



Standard Practice for Ultrasonic Angle-Beam Examination by the Contact Method¹

This standard is issued under the fixed designation E 587; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers ultrasonic examination of materials by the pulse-echo technique, using continuous coupling of angular incident ultrasonic vibrations.

1.2 The values stated in inch-pound units are regarded as standard. The SI equivalents are in parentheses and may be approximate.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

E 114 Practice for Ultrasonic Pulse-Echo Straight-Beam Examination by the Contact Method²

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments²

E 543 Practice for Agencies Performing Nondestructive Testing²

E 1316 Terminology for Nondestructive Examinations²

2.2 ASNT Documents:

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification³

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel³

2.3 Military Standards:

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification⁴

2.4 Aerospace Industries Association Document:

NAS 410 Certification and Qualification of Nondestructive Testing Personnel⁵

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, see Terminology E 1316.

4. Significance and Use

4.1 An electrical pulse is applied to a piezoelectric transducer which converts electrical to mechanical energy. In the angle-beam search unit, the piezoelectric element is generally a thickness expander which creates compressions and rarefactions. This longitudinal (compressional) wave travels through a wedge (generally a plastic). The angle between transducer face and the examination face of the wedge is equal to the angle between the normal (perpendicular) to the examination surface and the incident beam. Fig. 1 shows the incident angle ϕ_1 , and the refracted angle ϕ_r , of the ultrasonic beam.

4.2 When the examination face of the angle-beam search unit is coupled to a material, ultrasonic waves may travel in the material. As shown in Fig. 2, the angle in the material (measured from the normal to the examination surface) and mode of vibration are dependent on the wedge angle, the ultrasonic velocity in the wedge, and the velocity of the wave in the examined material. When the material is thicker than a few wavelengths, the waves traveling in the material may be longitudinal and shear, shear alone, shear and Rayleigh, or Rayleigh alone. Total reflection may occur at the interface. (Refer to Fig. 3.) In thin materials (up to a few wavelengths thick), the waves from the angle-beam search unit traveling in the material may propagate in different Lamb wave modes.

4.3 All ultrasonic modes of vibration may be used for angle-beam examination of material. The material forms and the probable flaw locations and orientations determine selection of beam directions and modes of vibration. The use of angle beams and the selection of the proper wave mode presuppose a knowledge of the geometry of the object; the probable location, size, orientation, and reflectivity of the expected flaws; and the laws of physics governing the propagation of ultrasonic waves. Characteristics of the examination system used and the ultrasonic properties of the material being

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² *Annual Book of ASTM Standards*, Vol 03.03.

³ Available from American Society for Nondestructive Testing, Inc., 1711 Arlington Lane, Columbus, OH 43228.

⁴ Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

⁵ Available from Aerospace Industries Association of America, Inc., 1250 Eye St. NW, Washington D.C. 20005.

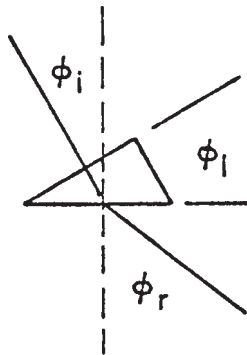


FIG. 1 Refraction

examined must be known or determined. Some materials, because of unique microstructure, are difficult to examine using ultrasonics. Austenitic material, particularly weld material, is one example of this material condition. Caution should be exercised when establishing examination practices for these type materials. While examination may be possible, sensitivity will be inferior to that achievable on ferritic materials. When examining materials with unique microstructures, empirical testing should be performed to assure that the examination will achieve the desired sensitivity. This may be accomplished by incorporating known reflectors in a mock up of the weld or part to be examined.

4.3.1 Angle-Beam Longitudinal Waves—As shown in Fig. 4, angle-beam longitudinal waves with refracted angles in the range from 1 to 40° (where coexisting angle-beam shear waves are weak, as shown in Fig. 3) may be used to detect fatigue cracks in axles and shafts from the end by direct reflection or by corner reflection. As shown in Fig. 5, with a crossed-beam dual-transducer search unit configuration, angle-beam longitudinal waves may be used to measure thickness or to detect reflectors parallel to the examination surface, such as laminations. As shown in Fig. 6, reflectors with a major plane at an angle up to 40° with respect to the examination surface, provide optimum reflection to an angle-beam longitudinal wave that is normal to the plane of the reflector. Angle-beam longitudinal waves in the range from 45 to 85° become weaker as the angle increases; at the same time, the coexisting angle-beam shear waves become stronger. Equal amplitude angle beams of approximately 55° longitudinal wave and 29° shear wave will coexist in the material, as shown in Fig. 7. Confusion created by two beams traveling at different angles and at different velocities has limited use of this range of angle beams.

