOD

      (1) Normally used for the screening of ferrous materials.

      (2) The metallurgical nature of 431 corrosion-resistant steel is such that in
           some cases magnetic particle testing indications are obtained which do
           not result from a crack or other harmful discontinuities. These indi-
           cations arise from a duplex structure within the material, wherein one
           portion exhibits strong magnetic retentivity and the other does not.

c.   RADIOGRAPHIC TESTING METHOD

(1) Normally detectable by radiography while testing for other casting discontinuities.

(2) Appear as a distinct dark line or band of variable length and width, and definite smooth outline.

(3) Casting configuration may have inaccessible areas which can only be detected by radiography.

d.   ULTRASONIC TESTING METHOD.   Not recommended. Cast structure and article configuration do not as a general rule lend themselves to ultrasonic testing.

e.   EDDY CURRENT TESTING METHOD.   Not recommended. Article configuration and inherent material variables restrict the use of this method.

A   SURFACE COLD SHUT
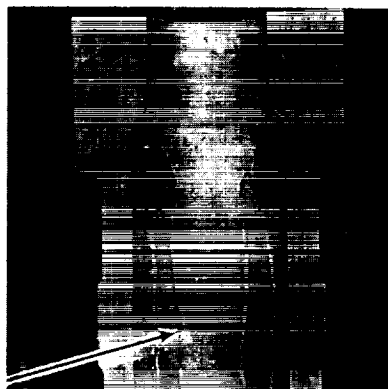
B   INTERNAL COLD SHUT

C   SURFACE COLD SHUT MICROGRAPH

Figure 7-7.   Cold Shuts Discontinuity

7-11

708 FILLET CRACKS (BOLTS)

1. **CATEGORY.** Service

2. **MATERIAL.** Ferrous and Nonferrous Wrought Material

3. **DISCONTINUITY CHARACTERISTICS**

Surface. Located at the junction of the fillet with the shank of the bolt and progressing inward. (See Figure 7-8.)

4. **METALLURGICAL ANALYSIS**

Fillet cracks occur where a marked change in diameter occurs, such as between the head-to-shank junction where stress risers are created. During the application of this bolt in service repeated loading takes place, whereby the tensile load fluctuates in magnitude due to the operation of the mechanism. These tensile loads can cause fatigue failure, starting at the point where the stress risers are built in. Fatigue failure, which is surface phenomenon, starts at the surface and propagates inward.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

    a. ULTRASONIC TESTING METHOD

        (1) Used extensively for service associated discontinuities of this type.

        (2) A wide selection of transducers and equipment enable on the spot evaluation for fillet crack.

        (3) Being a definite break in the material, the scope pattern will be a very sharp reflection. (Actual propagation can be monitored by using ultrasonics.)

        (4) Ultrasonic equipment has extreme sensitivity, and established standards should be used to give reproducible and reliable results.

    b. LIQUID PENETRANT TESTING METHOD

        (1) Normally used during in-service overhaul or troubleshooting.

        (2) May be used for both ferrous and nonferrous bolts, although usually confined to the nonferrous.

        (3) Will appear as a sharp clear indication.

        (4) Structural damage may result from exposure of high strength steels to paint strippers, alkaline coating removers, deoxidizer solutions, etc.

        (5) Entrapment under fasteners, in holes, under splices, and in similar areas may cause corrosion due to the penetrant's affinity for moisture.

c. MAGNETIC PARTICLE TESTING METHOD

    (1) Normally used on ferrous bolts.

    (2) Will appear as clear sharp indication with a heavy buildup.

    (3) Sharp fillet areas may produce non-relevant magnetic indications.

    (4) 17.7 pH is only slightly magnetic in the annealed condition, but becomes strongly magnetic after heat treatment, when it may be magnetic particle tested.

d. EDDY CURRENT TESTING METHOD. Not normally used for detection of fillet cracks. Other NDT methods are more compatible to the detection of this type of discontinuity.

e. RADIOGRAPHIC TESTING METHOD. Not normally used for detection of fillet cracks. Surface discontinuities of this type would be difficult to evaluate due to size of crack in relation to the thickness of material.
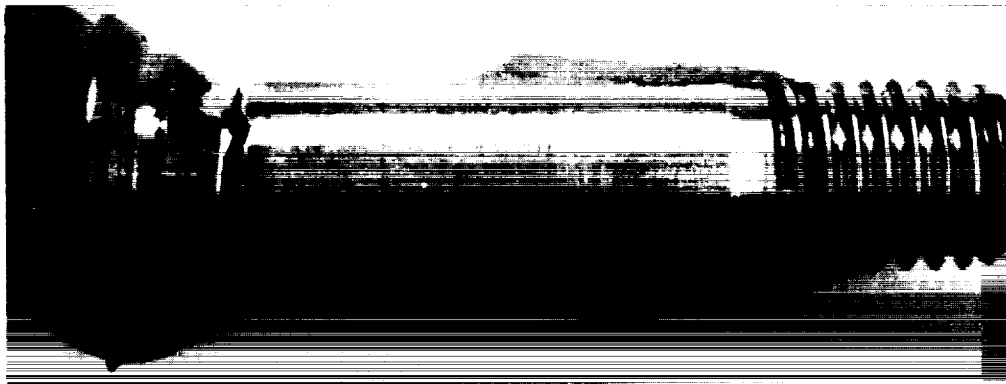
A FILLET FATIGUE FAILURE
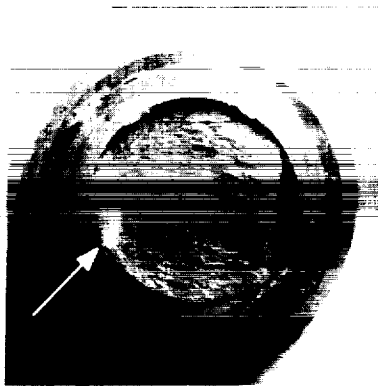
B FRACTURE AREA OF (A) SHOWING TANGENCY POINT OF FAILURE
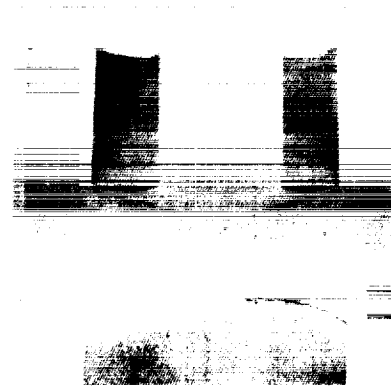
C CROSS-SECTIONAL AREA OF FATIGUE CRACK IN FILLET SHOWING TANGENCY POINT IN RADIUS

Figure 7-8. Fillet Crack Discontinuity

709   GRINDING CRACKS

1.   CATEGORY.   Processing

2.   MATERIAL.   Ferrous and Nonferrous

3.   DISCONTINUITY CHARACTERISTICS

Surface. Very shallow and sharp at the root. Similar to heat treat cracks and usually,
but not always, occur in groups. Grinding cracks are generally at right angles to the
direction of grinding. They are found in highly heat treated articles, chrome plated,
case hardened and ceramic materials that are subjected to grinding operations. (See
Figure 7-9.)

4.   METALLURGICAL ANALYSIS

Grinding of hardened surfaces frequently introduces cracks. These thermal cracks
are caused by local overheating of the surface being ground. The overheating is
usually caused by lack of or poor coolant, a dull or improperly ground wheel, too
rapid feed, or too heavy cut.

5.   NDT METHODS APPLICATION AND LIMITATIONS

   a.   LIQUID PENETRANT TESTING METHOD

     (1)   Normally used on both ferrous and nonferrous materials for the detec-
tion of grinding cracks.

     (2)   Liquid penetrant indication will appear as irregular, checked, or
shattered pattern of fine lines.

     (3)   Cracks are the most difficult discontinuity to indicate and require the
longest penetration time.

     (4)   Articles that have been degreased may still have solvent entrapped in
the discontinuity and should be allowed sufficient time for evaporation
prior to the application of the penetrant.

   b.   MAGNETIC PARTICLE TESTING METHOD

     (1)   Restricted to ferrous materials.

     (2)   Grinding cracks are generally at right angles to grinding direction,
although in extreme cases a complete network of cracks may appear,
in which case they may be parallel to the magnetic field.

     (3)   Magnetic sensitivity decreases as the size of grinding crack decreases
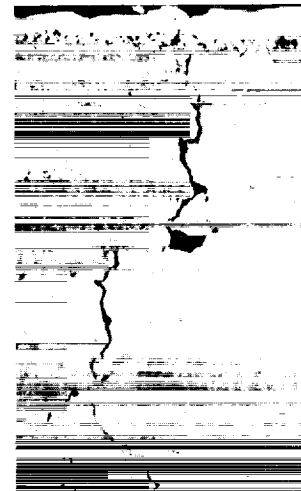and as its depth below the surface increases.

c. EDDY CURRENT TESTING METHOD. Not normally used for detection of grinding cracks. Eddy current equipment has the capability and can be developed for a specific nonferrous application.

d. ULTRASONIC TESTING METHOD. Not normally used for detection of grinding cracks. Other forms or NDT are more economical, faster, and better adapted to this type of discontinuity than ultrasonics.

e. RADIOGRAPHIC TESTING METHOD. Not recommended for detection of grinding cracks. Grinding cracks are too tight and small. Other NDT methods are more suitable for detection of grinding cracks.
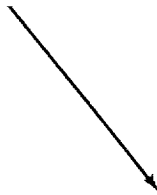
A TYPICAL CHECKED GRINDING CRACK PATTERN
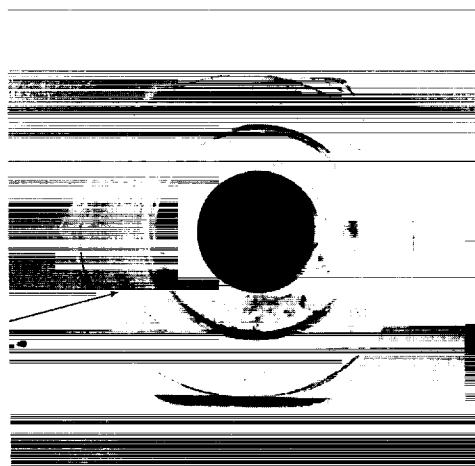
B GRINDING CRACK PATTERN NORMAL TO GRINDING   C MICROGRAPH OF GRINDING CRACK

Figure 7-9.   Grinding Crack Discontinuity

710   CONVOLUTION CRACKS

1.   CATEGORY.   Processing

2.   MATERIAL.   Nonferrous

3.   DISCONTINUITY CHARACTERISTICS

Surface.   Range in size from micro fractures to open fissures.   Situated on the periphery of the convolutions and extend longitudinally in direction of rolling.   (See Figure 7-10.)

4.   METALLURGICAL ANALYSIS

The rough 'orange peel' effect of convolution cracks is the result of either a forming operation which stretches the material or from chemical attack such as pickling treatment.   The roughened surface contains small pits which form stress risers. Subsequent service application (vibration and flexing) may introduce stresses that act on these pits and form fatigue cracks as shown in the accompanying photograph.

5.   NDT METHODS APPLICATION AND LIMITATIONS

   a.   RADIOGRAPHIC TESTING METHOD

   (1)   Used extensively for this type of failure.

   (2)   Configuration of article and location of discontinuity limits detection almost exclusively to radiography.

   (3)   Orientation of convolutions to X-ray source is very critical since those discontinuities which are not normal to X-ray may not register on the film due to the lack of difference in density.

   (4)   Liquid penetrant and magnetic particle testing may supplement but not replace radiographic and ultrasonic testing.

   (5)   The type of marking material (e.g., grease pencil on titanium) used to identify the area of discontinuities may affect the structure of the article.

   b.   ULTRASONIC TESTING METHOD.   Not normally used for the detection of convolution cracks.   Configuration of the article (double-walled convolutions) and internal micro fractures are all factors which restrict the use of ultrasonics.

   c.   EDDY CURRENT TESTING METHOD.   Not normally used for the detection of convolution cracks.   As in the case of ultrasonic testing, the configuration does not lend itself to this method of testing.

d. LIQUID PENETRANT TESTING METHOD. Not recommended for the detection of convolution cracks. Although the discontinuities are surface, they are internal and are superimposed over an exterior shell which creates a serious problem of entrapment.

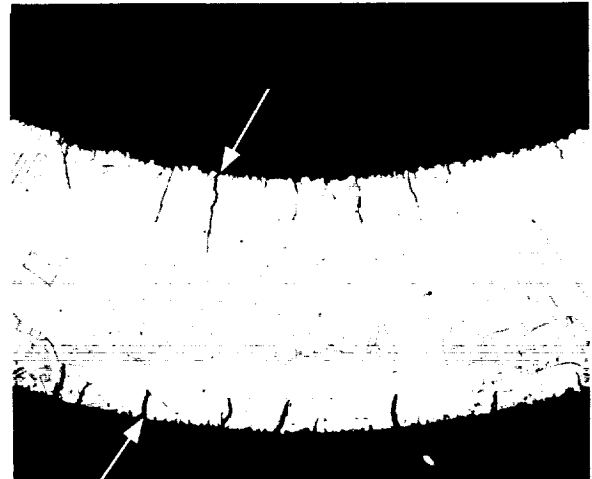e. MAGNETIC TESTING METHOD. Not applicable. Material is nonferrous.