4.3.2 Angle-Beam Shear Waves (Transverse Waves)—Angle-beam shear waves in the range from 40 to 75° are the most used angle beams. They will detect imperfections in materials by corner reflection and reradiation (as shown in Fig. 8) if the plane of the reflector is perpendicular to a material surface, and by direct reflection if the ultrasonic beam is normal to the plane of the reflector (as shown in Fig. 9). Reflectors parallel to the examination surface (such as laminations in plate, as shown in Fig. 10) can rarely be detected by an angle beam unless accompanied by another reflector; for example, a lamination at the edge of a plate (as shown in Fig. 11) can be detected by corner reflection from the lamination

and plate edge. Generally, laminations should be detected and evaluated by the straight-beam technique. Angle-beam shear waves applied to weld testing will detect incomplete penetration (as shown in Fig. 12) by corner reflection, incomplete fusion (as shown in Fig. 13) by direct reflection (when the beam angle is chosen to be normal to the plane of the weld preparation), slag inclusion by cylindrical reflection (as shown in Fig. 14), porosity by spherical reflection, and cracks (as shown in Fig. 15) by direct or corner reflection, depending on their orientation. Angle-beam shear waves of 80 to 85° are frequently accompanied by a Rayleigh wave traveling on the surface. Confusion created by two beams at slightly different angles, traveling at different velocities, has limited applications in this range of angle beams.

4.3.3 Surface-Beam Rayleigh Waves—Surface-beam Rayleigh waves travel at 90° to the normal of the examination surface on the examination surface. In material greater than two wavelengths thick, the energy of the Rayleigh wave penetrates to a depth of approximately one wavelength; but, due to the exponential distribution of the energy, one half of the energy is within one-quarter wavelength of the surface. Surface cracks with length perpendicular to the Rayleigh wave can be detected and their depth evaluated by changing the frequency of the Rayleigh wave, thus changing its wavelength and depth of penetration. Wavelength equals velocity divided by frequency.

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

Subsurface reflectors may be detected by Rayleigh waves if they lie within one wavelength of the surface.

4.3.4 Lamb Waves—Lamb waves travel at 90° to the normal of the test surface and fill thin materials with elliptical particle vibrations. These vibrations occur in various numbers of layers and travel at velocities varying from slower than Rayleigh up to nearly longitudinal wave velocity, depending on material thickness and examination frequency. Asymmetrical-type Lamb waves have an odd number of elliptical layers of vibration, while symmetrical-type Lamb waves have an even number of elliptical layers of vibration. Lamb waves are most useful in materials up to five wavelengths thick (based on Rayleigh wave velocity in a thick specimen of the same material). They will detect surface imperfections on both the examination and opposite surfaces. Centrally located laminations are best detected with the first or second mode asymmetrical Lamb waves (one or three elliptical layers). Small thickness changes are best detected with the third or higher mode symmetrical or asymmetrical-type Lamb waves (five or more elliptical layers). A change in plate thickness causes a change of vibrational mode just as a lamination causes a mode change. The mode conversion is imperfect and may produce indications at the leading and the trailing edges of the lamination or the thin area.

5. Basis of Application

5.1 Purchaser-Supplier Agreements: The following items require agreement between using parties for this practice to be used effectively:

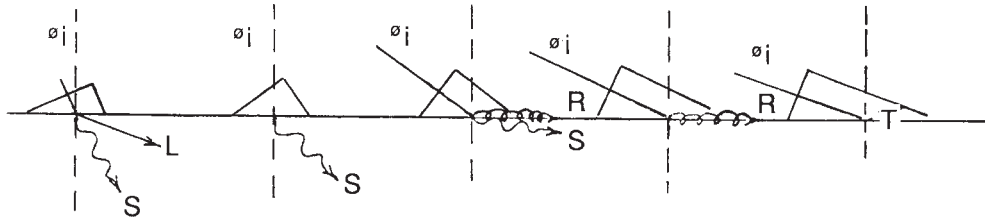


FIG. 2 Mode of Vibration

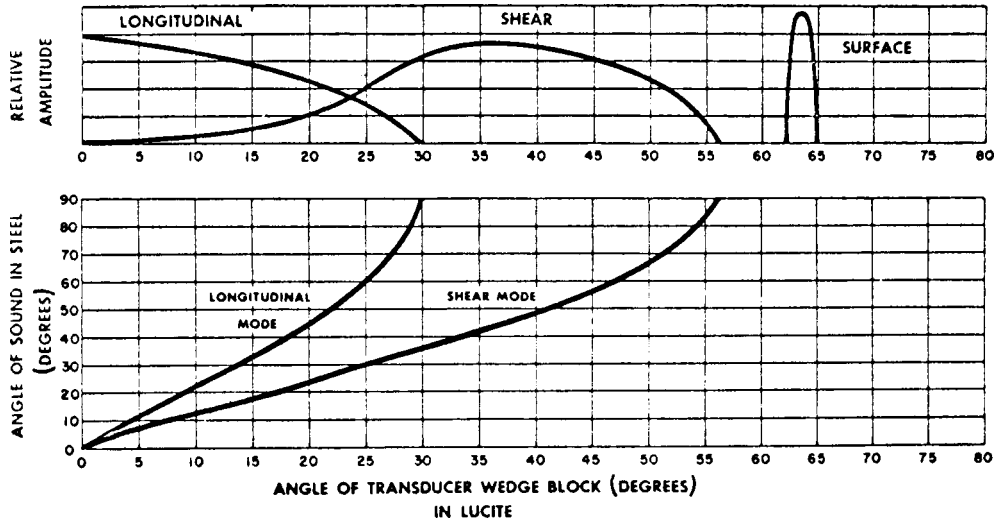


FIG. 3 Effective Angles in the Steel versus Wedge Angles in Acrylic Plastic

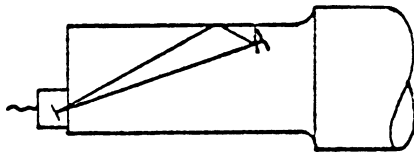


FIG. 4 Axle

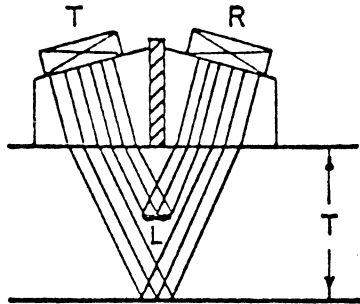


FIG. 5 Thickness

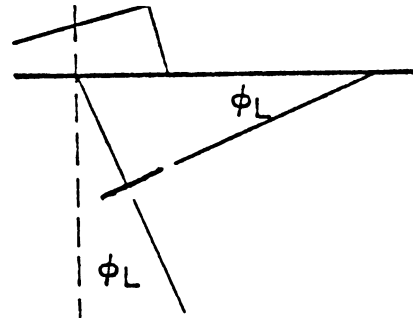


FIG. 6 Angle Longitudinal

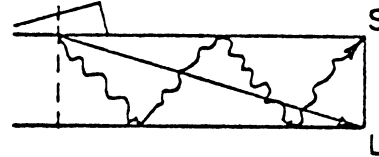


FIG. 7 Coincident Beams

5.1.1 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this practice shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, MIL STD-410, NAS-410, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

NOTE 1—MIL STD-410 is canceled and has been replaced with

NAS-410, however, it may be used with agreement between contracting parties.

5.1.2 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E 543. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

5.2 For material with unique microstructures as described in 4.3, a technique and procedure shall be agreed upon between contracting parties.