A TYPICAL CONVOLUTION DUCTING
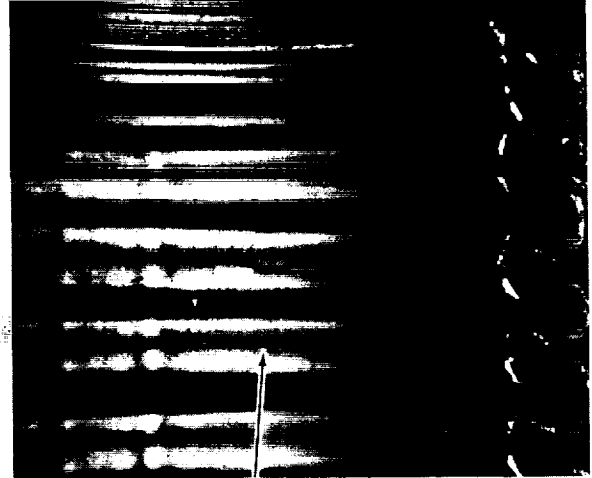
B CROSS-SECTION OF CRACKED CONVOLUTION
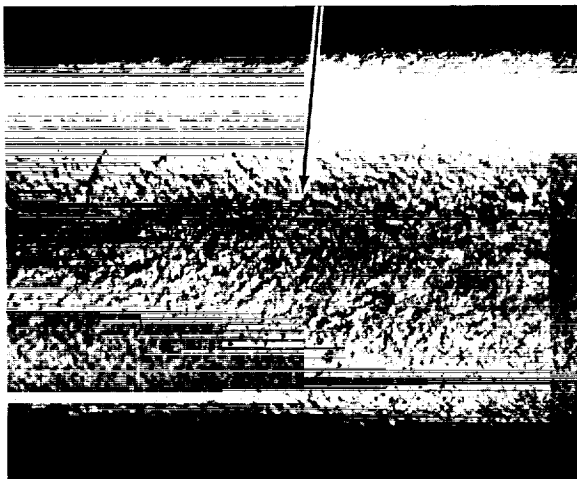
C HIGHER MAGNIFICATION OF CRACK SHOWING ORANGE PEEL

D MICROGRAPH OF CONVOLUTION WITH PARTIAL CRACKING ON SIDES

Figure 7-10. Convolution Cracks Discontinuity

711 HEAT-AFFECTED ZONE CRACKING

1. **CATEGORY.** Processing (Weldments)

2. **MATERIAL.** Ferrous and Nonferrous

3. **DISCONTINUITY CHARACTERISTICS**

Surface. Often quite deep and very tight. Usually parallel with the weld in the heat-affect zone of the weldment. (See Figure 7-11.)

4. **METALLURGICAL ANALYSIS**

Hot cracking of heat-affected zones of weldments increases in severity with increasing carbon content. Steels that contain more than 0.30% carbon are prone to this type of failure and require preheating prior to welding.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

    a. **MAGNETIC PARTICLE TESTING METHOD**

        (1) Normally used for ferrous weldments.

        (2) Prod burns are very detrimental, especially on highly heat treated articles. May contribute to structural failure of article.

        (3) Demagnetization of highly heat treated articles can be very difficult due to metallurgical structure.

    b. **LIQUID PENETRANT TESTING METHOD**

        (1) Normally used for nonferrous weldments.

        (2) Material that has had its surface obliterated, blurred, or blended due to manufacturing processes should not be penetrant tested until the smeared surface has been removed.

        (3) Liquid penetrant testing after the application of certain types of chemical film coatings may be invalid due to the covering or filling of the discontinuities.

    c. **RADIOGRAPHIC TESTING METHOD.** Not normally used for the detection of heat-affected zone cracking. Discontinuity orientation and surface origin make other NDT methods more suitable.

    d. **ULTRASONIC TESTING METHOD**

        (1) Used where specialized applications have been developed.

        (2) Rigid standards and procedures are required to develop valid tests.

        (3) The configuration of the surface roughness (i.e., sharp versus rounded root radii and the slope condition) are major factors in deflecting the sound beam.

e. EDDY CURRENT TESTING METHOD. Not normally used for the detection of heat-affected zone cracking. Eddy current equipment has capability of detecting nonferrous surface discontinuities; however, it is not as universally used as magnetic particle or liquid penetrant.
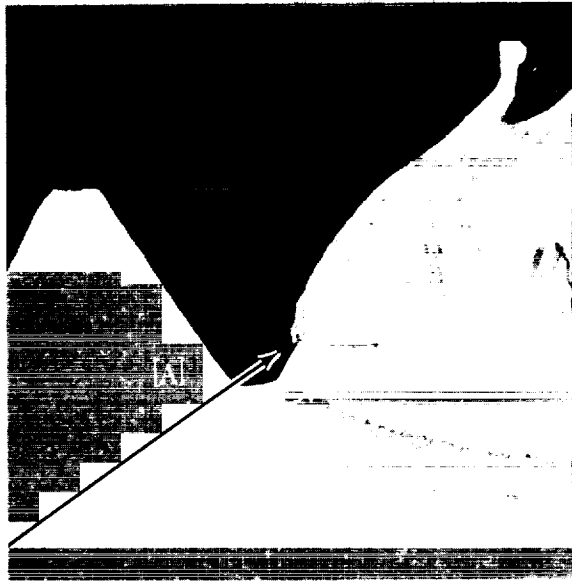
A MICROGRAPH OF WELD AND HEAT-AFFECTED ZONE
   SHOWING CRACK NOTE COLD LAP WHICH MASKS THE
   ENTRANCE TO THE CRACK
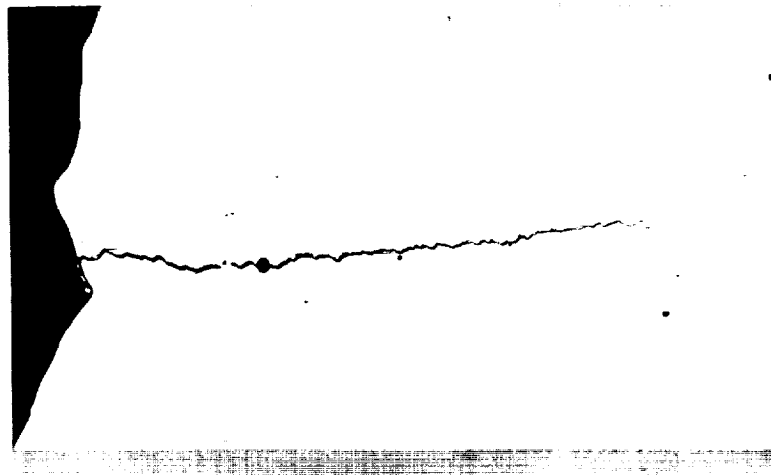
B MICROGRAPH OF CRACK SHOWN IN (A)

Figure 7-11. Heat-Affected Zone Cracking Discontinuity

712   HEAT TREAT CRACKS

1.   **CATEGORY.**   Processing

2.   **MATERIAL.**   Ferrous and Nonferrous Wrought and Cast Material

3.   **DISCONTINUITY CHARACTERISTICS**

Surface.   Usually deep and forked.   Seldom follow a definite pattern and can be in any direction on the part.   Originate in areas with rapid change of material thickness, sharp machining marks, fillets, nicks, and discontinuities which have been exposed to the surface of the material.   (See Figure 7-12.)

4.   **METALLURGICAL ANALYSIS**

During the heating and cooling process localized stresses may be set up by unequal heating or cooling, restricted movement of the article, or unequal cross-sectional thickness.   These stresses may exceed the tensile strength of the material causing it to rupture.   Where built-in stress risers occur (keyways or grooves) additional cracks may develop.

5.   **NDT METHODS APPLICATION AND LIMITATIONS**

   a.   MAGNETIC PARTICLE TESTING METHOD

   (1)   For ferrous materials, heat treat cracks are normally detected by magnetic particles testing.

   (2)   The magnetic particles indications will normally be straight, forked, or curved indications.

   (3)   Likely points of origin are areas that would develop stress risers, such as keyways, fillets, or areas with rapid changes in material thickness.

   (4)   Metallurgical structure of age hardenable and heat treatable stainless steels (17.4, 17.7, and 431) may produce irrelevant indications.

   b.   LIQUID PENETRANT TESTING METHOD

   (1)   For nonferrous materials liquid penetrant testing is the recommended method.

   (2)   Likely points of origin would be the same as those listed above for magnetic particle testing.

   (3)   Materials or articles that will eventually be used in LOX systems must be tested with compatible penetrants.

   c.   EDDY CURRENT TESTING METHOD

   (1)   Normally not used.

   (2)   Magnetic particles and liquid penetrant are more direct and economical.

d. ULTRASONIC TESTING METHOD.   Not normally used for detection of heat treat cracks.   If used the scope pattern will show a definite indication of a discontinuity.   Recommended wave mode would be surface.

e. RADIOGRAPHIC TESTING METHOD.   Not normally used for detection of heat treat cracks.   Surface discontinuities are more easily detected by other NDT methods designed for surface application.
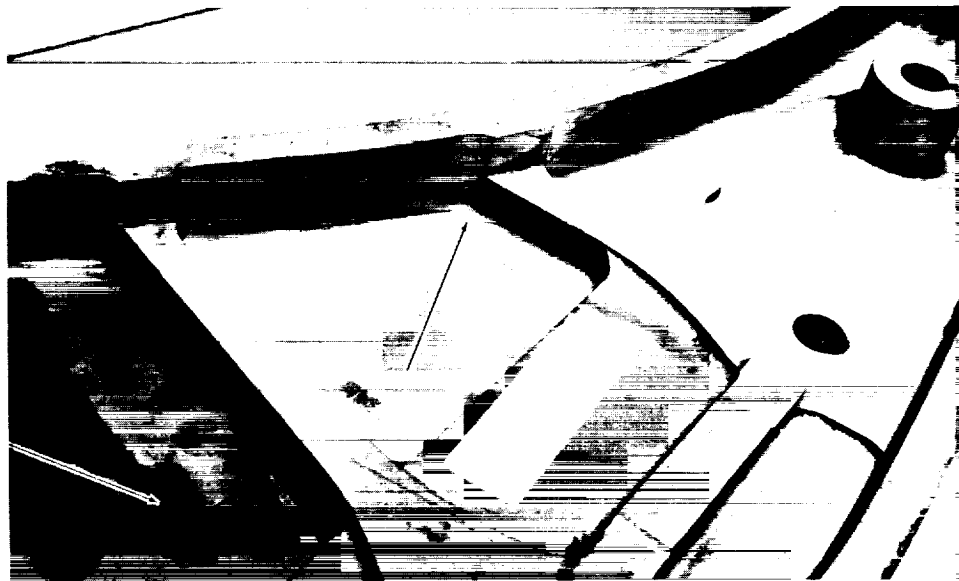
A FILLET AND MATERIAL THICKNESS CRACKS (TOP CENTER)
RELIEF RADIUS CRACKING (LOWER LEFT)
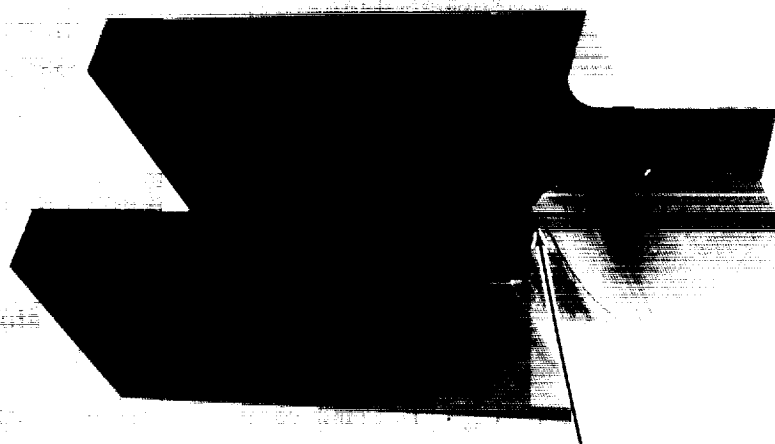
B HEAT TREAT CRACK DUE TO SHARP MACHINING MARKS

Figure 7-12.   Heat Treat Cracks Discontinuity

713   SURFACE SHRINK CRACKS

1. **CATEGORY.**   Processing (Welding)

2. **MATERIAL.**   Ferrous and Nonferrous

3. **DISCONTINUITY CHARACTERISTICS**

Surface. Situated on the face of the weld, fusion zone, and base metal. Range in size from very small, tight, and shallow, to open and deep. Cracks may run parallel or transverse the direction of welding. (See Figure 7-13.)

4. **METALLURGICAL ANALYSIS**

Surface shrink cracks are generally the result of improper heat application, either in heating or welding of the article. Heating or cooling in a localized area may set up stresses that exceed the tensile strength of the material causing the material to crack. Restriction of the movement (contraction or expansion) of the material during heating, cooling, or welding may also set up excessive stresses.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

    a.   **LIQUID PENETRANT TESTING METHOD**

        (1)   Surface shrink cracks are normally detected by liquid penetrant.

        (2)   Liquid penetrant equipment is easily portable and can be used during in-process control for both ferrous and nonferrous weldments.

        (3)   Assemblies which are joined by bolting, riveting, intermittent welding, or press fittings will retain the penetrant, which will seep out after developing and mask the adjoining surfaces.

        (4)   When articles are dried in a hot air dryer or by similar means, excessive drying temperature should be avoided to prevent evaporation of the penetrant.

    b.   **MAGNETIC PARTICLE TESTING METHOD**

        (1)   Ferrous weldments are normally tested by magnetic particle method.

        (2)   Surface discontinuities that are parallel to the magnetic field will not produce indications since they do not interrupt or distort the magnetic field.

        (3)   Areas of grease fittings, bearing races, or other similar items that might be damaged or clogged by the suspension solution or magnetic solids should be masked before testing.

c. EDDY CURRENT TESTING METHOD

    (1) Normally confined to nonferrous welded pipe and tubing.

    (2) Probe or encircling coil could be used where article configuration permits.

d. RADIOGRAPHIC TESTING METHOD. Not normally used for the detection of surface discontinuities. During the radiographic testing of weldments for other types of discontinuities, surface indications may be detected.
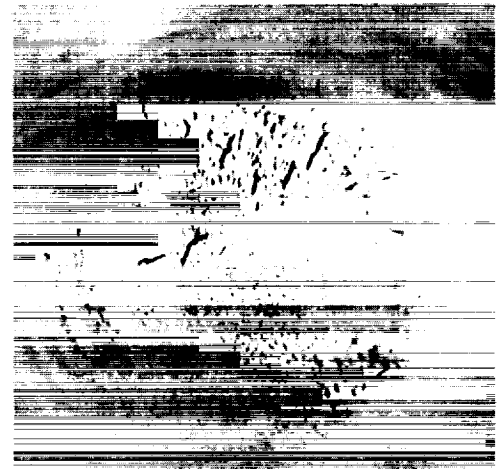
e. ULTRASONIC TESTING METHOD. Not normally used for detection of surface shrink cracks. Other forms of NDT (liquid penetrant and magnetic particle) give better results, are more economical, and are faster.

A TRANSVERSE CRACKS IN HEAT-AFFECTED ZONE
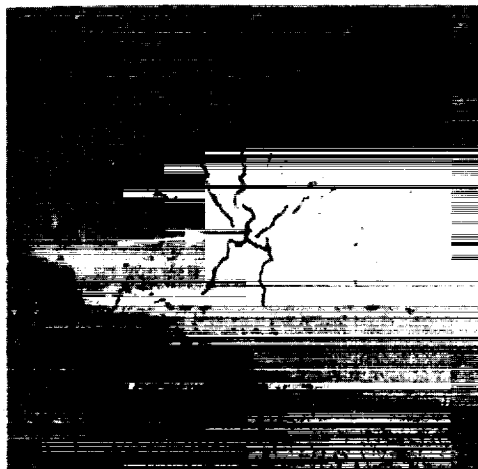
B TYPICAL STAR-SHAPED CRATER CRACK

C SHRINKAGE CRACK AT WELD TERMINAL

Figure 7-13. Surface Shrink Crack Discontinuity

714 THREAD CRACKS

1. **CATEGORY.** Service

2. **MATERIAL.** Ferrous and Nonferrous Wrought Material

3. **DISCONTINUITY CHARACTERISTICS**

Surface. Cracks are transverse to the grain (transgranular) starting at the root of the thread. (See Figure 7-14.)

4. **METALLURGICAL ANALYSIS**

Fatigue failures of this type are not uncommon. High cyclic stresses resulting from vibration and/or flexing act on the stress risers created by the thread roots and produce cracks. Fatigue cracks may start as fine submicroscopic discontinuities and/ or cracks and propagate in the direction of applied stresses.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

    a. **LIQUID PENETRANT TESTING METHOD**

        (1) Fluorescent penetrant is recommended over non-fluorescent.

        (2) Low surface tension solvents such as gasoline and kerosene are not recommended cleaners.

        (3) When applying liquid penetrant to components within an assembly or structure, the adjacent areas should be effectively masked to prevent overspraying.

    b. **MAGNETIC PARTICLE TESTING METHOD**

        (1) Normally used on ferrous materials.

        (2) Irrelevent magnetic indications may result from the thread configuration.

        (3) Cleaning titanium and 440C stainless in halogeneated hydrocarbons may result in structural damage to the material.

    c. **EDDY CURRENT TESTING METHOD.** Not normally used for detecting thread cracks. The article configuration would require specialized equipment if adaptable.

    d. **ULTRASONIC TESTING METHOD.** Not recommended for detecting thread cracks. Thread configuration does not lend itself to ultrasonic testing.

e. RADIOGRAPHIC TESTING METHOD. Not recommended for detecting thread cracks. Surface discontinuities are best screened by NDT method designed for the specific condition. Fatigue cracks of this type are very tight and surface connected, their detection by radiography would be extremely difficult.
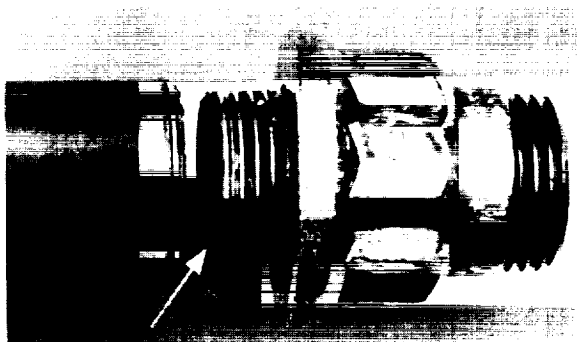
A COMPLETE THREAD ROOT FAILURE
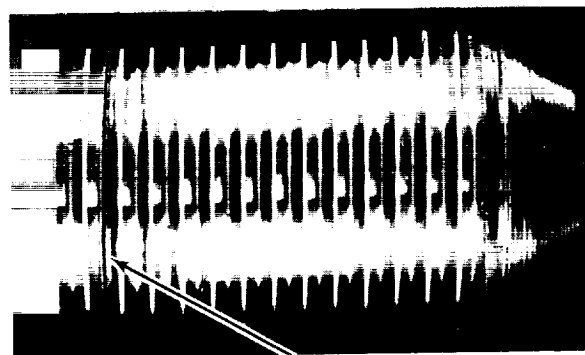
B TYPICAL THREAD ROOT FAILURE

C MICROGRAPH OF (A) SHOWING CRACK AT BASE OF ROOT

D MICROGRAPH OF (B) SHOWING TRANSGRANULAR CRACK AT THREAD ROOT

Figure 7-14. Thread Crack Discontinuity

715   TUBING CRACKS (INCONEL "X")

1.   **CATEGORY.**   Inherent

2.   **MATERIAL.**   Nonferrous

3.   **DISCONTINUITY CHARACTERISTICS**

Tubing cracks formed on the inner surface (I.D.), parallel to direction of grain flow.
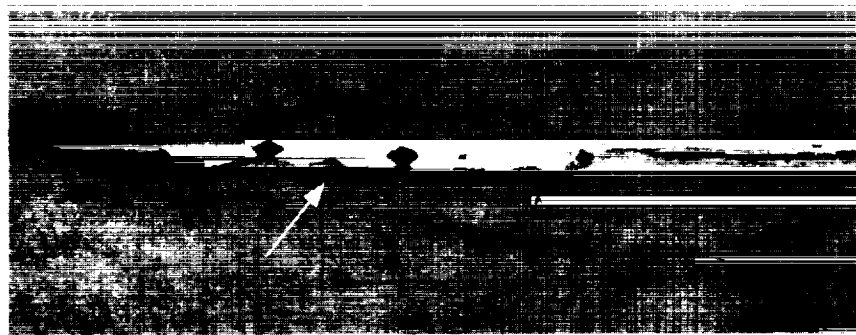(See Figure 7-15.)

4.   **METALLURGICAL ANALYSIS**

Tubing I. D. cracks may be attributed to one or a combination of the following:

   a.   Improper cold reduction of the tube during fabrication.

   b.   Foreign material may have been embedded on the inner surface of the tubes
        causing embrittlement and cracking when the cold worked material was
        heated during the annealing operation.

   c.   Insufficient heating rate to the annealing temperature with possible cracking
   occurring in the 1200-1400° F range.

5.   **NDT METHODS APPLICATION AND LIMITATIONS**

   a.   EDDY CURRENT TESTING METHOD

        (1)   Normally used for detection of this type of discontinuity.

        (2)   The diameter (1 inch) and wall thickness (0.156 inch) are well within
              equipment capability.

        (3)   Testing of ferro-magnetic material may be difficult.

   b.   ULTRASONIC TESTING METHOD

        (1)   Normally used on heavy gauge tubing.

        (2)   A wide variety of equipment and transducers are available for screening
              tubing for internal discontinuities of this type.

        (3)   Ultrasonic transducers have varying temperature limitations.

        (4)   Certain ultrasonic contact couplants may have high sulfur content
              which will have an adverse effect on high nickel alloys.

   c.   RADIOGRAPHIC TESTING METHOD

   (1)   Not normally used for detecting tubing cracks.

(2) Discontinuity orientation and thickness of material govern the radio-graphic sensitivity.

(3) Other forms of NDT (eddy current and ultrasonic) are more economical, faster, and reliable.

d. LIQUID PENETRANT TESTING METHOD. Not recommended for detecting tubing cracks. Internal discontinuity would be difficult to process and interpret.

e. MAGNETIC PARTICLES TESTING METHOD. Not applicable. Material is nonferrous under normal conditions.

A TYPICAL CRACK ON INSIDE OF TUBING SHOWING COLD LAP
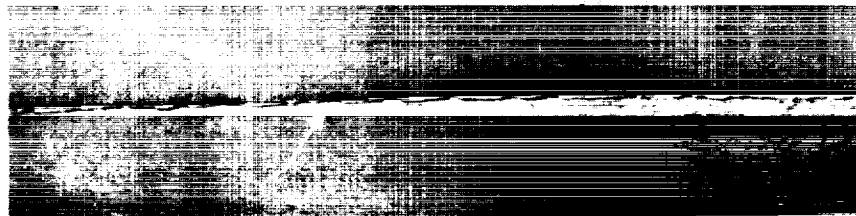
B ANOTHER PORTION OF SAME CRACK SHOWING CLEAN FRACTURE
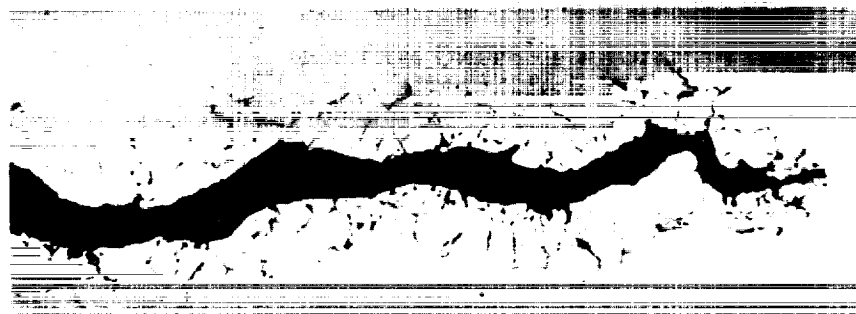
C MICROGRAPH OF (B)

Figure 7-15. Tubing Crack Discontinuity

716   HYDROGEN FLAKE

1.   CATEGORY.   Processing

2.   MATERIAL.   Ferrous

3.   DISCONTINUITY CHARACTERISTICS

Internal fissures in a fractured surface, flakes appear as bright silvery areas. On an etched surface they appear as short discontinuities. Sometimes known as chrome checks and hairline cracks when revealed by machining, flakes are extremely thin and generally aligned parallel with the grain. They are usually found in heavy steel forgings, billets, and bars. (See Figure 7-16.)

4.   METALLURGICAL ANALYSIS

Flakes are internal fissures attributed to stresses produced by localized transformation and decreased solubility of hydrogen during cooling after hot working. Usually found only in heavy alloy steel forgings.

5.   NDT METHODS APPLICATION AND LIMITATIONS

    a.   ULTRASONIC TESTING METHOD

        (1)   Used extensively for the detection of hydrogen flake.

        (2)   Material in the wrought condition can be screened successfully using either the immersion or the contact method. The surface condition will determine the method most suited.

        (3)   On the A-scan presentation, hydrogen flake will appear as hash on the screen or as loss of back reflection.

        (4)   All foreign materials (loose scale, dirt, oil, grease) should be removed prior to any testing. Surface irregularities such as nicks, gouges, tool marks, and scarfing may cause loss of back reflection.

    b.   MAGNETIC PARTICLE TESTING METHOD

        (1)   Normally used on finished machined articles.

        (2)   Flakes appear as short discontinuities and resemble chrome checks or hairline cracks.

        (3)   Machined surfaces with deep tool marks may obliterate the detection of the flake.

        (4)   Where the general direction of a discontinuity is questionable, it may be necessary to magnetize in two or more directions.

c. LIQUID PENETRANT TESTING METHOD. Not normally used for detecting flakes. Discontinuities are very small and tight and would be difficult to detect by liquid penetrant.

d. EDDY CURRENT TESTING METHOD. Not recommended for detecting flakes. The metallurgical structure of ferrous materials limits their adaptability to the use of eddy current.

e. RADIOGRAPHIC TESTING METHOD. Not recommended for detecting flakes. The size of the discontinuity, its location and orientation with respect to the material surface restricts the application of radiography.

A 4340 CMS HAND FORGING REJECTED FOR HYDROGEN FLAKE
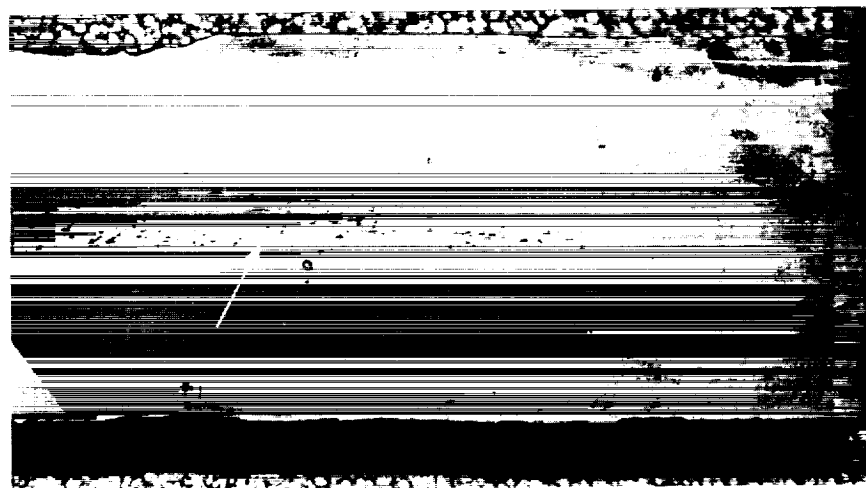
B CROSS-SECTION OF (A) SHOWING FLAKE CONDITION IN CENTER OF MATERIAL

Figure 7-16. Hydrogen Flake Discontinuity

717   HYDROGEN EMBRITTLEMENT

1. **CATEGORY.**   Processing and Service

2. **MATERIAL.**   Ferrous

3. **DISCONTINUITY CHARACTERISTICS**

Surface.   Small, nondimensional (interface) with no orientation or direction.   Found in highly heat treated material that was subjected to pickling and/or plating or in material exposed to free hydrogen.   (See Figure 7-17.)

4. **METALLURGICAL ANALYSIS**

Operations such as pickling and cleaning prior to electroplating or electroplating generate hydrogen at the surface of the material.   This hydrogen penetrates the surface of the material creating immediate or delayed embrittlement and cracking.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

   a.   MAGNETIC PARTICLES TESTING METHOD

      (1)   Magnetic indications appear as a fractured pattern.

      (2)   Hydrogen embrittlement cracks are randomly orientated and may follow the magnetic field.

      (3)   Magnetic particle testing should be accomplished before and after plating.

      (4)   Care should be taken to produce no confusing or irrelevant indications or cause damage to the article by overheating.

      (5)   301 corrosion resistant steel is non-magnetic in the annealed condition, but becomes magnetic with cold working.

   b.   LIQUID PENETRANT TESTING METHOD

      (1)   Not normally used for detecting hydrogen embrittlement.

      (2)   Discontinuities on the surface are extremely tight, small, and difficult to detect.   Subsequent plating deposit may mask the discontinuity.

   c.   ULTRASONIC TESTING METHOD

      (1)   Not normally used for detecting hydrogen embrittlement.

      (2)   Article configurations and size do not, in general, lend themselves to this method of testing.

      (3)   Equipment has capability of detecting hydrogen embrittlement . Recommend surface wave technique.

d. EDDY CURRENT TESTING METHOD. Not recommended for detecting hydrogen embrittlement. Many variables inherent in the specific material may produce conflicting patterns.

e. RADIOGRAPHIC TESTING METHOD. Not recommended for detecting hydrogen embrittlement. The sensitivity required to detect hydrogen embrittlement is in most cases in excess of radiographic capabilities.
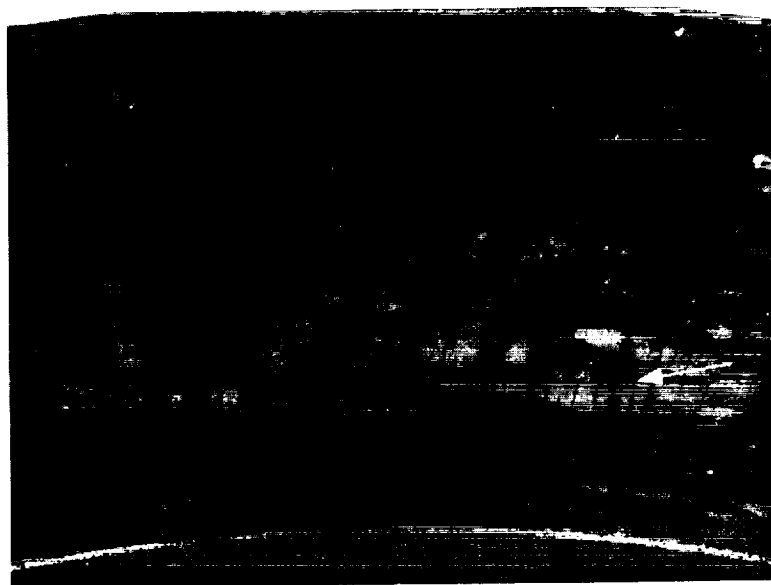
A DETAILED CRACK PATTERN OF HYDROGEN EMBRITTLEMENT
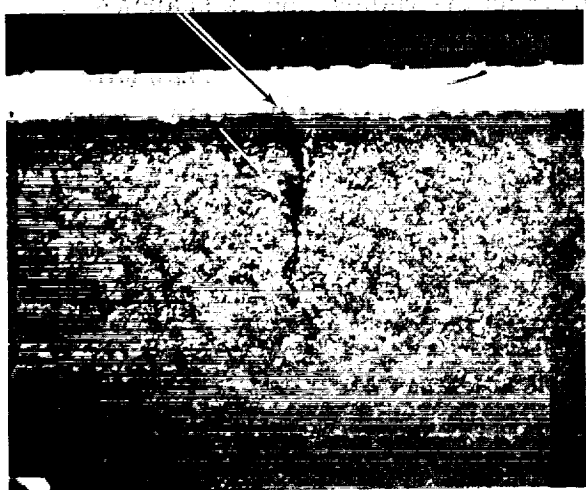
B HYDROGEN EMBRITTLEMENT UNDER CHROME PLATE

C HYDROGEN EMBRITTLEMENT PROPAGATED THROUGH CHROME PLATE

Figure 7-17. Hydrogen Embrittlement Discontinuity

718   INCLUSIONS

1. **CATEGORY.**   Processing (Weldments)

2. **MATERIAL.**   Ferrous and Nonferrous Welded Material

3. **DISCONTINUITY CHARACTERISTICS**

Surface and subsurface. Inclusions may be any shape. They may be metallic or non-metallic and may appear singly or be linearly distributed or scattered throughout the weldment. (See Figure 7-18.)

4. **METALLURGICAL ANALYSIS**

Metallic inclusions are generally particles of metals of different density as compared to the weld or base metal. Non-metallic inclusions are oxides, sulphides, slag or other non-metallic foreign material entrapped in the weld or between the weld metal and the base metal.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

    a. **RADIOGRAPHIC TESTING METHOD**

        (1) This NDT method is universally used.

        (2) Metallic inclusions appear on the radiograph as sharply defined, round, erratically shaped, or elongated white spots and may be isolated or in small linear or scattered groups.

        (3) Non-metallic inclusions will appear on the radiograph as shadows of round globules or elongated or irregularly shaped contours occurring singly, linearly, or scattered throughout the weldment. They will generally appear in the fusion zone or at the root of the weld. Less absorbent material is indicated by a greater film density and more absorbent materials by a lighter film density.

        (4) Foreign material such as loose scales, splatter, or flux may invalidate test results.

    b. **EDDY CURRENT TESTING METHOD**

        (1) Normally confined to thin wall welded tubing.

        (2) Established standards may be required if valid results are to be obtained.

    c. **MAGNETIC PARTICLE TESTING METHOD**

        (1) Normally not used for detecting inclusions in weldments.

        (2) Confined to machined weldments where the discontinuities are surface or near surface.

(3) The indications would appear jagged, irregularly shaped, individually or clustered, and would not be too pronounced.

(4) Discontinuities may go undetected when improper contact exists between the magnetic particles and the surface of the article.
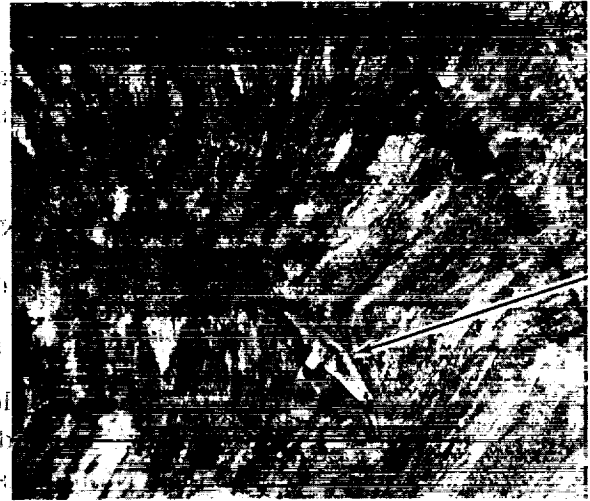
d. ULTRASONIC TESTING METHOD

(1) Not normally used for detecting inclusions.

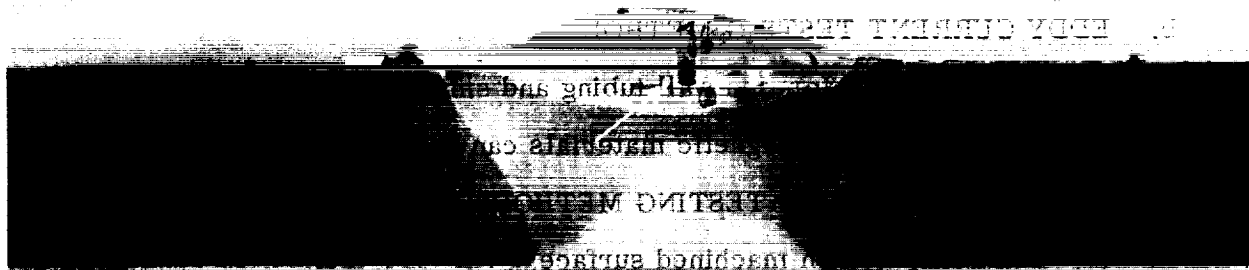(2) Specific applications of design or of article configuration may require ultrasonic testing.

e. LIQUID PENETRANT TESTING METHOD. Not applicable. Inclusions are normally not open fissures.

A METALLIC INCLUSIONS

B INCLUSIONS TRAPPED IN WELD

C CROSS-SECTION OF WELD SHOWING INTERNAL INCLUSIONS

Figure 7-18.   Weldment Inclusion Discontinuity

719 INCLUSIONS

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Wrought Material

3. DISCONTINUITY CHARACTERISTICS

Subsurface (original bar) or surface (after machining). There are two types: one is non-metallic with long straight lines parallel to flow lines and quite tightly adherent. Often short and likely to occur in groups. The other type is non-plastic, appearing as a comparatively large mass and not parallel to flow lines. Found in forged, extruded, and rolled material. (See Figure 7-19.)

4. METALLURGICAL ANALYSIS

Non-metallic inclusions (stringers) are caused by the existence of slag or oxides in the billet or ingot. Non-plastic inclusions are caused by particles remaining in the solid state during billet melting.

5. NDT METHODS APPLICATIONS AND LIMITATIONS

    a. ULTRASONIC TESTING METHOD

        (1) Normally used to evaluate inclusions in wrought material.

        (2) Inclusions will appear as definite interfaces within the metal. Small clustered condition or conditions on different planes causing a loss in back reflection. Numerous small scattered conditions cause excessive "noise".

        (3) Inclusion orientation in relationship to ultrasonic beam is critical.

        (4) The direction of the ultrasonic beam should be perpendicular to the direction of the grain flow whenver possible.

    b. EDDY CURRENT TESTING METHOD

        (1) Normally used for thin wall tubing and small diameter rods.

        (2) Testing of ferro-magnetic materials can be difficult.

    c. MAGNETIC PARTICLE TESTING METHOD

        (1) Normally used on machined surface.

        (2) Inclusions will appear as a straight intermittent or as a continuous indication. They may be individual or clustered.

        (3) The magnetic technique should be such that a surface or near surface inclusion can be satisfactorily detected when its axis is in any direction.

(4) A knowledge of the grain flow of the material is critical since inclusions will be parallel to that direction.

(5) Certain types of steels are more prone to inclusions than other.
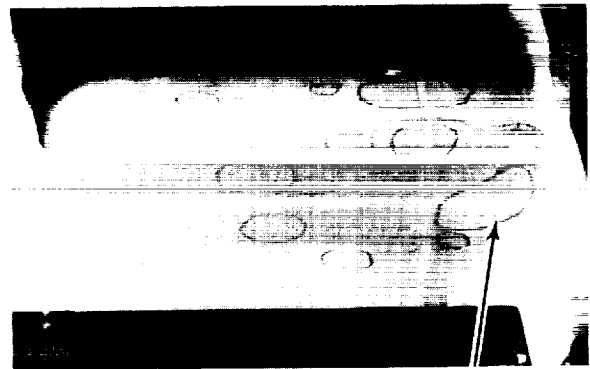
d. LIQUID PENETRANT TESTING METHOD

(1) Not normally used for detecting inclusions in wrought material.

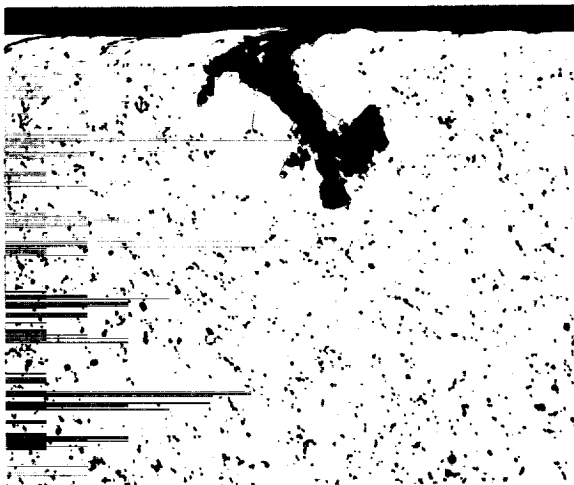(2) Inclusions are generally not openings in the material surface.

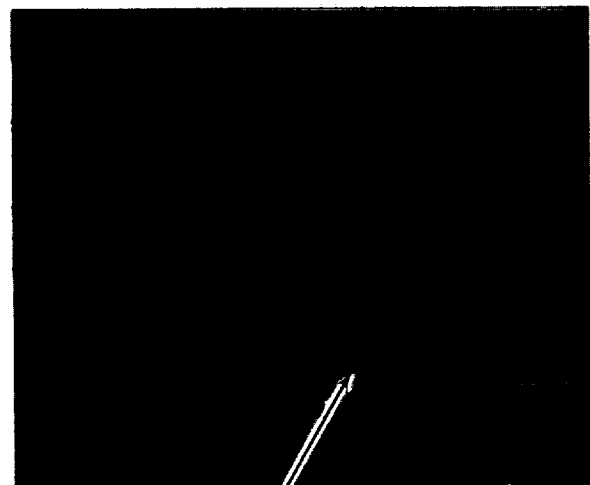e. RADIOGRAPHIC TESTING METHOD. Not recommended. NDT methods designed for surface testing are more suitable for detecting surface inclusions.

A TYPICAL INCLUSION PATTERN ON MACHINED SURFACES

B STEEL FORGING SHOWING NUMEROUS INCLUSIONS

C MICROGRAPH OF TYPICAL INCLUSION

D LONGITUDINAL CROSS-SECTION SHOWING ORIENTATION OF INCLUSIONS

Figure 7-19. Wrought Inclusion Discontinuity

720 LACK OF PENETRATION

1. **CATEGORY.** Processing

2. **MATERIAL.** Ferrous and Nonferrous Weldments

3. **DISCONTINUITY CHARACTERISTICS**

Internal or external. Generally irregular and filamentary occuring at the root and running parallel with the weld. (See Figure 7-20.)

4. **METALLURGICAL ANALYSIS**

Caused by root face of joint not reaching fusion temperature before weld metal was deposited. Also caused by fast welding rate, too large a welding rod, or too cold a bead.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

    a. RADIOGRAPHIC TESTING METHOD

        (1) Used extensively on a wide variety of welded articles to determine the lack of penetration.

        (2) Lack of penetration will appear on the radiograph as an elongated dark area of varying length and width. It may be continuous or intermittent and may appear in the center of the weld at the junction of multipass bends.

        (3) Lack of penetration orientation in relationship to the radiographic source is critical.

        (4) Sensitivity levels govern the capability to detect small or tight discontinuities.

    b. ULTRASONIC TESTING METHOD

        (1) Commonly used for specific applications.

        (2) Complex weld configurations, or thin wall weldments do not lend themselves to ultrasonic testing.

        (3) Lack of penetration will appear on the scope as a definite break or discontinuity resembling a crack and will give a very sharp reflection.

        (4) Repeatability of ultrasonic test results is difficult unless equipment is standardized.

c. EDDY CURRENT TESTING METHOD

(1) Normally used to determine lack of penetration in nonferrous welded pipe and tubing.

(2) Eddy current can be used where other nonferrous articles can meet the configuration requirement of the equipment.

d. MAGNETIC PARTICLE TESTING METHOD

(1) Normally used where backside of weld is visible.

(2) Lack of penetration appears as an irregular indication of varying width.
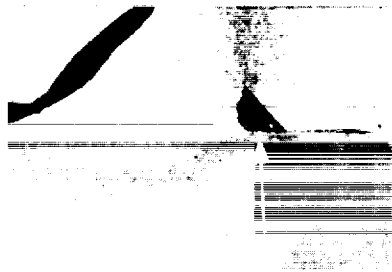
e. LIQUID PENETRANT TESTING METHOD

(1) Normally used where backside of weld is visible.

(2) Lack of penetration appears as an irregular indication of varying width.

(3) Residue left by the penetrant and the developer could contaminate any re-welding operation.
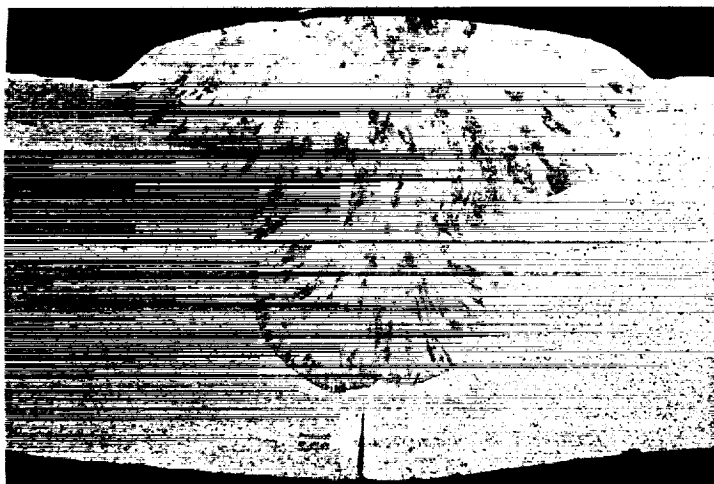
A   INADEQUATE ROOT PENETRATION
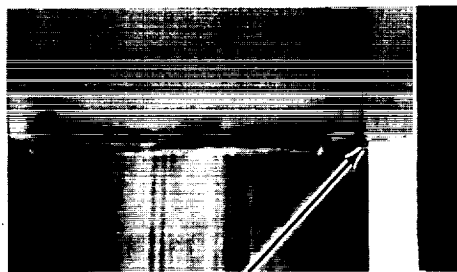
B   INADEQUATE ROOT PENETRATION OF BUTT   C   INADEQUATE FILLET WELD PENETRATION
    WELDED TUBE   KNOWN AS BRIDGING

Figure 7-20.   Lack of Penetration Discontinuity

721 LAMINATIONS

1. CATEGORY. Inherent

2. MATERIAL. Ferrous and Nonferrous Wrought Material

3. DISCONTINUITY CHARACTERISTICS

Surface and internal. Flat, extremely thin, generally aligned parallel to the work surface of the material. May contain a thin film of oxide between the surfaces. Found in forged, extruded, and rolled material. (See Figure 7-21.)

4. METALLURGICAL ANALYSIS

Laminations are separations or weaknesses generally aligned parallel to the work surface of the material. They may be the result of pipe, blister, seam, inclusions, or segregations elongated and made directional by working. Laminations are flattened impurities that are extremely thin.

5. NDT METHODS APPLICATION AND LIMITATIONS

    a. ULTRASONIC TESTING METHOD

        (1) For heavier gauge material the geometry and orientation of lamination (normal to the beam) makes their detection limited to ultrasonic.

        (2) Numerous wave modes may be used depending upon the material thickness or method selected for testing. Automatic and manual contact or immersion methods are adaptable.

        (3) Lamination will appear as a definite interface with a loss of back reflection.

        (4) Through transmission and reflection techniques are applicable for very thin sections.

    b. MAGNETIC PARTICLE TESTING METHOD

        (1) Articles fabricated from ferrous materials are normally tested for lamination by magnetic particle.

        (2) Magnetic indication will appear as a straight, intermittent indication.

        (3) Magnetic particle testing is not capable of determining the over-all size or depth of the lamination.

    c. LIQUID PENETRANT TESTING METHOD

        (1) Normally used on nonferrous materials.

(2) Machining, honing, lapping, or blasting may smear surface of material and thereby close or mask surface lamination.

(3) Acid and alkalines seriously limit the effectiveness of liquid penetrant testing. Thorough cleaning of the surface is essential.

d. EDDY CURRENT TESTING METHOD. Not normally used to detect laminations. If used, the method must be confined to thin sheet stock.

e. RADIOGRAPHIC TESTING METHOD. Not recommended for detecting laminations Laminations have very small thickness changes in the direction of the X-ray beam, thereby making radiographic detection almost impossible.
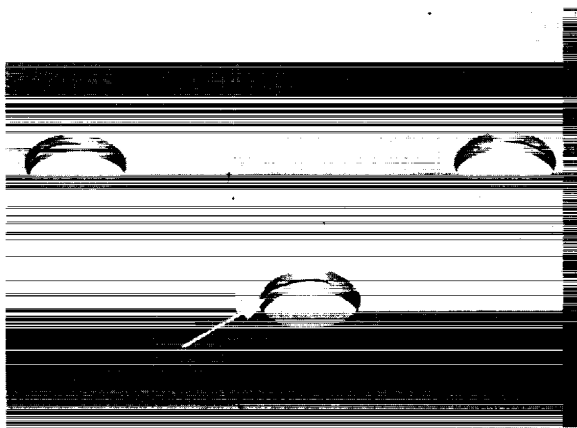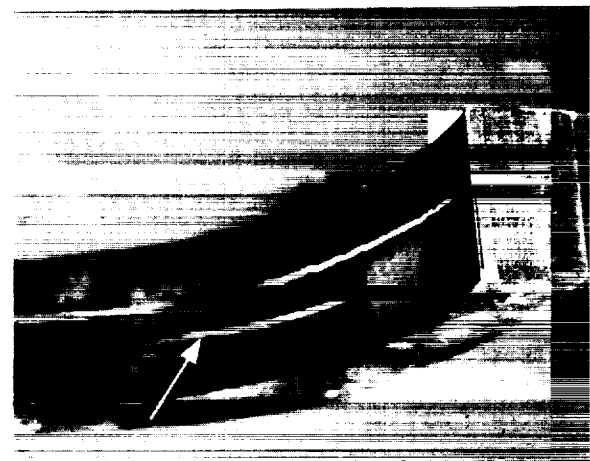

A LAMINATION IN 0.250 IN. PLATE
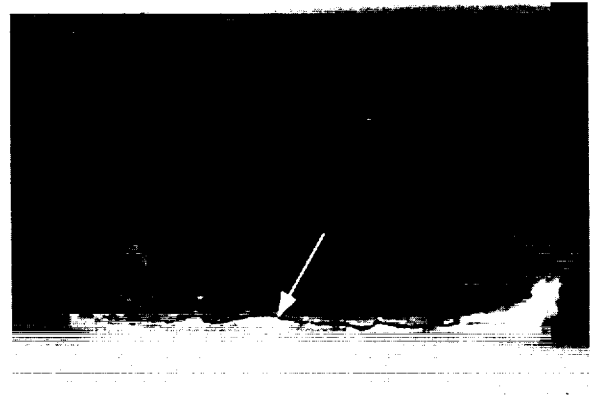
B LAMINATION IN 0.040 TITANIUM SHEET
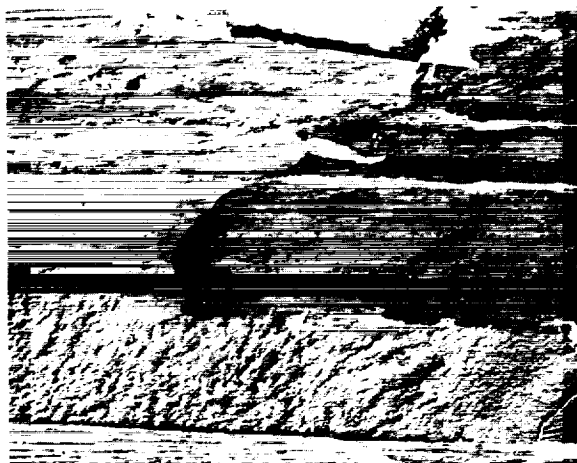
C LAMINATION IN PLATE SHOWING SURFACE ORIENTATION

D LAMINATION IN 1 IN. BAR SHOWING SURFACE ORIENTATION

Figure 7-21. Lamination Discontinuity

722 LAPS AND SEAMS

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Rolled Threads

3. DISCONTINUITY CHARACTERISTICS

Surface. Wavy lines, often quite deep and sometime very tight, appearing as hairline cracks. Found in rolled threads in the minor, pitch, and major diameter of the thread, and in direction of rolling. (See Figure 7-22.)

4. METALLURGICAL ANALYSIS

During the rolling operation, faulty or oversized dies or an overfill of material may cause material to be folded over and flattened into the surface of the thread but not fused.

5. NDT METHODS APPLICATION AND LIMITATIONS

   a. LIQUID PENETRANT TESTING METHOD

      (1) Compatibility with both ferrous and nonferrous materials makes fluorescent liquid penetrant the first choice.

      (2) Liquid penetrant indications will be circumferential, slightly curved, intermittent or continuous indications. Laps and seams may occur individually or in clusters.

      (3) Foreign material may not only interfere with the penetration of the penetrant into the discontinuity but may cause an accumulation of penetrant in a nondefective area.

      (4) Surface of threads may be smeared due to rolling operation, thereby sealing off laps and seams.

      (5) Fluorescent and dye penetrants are not compatible. Dye penetrants tend to kill the fluorescent qualities in fluorescent penetrants.

   b. MAGNETIC PARTICLE TESTING METHOD

      (1) Magnetic particle indications would generally appear the same as liquid penetrant.

      (2) Irrelevent magnetic indications may result from the thread configuration.

   (3) Questionable magnetic particles indications can be verified by liquid penetrant testing.

c. **EDDY CURRENT TESTING METHOD.** Not normally used for detecting laps and seams. Article configuration is the restricting factor.

d. **ULTRASONIC TESTING METHOD.** Not recommended for detecting laps and seams. Thread configurations restrict ultrasonic capability.

e. **RADIOGRAPHIC TESTING METHOD.** Not recommended for detecting laps and seams. Size and orientation of discontinuities restricts the capability of radiographic testing.

A   TYPICAL AREAS OF FAILURE LAPS AND SEAMS
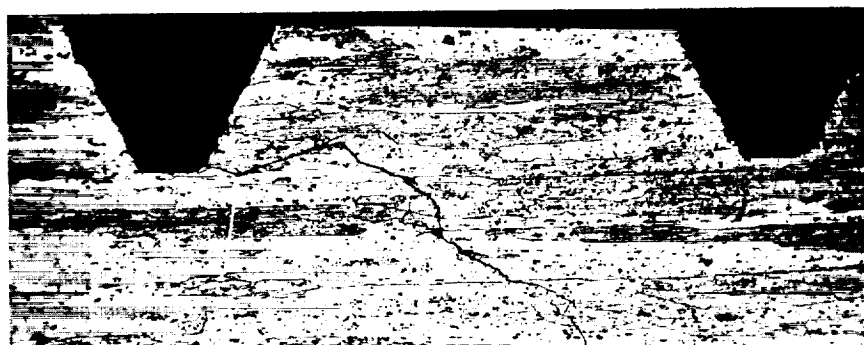
B   FAILURE OCCURRING AT ROOT OF THREAD
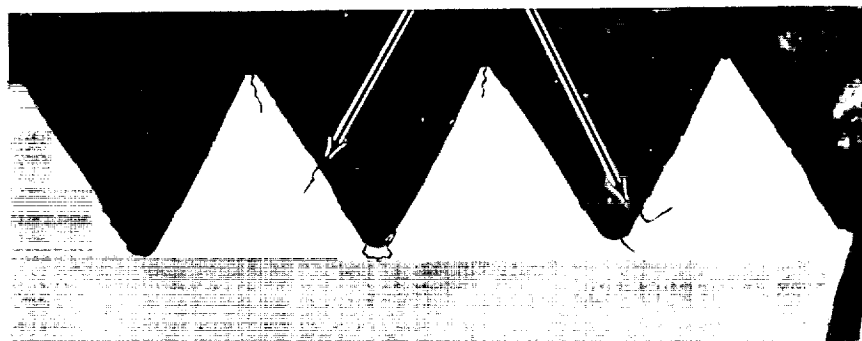
C   AREAS WHERE LAPS AND SEAMS USUALLY OCCUR

Figure 7-22.   Laps and Seams Discontinuity in Rolled Threads

723   LAPS AND SEAMS

1.   CATEGORY.   Processing

2.   MATERIAL.   Ferrous and Nonferrous Wrought Material

3.   DISCONTINUITY CHARACTERISTICS

   a.   Lap Surface. Wavy lines usually not very pronounced or tightly adherent
         since they usually enter the surface at a small angle. Laps may have surface
         openings smeared closed. Found in wrought forgings, plate, tubing, bar,
         and rod. (See Figure 7-23.)

   b.   Seam Surface. Lengthy, often quite deep and sometimes very tight, usually
         parallel fissures with the grain and at times spiral when associated with
         rolled rod and tubing.

4.   METALLURGICAL ANALYSIS

Seams originate from blowholes, cracks, splits, and tears introduced in earlier
processing and elongated in the direction of rolling or forging. The distance between
adjacent innerfaces of the discontinuity is very small.

Laps are similar to seams and may result from improper rolling, forging, or sizing
operations. During the processing of the material, corners may be folded over or
an overfill may exist during the sizing resulting in material being flattened into the
surface but not fused. Laps may occur on any part of the article.

5.   NDT METHODS APPLICATION AND LIMITATIONS

   a.   MAGNETIC PARTICLE TESTING METHOD

      (1) Magnetic particle is recommended for ferrous material.

      (2) Surface and near-surface laps and seams may be detected by this
           method.

      (3) Laps and seams may appear as a straight, spiral, or slightly curved
           indication. They may be individual or clustered and continuous or
           intermittent.

      (4) Magnetic buildup of laps and seams is very small. Therefore, a
           magnetizing current greater than that used for the detection of a
           crack is necessary.

      (5) Correct magnetizing technique should be used when examining for
           forging laps since the discontinuity may lie in a plane nearly parallel
           to the surface.

b. LIQUID PENETRANT TESTING METHOD

    (1) Liquid penetrant is recommended for nonferrous material.

    (2) Laps and seams may be very tight and difficult to detect especially by liquid penetrant.

    (3) Liquid penetrant testing of laps and seams can be improved slightly by heating the article before applying the penetrant.

c. ULTRASONIC TESTING METHOD

    (1) Normally used to test wrought material prior to machining.

    (2) Surface wave technique permits accurate evaluation of the depth, length, and size of laps and seams.

   (3) Ultrasonic indication of laps and seams will appear as definite inner faces within the metal.

d. EDDY CURRENT TESTING METHOD

    (1) Normally used for the evaluation of laps and seams in tubing and pipe.

    (2) Other articles can be screened by eddy current where article configuration and size permit.

e. RADIOGRAPHIC TESTING METHOD. Not recommended for detecting laps and seams in wrought material. Although the ratio between the discontinuity size and the material thickness exceeds 2% of sensitivity in most cases, discontinuities have a very small thickness change in the direction of the X-ray beam, thereby making radiographic detection almost impossible.
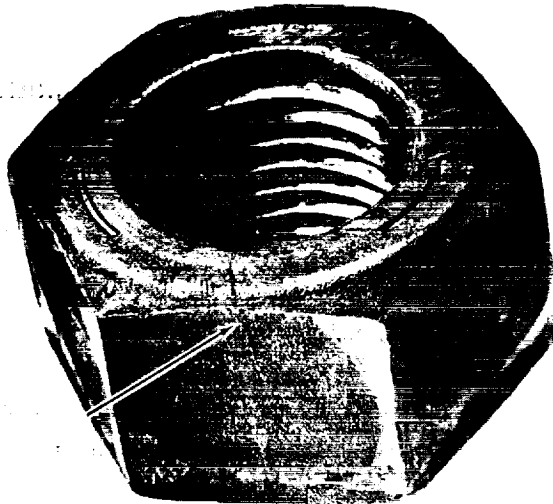
A TYPICAL FORGING LAP
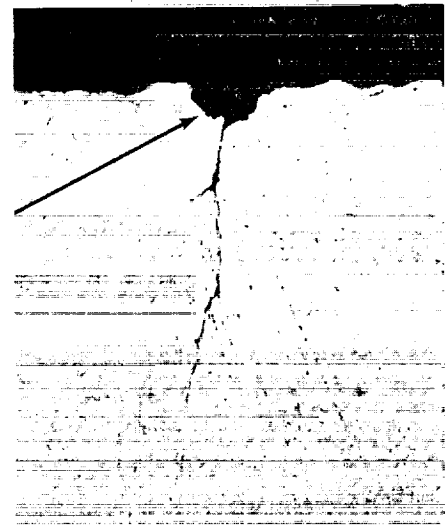
B MICROGRAPH OF A LAP

Figure 7-23. Laps and Seams Discontinuity in Wrought Material

724 MICRO-SHRINKAGE

1. CATEGORY. Processing

2. MATERIAL. Magnesium Casting

3. DISCONTINUITY CHARACTERISTICS

Internal. Small filamentary voids in the grain boundaries appear as concentrated porosity in cross section. (See Figure 7-24.)

4. METALLURGICAL ANALYSIS

Shrinkage occurs while the metal is in a plastic or semi-molten state. If sufficient molten metal cannot flow into different areas as it cools, the shrinkage will leave a void. The void is identified by its appearance and by the time in the plastic range it occurs. Micro-shrinkage is caused by the withdrawal of the low melting point constituent from the grain boundaries.

5. NDT METHODS APPLICATION AND LIMITATIONS

    a. RADIOGRAPHIC TESTING METHOD

        (1) Radiography is universally used to determine the acceptance level of micro-shrinkage.

        (2) Micro-shrinkage will appear on the radiograph as an elongated swirl resembling feathery streaks or as dark irregular patches, which are indicative of cavities in the grain boundaries.

    b. LIQUID PENETRANT TESTING METHOD

        (1) Normally used on finished machined surfaces.

        (2) Micro-shrinkage is not normally open to the surface. These conditions will, therefore, be detected in machined areas.

        (3) The appearance of the indication depends on the plane through which the condition has been cut. The appearance varies from a continuous hairline to a massive porous indication.

        (4) Penetrant may act as a contaminant by saturating the micro porous casting affecting their ability to accept a surface treatment.

        (5) Serious structural and a dimensional damage to the article can result from the improper use of acids or alkalies. They should never be used unless approval is obtained.

c. EDDY CURRENT TESTING METHOD. Not recommended for detecting micro-shrinkage. Article configuration and type of discontinuity do not lend themselves to eddy current.

d. ULTRASONIC TESTING METHOD. Not recommended for detecting micro-shrinkage. Cast structure and article configuration are restricting factors.

e. MAGNETIC PARTICLE TESTING METHOD. Not applicable. Material is nonferrous.
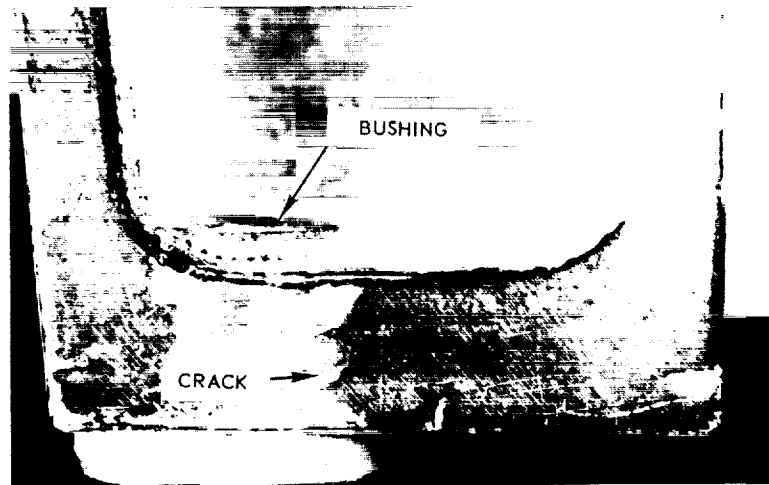
A CRACKED MAGNESIUM HOUSING

B CLOSE-UP VIEW OF (A)
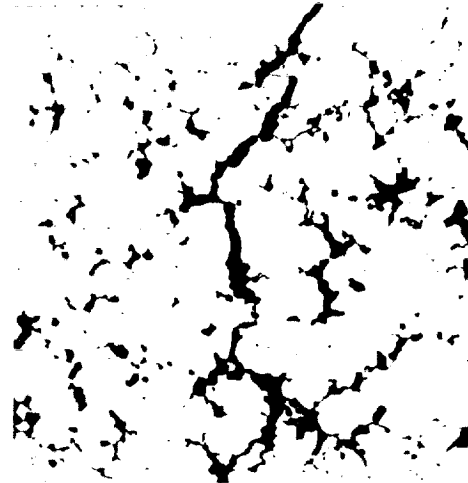
C MICROGRAPH OF CRACKED AREA

Figure 7-24. Micro-Shrinkage Discontinuity

725 GAS POROSITY

1. CATEGORY. Processing

2. MATERIAL. Ferrous and Nonferrous Weldments

3. DISCONTINUITY CHARACTERISTICS

Surface or subsurface. Rounded or elongated, teardrop shaped with or without a sharp discontinuity at the point. Scattered uniformly throughout the weld or isolated in small groups. May also be concentrated at the root or toe. (See Figure 7-25.)

4. METALLURGICAL ANALYSIS

Porosity in welds is caused by gas entrapment in the molten metal, too much moisture on the base or filler metal, or improper cleaning or preheating.

5. NDT METHODS APPLICATION AND LIMITATIONS

    a. RADIOGRAPHY TESTING METHOD

        (1) Radiography is the most universally used NDT method for the detection of gas porosity in weldments.

        (2) The radiographic image of a 'round' porosity will appear as oval shaped spots with smooth edges, while 'elongated' porosity will appear as oval shaped spots with the major axis sometimes several times longer than the minor axis.

        (3) Foreign material such as loose scale, flux, or splatter will affect validity of test results.

    b. ULTRASONIC TESTING METHOD

        (1) Ultrasonic testing equipment is highly sensitive, capable of detecting micro-separations. Established standards should be used if valid test results are to be obtained.

        (2) Surface finish and grain size will affect the validity of the test results.

    c. EDDY CURRENT TESTING METHOD

        (1) Normally confined to thin wall welded pipe and tube.

   (2) Penetration restricts testing to a depth of more than one-quarter inch.

    d. LIQUID PENETRANT TESTING METHOD

   (1) Normally confined to in-process control of ferrous and nonferrous weldments.

(2) Liquid penetrant testing, like magnetic particle, is restricted to surface evaluation.

(3) Extreme caution must be exercised to prevent any cleaning material, magnetic (iron oxide), and liquid penetrant materials from becoming entrapped and contaminating the rewelding operation.
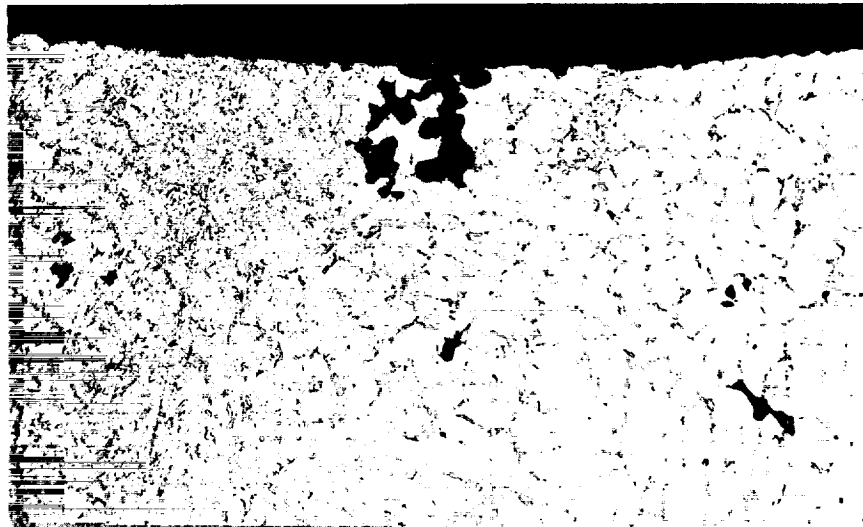
e. MAGNETIC PARTICLE TESTING METHOD

(1) Not normally used to detect gas porosity.

(2) Only surface porosity would be evident. Near surface porosity would not be clearly defined since it is neither strong or pronounced.
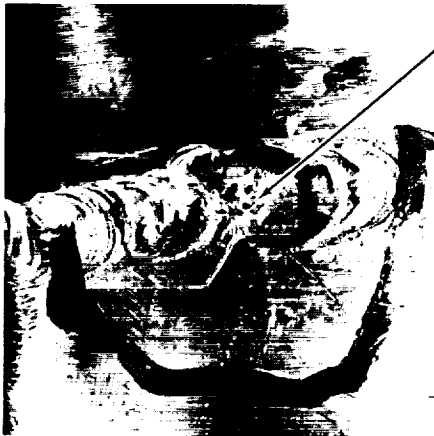
A   TYPICAL SURFACE POROSITY
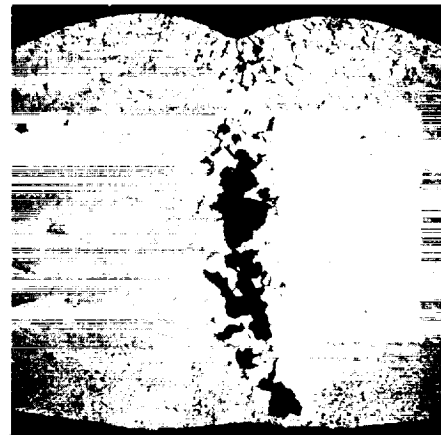
B   CROSS-SECTION OF (A) SHOWING EXTENT OF POROSITY

C   MICROGRAPH OF CROSS-SECTION SHOWING TYPICAL SHRINKAGE POROSITY

Figure 7-25.   Gas Porosity Discontinuity

726   UNFUSED POROSITY

1.   CATEGORY.   Processing

2.   MATERIAL.   Aluminum

3.   DISCONTINUITY CHARACTERISTICS

Internal. Wafer-thin fissures aligned parallel with the grain flow. Found in wrought aluminum which is rolled, forged, or extruded. (See Figure 7-26.)

4.   METALLURGICAL ANALYSIS

Unfused porosity is attributed to porosity which is in the cast ingot. During the rolling, forging, or extruding operations it is flattened into wafer-thin shape. If the internal surface of these discontinuities is oxidized or is composed of a foreign material, they will not fuse during the subsequent processing, resulting in an extremely thin interface or void.

5.   NDT METHODS APPLICATION AND LIMITATIONS

    a.   ULTRASONIC TESTING METHOD

        (1)   Used extensively for the detection of unfused porosity.

        (2)   Material may be tested in the wrought as received configuration.

        (3)   Ultrasonic testing fixes the location of the void in all three directions.

        (4)   Where the general direction of the discontinuity is unknown, it may be necessary to test from several directions.

        (5)   Method of manufacture and subsequent article configuration will determine the orientation of the unfused porosity to the material surface.

    b.   LIQUID PENETRANT TESTING METHOD

        (1)   Normally used on nonferrous machined articles.

        (2)   Unfused porosity will appear as a straight line of varying lengths running parallel with the grain. Liquid penetrant is restricted to surface evaluation.

        (3)   Surface preparations such as vapor blasting, honing, or sanding may obliterate by masking the surface discontinuities, thereby restricting the reliability of liquid penetrant testing.

   (4)   Excessive agitation of powder in a large container may produce foaming.

c. EDDY CURRENT TESTING METHOD. Not normally used for detecting unfused porosity.

d. RADIOGRAPHIC TESTING METHOD

(1) Not normally used for detecting unfused porosity.

(2) Wafer-thin discontinuities are difficult to detect by a method which measures density or which requires that the discontinuity be parallel and perpendicular to the X-ray beam.

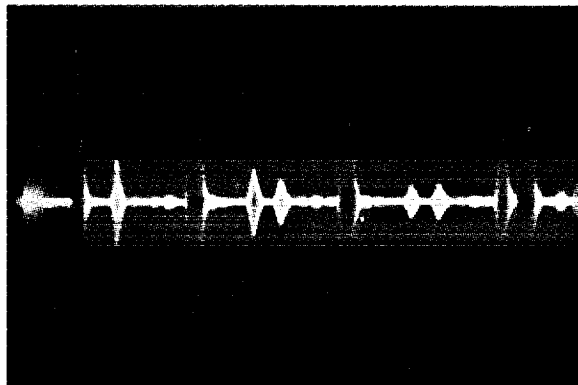e. MAGNETIC PARTICLE TESTING METHOD. Not applicable. Material is nonferrous.
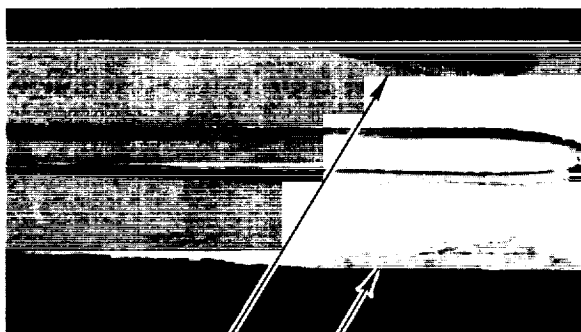
A FRACTURED SPECIMEN SHOWING UNFUSED POROSITY
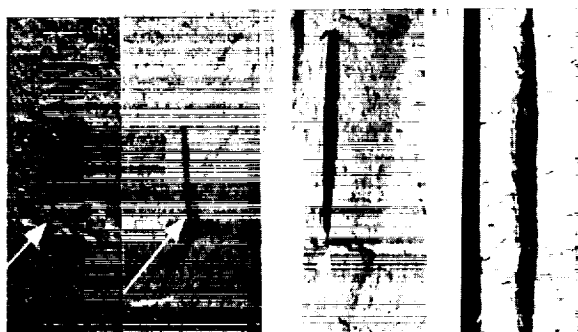
B UNFUSED POROSITY EQUIVALENT TO 1/64, 3/64, 5/64 AND 8/64 (LEFT TO RIGHT)
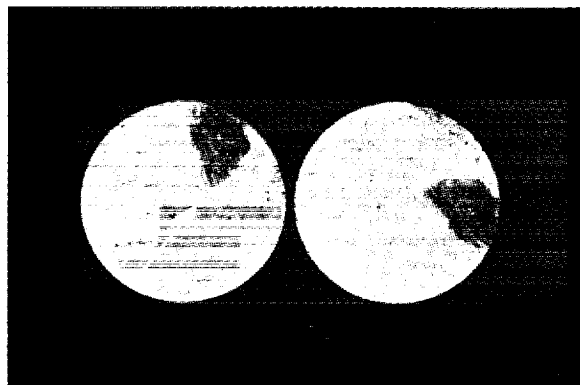
C TYPICAL UNFUSED POROSITY

D ULTRASONIC SCOPE PATTERN OF (C)

Figure 7-26. Unfused Porosity Discontinuity

727 STRESS CORROSION

1. **CATEGORY.** Service

2. **MATERIAL.** Ferrous and Nonferrous

3. **DISCONTINUITY CHARACTERISTICS**

Surface. Range from shallow to very deep, and usually follow the grain flow of the material; however, transverse cracks are also possible. (See Figure 7-27.)

4. **METALLURGICAL ANALYSIS**

Three factors are necessary for the phenomenon of stress corrosion to occur: 1) a sustained static tensile stress, 2) the presence of a corrosive environment, and 3) the use of a material that is susceptible to this type of failure. Stress corrosion is much more likely to occur faster at high levels of stress than at low levels of stress. The type of stresses include residual (internal) as well as those from external (applied) loading.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

    a. **LIQUID PENETRANT TESTING METHOD**

        (1) Liquid penetrant is normally used for the detection of stress corrosion.

        (2) In the preparation, application, and final cleaning of articles, extreme care must be exercised to prevent over spraying and contamination of the surrounding articles.

        (3) Chemical cleaning immediately before the application of liquid penetrant may seriously affect the test results if the solvents are not given time to evaporate.

        (4) Service articles may contain moisture within the discontinuity which will dilute, contaminate, and invalid results if the moisture is not removed.

    b. **EDDY CURRENT TESTING METHOD**

        (1) Not normally used to detect stress corrosion.

        (2) Eddy current equipment is capable of resolving stress corrosion where article configuration is compatible with equipment limitations.

    c. **ULTRASONIC TESTING METHOD**

        (1) Not normally used to detect stress corrosion.

        (2) Discontinuities are perpendicular to surface of material and require surface technique.

d. MAGNETIC PARTICLE TESTING METHOD

    (1) Not normally used to detect stress corrosion.

    (2) Configuration of article and usual nonmagnetic condition exclude magnetic particle testing.

e. RADIOGRAPHIC TESTING METHOD

    (1) Not normally used to detect stress corrosion.

    (2) Surface indications are best detected by NDT method designed for such application. However, radiography can and has shown stress corrosion with the use of the proper technique.
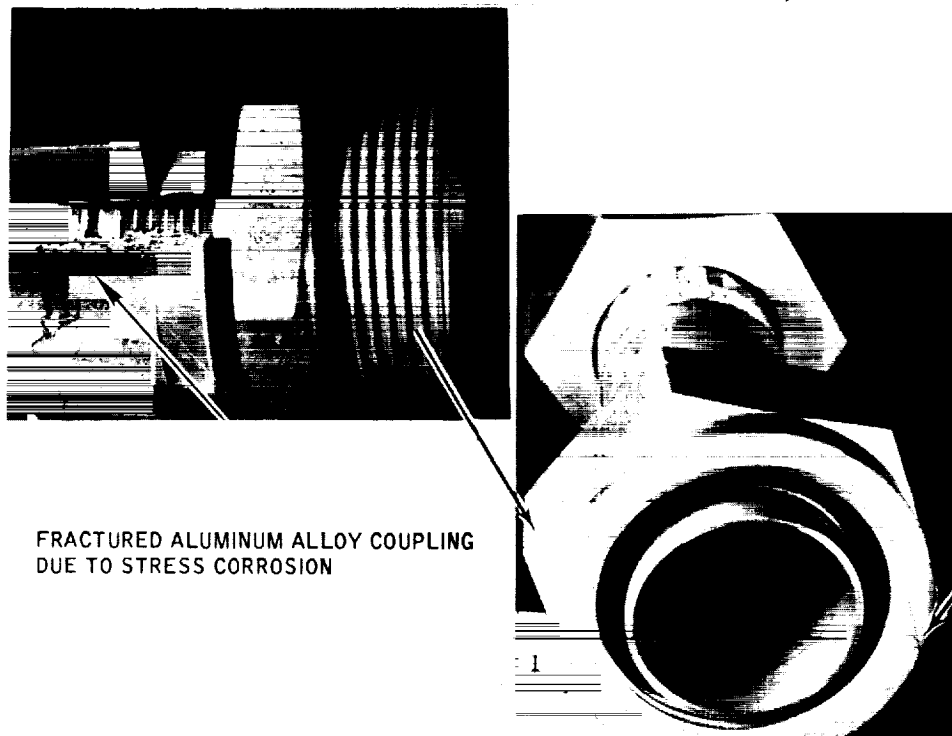

FRACTURED ALUMINUM ALLOY COUPLING
DUE TO STRESS CORROSION

Figure 7-27. Stress Corrosion Discontinuity

728   HYDRAULIC TUBING

1. CATEGORY.   Processing and Service

2. MATERIAL.   Aluminum 6061-T6

3. DISCONTINUITY CHARACTERISTICS

Surface and internal.   Range in size from short to long, shallow to very tight and deep.   Usually they will be found in the direction of the grain flow with the exception of stress corrosion, which has no direction.   (See Figure 7-28.)

4. METALLURGICAL ANALYSIS

Hydraulic tubing discontinuities are usually one of the following:

    a.   Foreign material coming in contact with the tube material and being embedded into the surface of the tube.

    b.   Laps which are the result of material being folded over and not fused.

    c.   Seams which originate from blowholes, cracks, splits and tears introduced in the earier processing, and then are elongated during rolling.

    d.   Intergranular corrosion which is due to the presence of a corrosive environment.

5. NDT METHODS APPLICATION AND LIMITATIONS

    a.   EDDY CURRENT TESTING METHOD

        (1) Universally used for testing of nonferrous tubing.

        (2) Heavier walled tubing (0.250 and above) may not be successfully tested due to the penetration ability of the equipment.

        (3) The specific nature of various discontinuities may not be clearly defined.

        (4) Test results may not be valid unless controlled by known standards.

        (5) Testing of ferro-magnetic material may be difficult.

        (6) All material should be free of any foreign material that would invalid the test results.

    b.   LIQUID PENETRANT TESTING METHOD

        (1) Not normally used for detecting tubing discontinuities.

        (2) Eddy current is more economical, faster, and with established standards is more reliable.

c. ULTRASONIC TESTING METHOD

   (1) Not normally used for detecting tubing discontinuities.

   (2) Eddy current is recommended over ultrasonic testing since it is faster and more economical for this range of surface discontinuity and non-ferrous material.
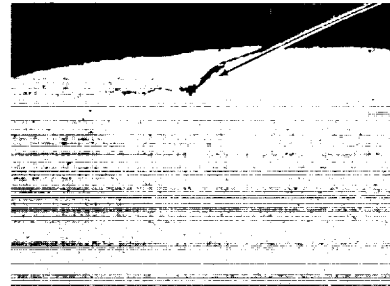
d. RADIOGRAPHIC TESTING METHOD

   (1) Not normally used for detecting tubing discontinuities.

   (2) The size and type of discontinuity and the configuration of the article limit the use of radiography for screening of material for this group of discontinuities.
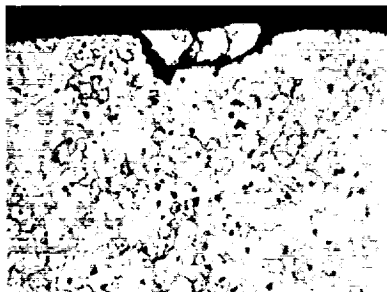
e. MAGNETIC PARTICLES TESTING METHOD. Not applicable. Material is nonferrous.
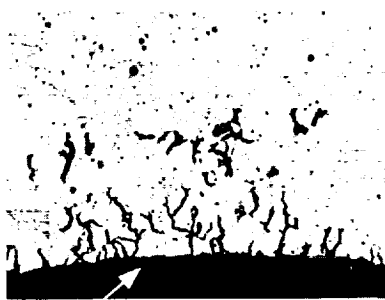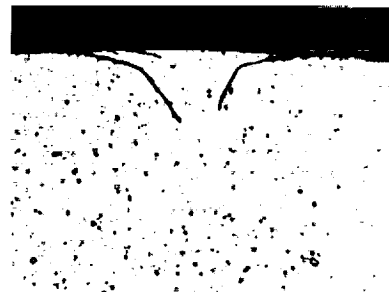

A INTERGRANULAR CORROSION

B LAP IN OUTER SURFACE OF TUBING

C EMBEDDED FOREIGN MATERIAL

D TWIN LAPS IN OUTER SURFACE OF TUBING

Figure 7-28. Hydraulic Tubing Discontinuity

729 **MANDREL DRAG**

1. **CATEGORY.** Processing

2. **MATERIAL.** Nonferrous Thick-Wall Seamless Tubing

3. **DISCONTINUITY CHARACTERISTICS**

Internal surface of thick-wall tubing. Range from shallow even gouges to ragged tears. Often a slug of the material will be embedded within the gouged area. (See Figure 7-29.)

4. **METALLURGICAL ANALYSIS**

During the manufacture of thick-wall seamless tubing, the billet is ruptured as it passes through the offset rolls. As the piercing mandrel follows this fracture, a portion of the material may break loose and be forced over the mandrel. As it does the surface of the tubing may be scored or have the slug embedded into the wall. Certain types of material are more prone to this type of failure than others.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

    a. **EDDY CURRENT TESTING METHOD**

        (1) Normally used for the testing of thin-wall pipe or tube.

        (2) Eddy current testing may be confined to nonferrous materials.

        (3) Discontinuities are qualitative, not quantative indications.

        (4) Several factors simultaneously affect output indications.

    b. **ULTRASONIC TESTING METHOD**

        (1) Normally used for the screening of thick-wall pipe or tube for mandrel drag.

        (2) Can be used to test both ferrous and nonferrous pipe or tube.

        (3) Requires access from one side only.

        (4) May be used in support of production line since it is adaptable for automatic instrumentation.

   (5) Configuration of mandrel drag or tear will produce very sharp and noticeable indications on the scope.

    c. **RADIOGRAPHIC TESTING METHOD**

        (1) Not normally used although it has been instrumental in the detection of mandrel drag during examination of adjacent welds.

   (2) Complete coverage requires several exposures around the circumference of the tube.

(3) This method is not designed for production support since it is very slow and costly for large volumes of pipe or tube.

(4) Radiograph will disclose only two dimensions and not the third.

d. **LIQUID PENETRANT TESTING METHOD.** Not recommended for detecting mandrel drag since discontinuity is internal and would not be detectable.

e. **MAGNETIC PARTICLE TESTING METHOD.** Not recommended for detecting mandrel drag. Discontinuities are not close enough to the surface to be detectable by magnetic particles. Most mandrel drag will occur in seamless stainless steel.
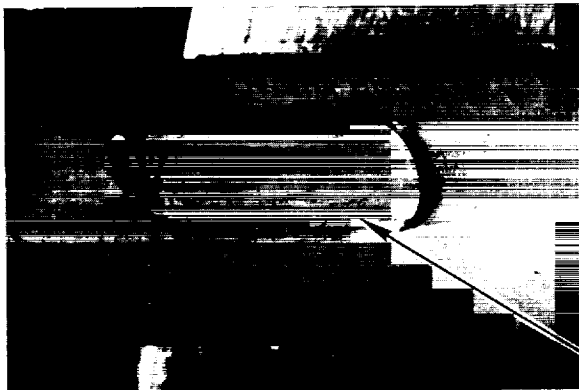
A   EMBEDDED SLUG SHOWING DEEP GOUGE MARKS
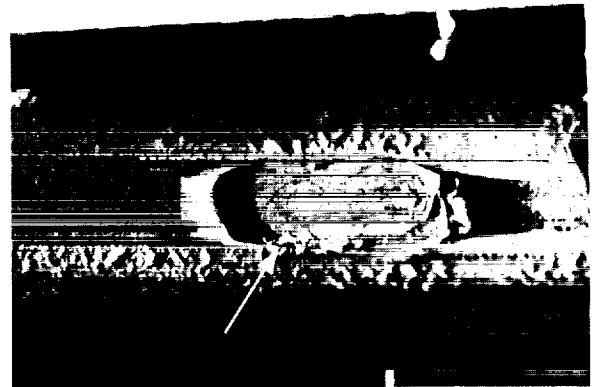
B   SLUG BROKEN LOOSE FROM TUBING WALL
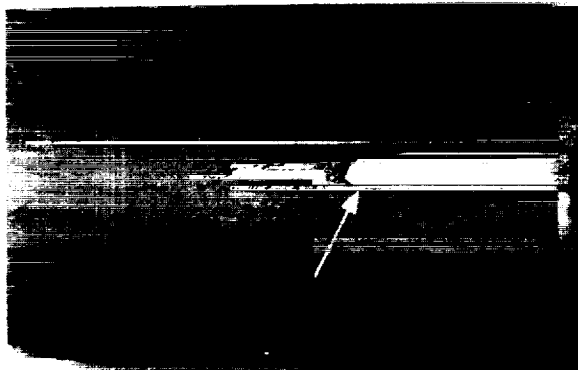
C   ANOTHER TYPE OF EMBEDDED SLUG

D   GOUGE ON INNER SURFACE OF PIPE

Figure 7-29.   Mandrel Drag Discontinuity

730 SEMICONDUCTORS

1. **CATEGORY.** Processing and Service

2. **MATERIAL.** Hardware

3. **DISCONTINUITY CHARACTERISTICS**

Internal. Appear in many sizes and shapes and various degrees of density. They may be misformed, aligned, damaged, or broken internal hardware. Found in transistors, diodes, resistors, and capacitors. (See Figure 7-30.)

4. **METALLURGICAL ANALYSIS**

Semiconductor discontinuities such as loose wire, weld splash, flakes, solder balls, loose leads, inadequate clearance between internal elements and case, and inclusions or voids in seals or around lead connections are the product of processing errors.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

   a. **RADIOGRAPHIC TESTING METHOD**

      (1) Universally used as the NDT method for the detection of discontinuities in semiconductors.

      (2) The configuration and internal structure of the various semiconductors limit the NDT method to radiography.

      (3) Semiconductors that have copper heat sinks may require more than one technique due to the density of the copper.

      (4) Internal wires in semiconductors are very fine and may be constructed from materials of different density such as copper, silver, gold and aluminum. If the latter is used with the others, special techniques may be needed to resolve its reliability.

      (5) Micro-particles may require the highest sensitivity to resolve.

      (6) The complexity of the internal structure of semiconductors may require additional views to exclude the possibility of non-detection of discontinuities due to masking by hardware.

      (7) Positive positioning of each semiconductor will prevent invalid interpretation.

      (8) Source angle should give minimum distortion.

      (9) Preliminary examination of semiconductors may be accomplished using a vidcon system that would allow visual observation during 360 degree rotation of the article.

b. EDDY CURRENT TESTING METHOD. Not recommended for detecting semiconductor discontinuities. Nature of discontinuity and method of construction of the article do not lend themselves to this form of NDT.

c. MAGNETIC PARTICLE TESTING METHOD. Not recommended for detecting semiconductor discontinuities.

d. LIQUID PENETRANT TESTING METHOD. Not recommended for detecting semiconductor discontinuities.

e. ULTRASONIC TESTING METHOD. Not recommended for detecting semiconductor discontinuities.
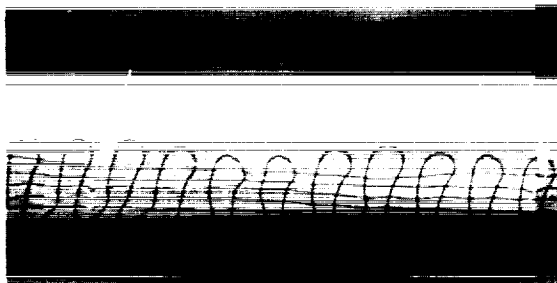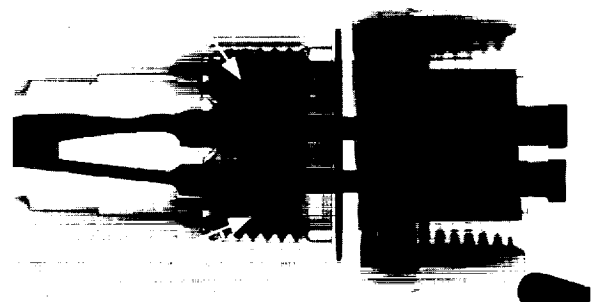
A STRANDS BROKEN IN HEATER BLANKET   B FINE CRACK IN PLASTIC CASING MATERIAL
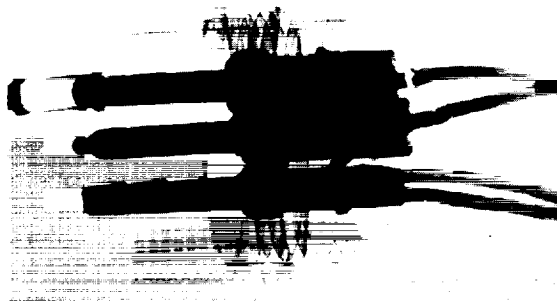
C BROKEN ELECTRICAL CABLE   D FOREIGN MATERIAL WITHIN SEMICONDUCTOR

Figure 7-30. Semiconductor Discontinuity

731 HOT TEARS

1. CATEGORY. Inherent

2. MATERIAL. Ferrous Castings

3. DISCONTINUITY CHARACTERISTICS

Internal or near surface. Appear as ragged line of variable width and numerous branches. Occur singly or in groups. (See Figure 7-31.)

4. METALLURGICAL ANALYSIS

Hot cracks (tears) are caused by non-uniform cooling resulting in stresses which rupture the surface of the metal while its temperature is still in the brittle range. Tears may originate where stresses are set up by the more rapid cooling of thin sections that adjoin heavier masses of metal, which are slower to cool.

5. NDT METHODS APPLICATION AND LIMITATIONS

    a. RADIOGRAPHIC TESTING METHOD

        (1) Radiographic testing is the first choice since the material is cast structure and the discontinuities may be internal and surface.

        (2) Orientation of the hot tear in relation to the source may influence the test results.

   (3) The sensitivity level may not be sufficient to detect fine surface hot tears.

    b. MAGNETIC PARTICLE TESTING METHOD

        (1) Hot tears that are exposed to the surface can be screened with magnetic particle method.

        (2) Article configuration and metallurgical composition may make demagnization difficult.

        (3) Although magnetic particle can detect near surface hot tears, radiography should be used for final analysis.

        (4) Foreign material not removed prior to testing will cause an invalid test.

    c. LIQUID PENETRANT TESTING METHOD

        (1) Liquid penetrant is recommended for nonferrous cast material.

        (2) Liquid penetrant is confined to surface evaluation.

(3) The use of penetrants on castings may act as a contaminant by saturating the porous structure and affect the ability to apply surface finish.

(4) Repeatability of indications may be poor after a long period of time.

d. ULTRASONIC TESTING METHOD. Not recommended for detecting hot tears. Discontinuities of this type when associated with cast structure do not lend themselves to ultrasonic testing.

e. EDDY CURRENT TESTING METHOD. Not recommended for detecting hot tears. Metallurgical structure along with the complex configurations do not lend themselves to eddy current testing.
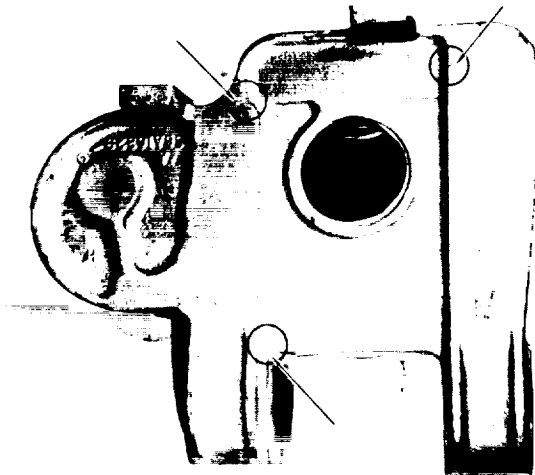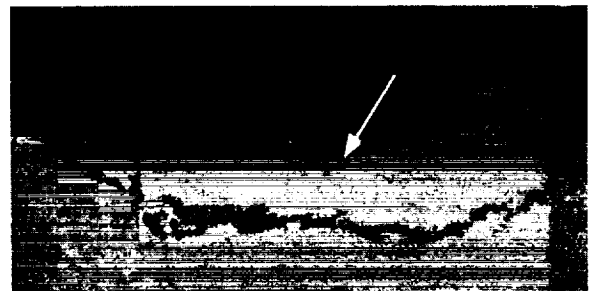
A   TYPICAL HOT TEARS IN CASTING
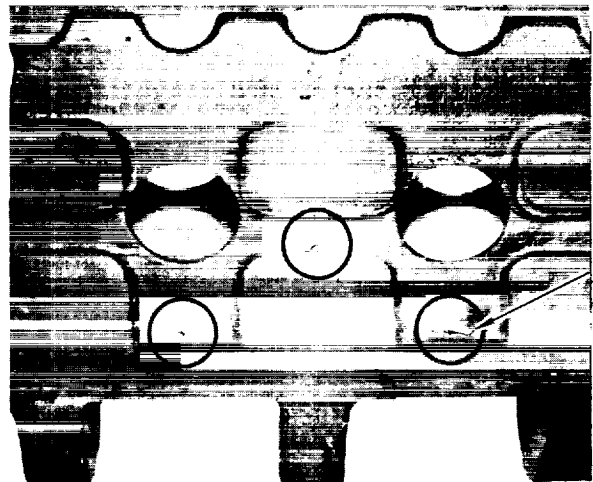
B   HOT TEARS IN FILLET OF CASTING

C   CLOSE-UP OF HOT TEARS IN (A)

D   CLOSE-UP OF HOT TEARS IN (B)

Figure 7-31. Hot Tear Discontinuity

732 INTERGRANULAR CORROSION

1. **CATEGORY.** Service

2. **MATERIAL.** Nonferrous

3. **DISCONTINUITY CHARACTERISTICS**

Surface or internal. A series of small micro-openings with no definite pattern. May
appear singly or in groups. The insidious nature of intergranular corrosion results
from the fact that very little corrosion or corrosion product is visible on the surface.
Intergranular corrosion may extend in any direction following the grain boundaries of
the material. (See Figure 7-32.)

4. **METALLURGICAL ANALYSIS**

Two factors that contribute to intergranular corrosion are:

  a. Metallurgical structure of the material that is prone to intergranular cor-
      rosion such as unstabilized 300 series stainless steel.

  b. Improper stress relieving or heat treat may create the susceptibility to
      intergranular corrosion. Either of these conditions coupled with a cor-
      rosive atmosphere will result in intergranular attack.

5. **NDT METHODS APPLICATION AND LIMITATIONS**

  a. LIQUID PENETRANT TESTING METHOD

      (1) Liquid penetrant is the first choice due to the size and location of this
           type of discontinuity.

      (2) Chemical cleaning operations immediately before the application of
           liquid penetrant may contaminate the article and seriously affect the
           test results.

      (3) Cleaning in solvents may release chlorine and accelerate intergranular
           corrosion.

      (4) Trapped penetrant solution may present a cleaning or removal problem.

  b. RADIOGRAPHIC TESTING METHOD

      (1) Intergranular corrosion in the more advanced stages has been detected
           with radiography.

      (2) Sensitivity levels may prevent the detection of fine intergranular cor-
           rosion.

      (3) Radiography may not determine on which surface the intergranular cor-
   rosion will occur.

c. EDDY CURRENT TESTING METHOD

    (1) Eddy current can be used for the screening of intergranular corrosion.

    (2) Tube or pipe lend themselves readily to this method of NDT testing.

    (3) Metallurgical structure of the material may seriously affect the output indications.

d. ULTRASONIC TESTING METHOD. Not normally used although the equipment has the capability to detect intergranular corrosion.

e. MAGNETIC PARTICLES TESTING METHOD. Not recommended for detecting intergranular corrosion. Type of discontinuity and material restrict the use of magnetic particles.
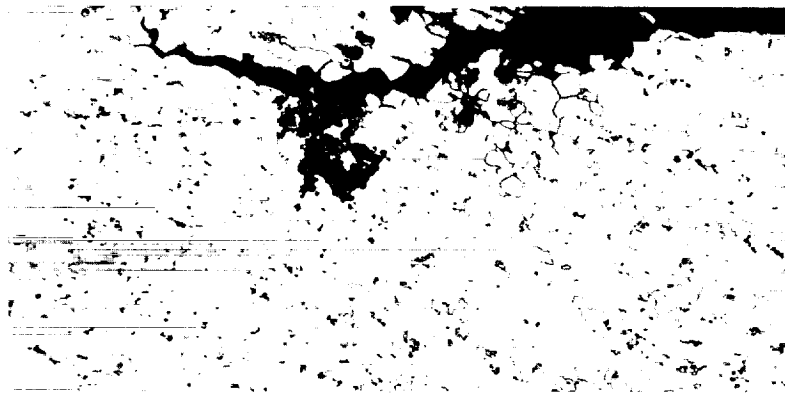
A MICROGRAPH OF INTERGRANULAR CORROSION SHOWING LIFTING OF SURFACE FROM SUBSURFACE CORROSION
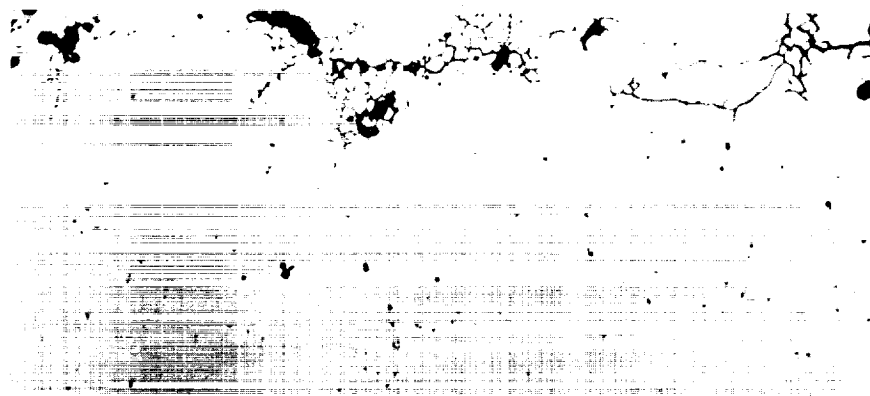
B MICROGRAPH SHOWING NATURE OF INTERGRANULAR CORROSION. ONLY MINOR EVIDENCE OF CORROSION IS EVIDENT FROM SURFACE

Figure 7-32. Intergranular Corrosion Discontinuity