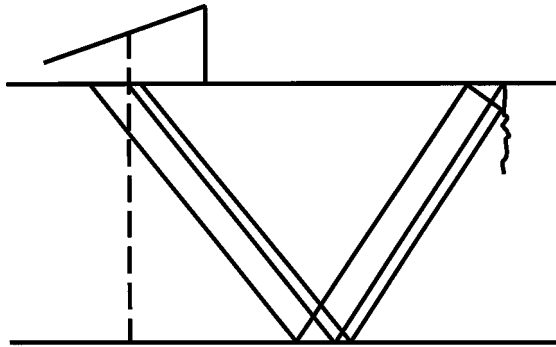


FIG. 8 Corner

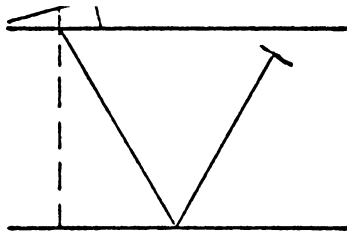


FIG. 9 Normal Plane

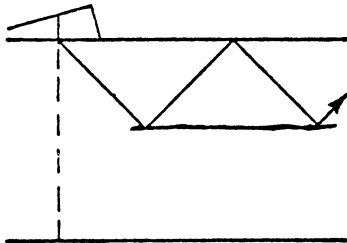


FIG. 10 Laminar

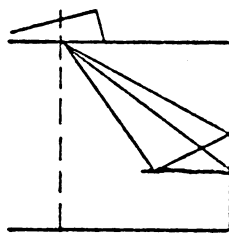


FIG. 11 Edge Lamination

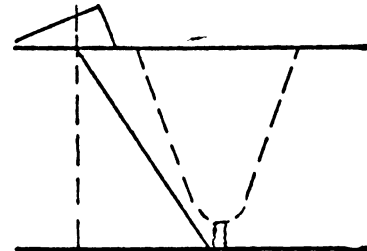


FIG. 12 Incomplete Penetration

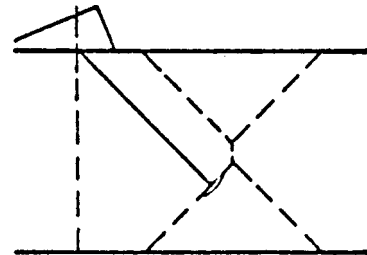


FIG. 13 Incomplete Fusion

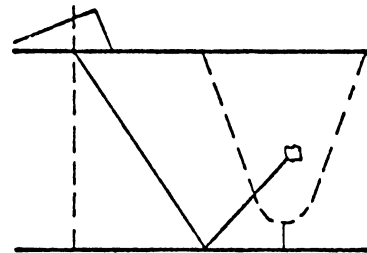


FIG. 14 Slag and Porosity

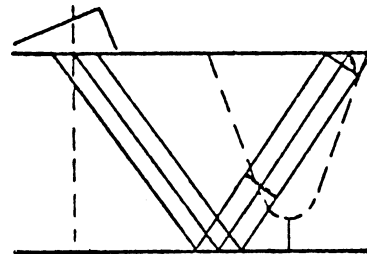


FIG. 15 Cracks

6. Apparatus

6.1 A complete ultrasonic system shall include the following:

6.1.1 *Instrumentation*—The ultrasonic instrument shall be capable of generating, receiving, amplifying, and displaying high-frequency electrical pulses.

6.1.2 *Search Units*—The ultrasonic search units shall be capable of transmitting and receiving ultrasonic waves in the material at frequencies and energy levels necessary for discontinuity detection as determined by the standardization procedure. The search units are fitted with wedges in order to transmit ultrasonic waves into the examination object at the desired angle and mode of operation.

6.1.3 *Couplant*—A couplant, usually a liquid or semiliquid, is required between the face of the search unit and the

examination surface to permit the transmission of ultrasonic waves from the search unit into the material under examination. Typical couplants include glycerin, water, cellulose gel, oil, water-soluble oils, and grease. Corrosion inhibitors or wetting agents or both may be used. Couplants must be selected that are not detrimental to the product or the process. The couplant used in standardization should be used for the examination. The standardization and examination surface temperatures should be within $\pm 25^{\circ}\text{F}$ (14°C) to avoid large attenuation and velocity differences in the wedge material.

6.1.3.1 The coupling medium should be selected so that its viscosity is appropriate for the surface finish of the material to be examined. The examination of rough surfaces generally requires a high-viscosity couplant. The temperature of the material's surface can change the couplant's viscosity. As an example, in the case of oil and greases, see Table 1.

TABLE 1 Suggested Viscosities—Oil Couplants

NOTE 1—The table is a guide only and is not meant to exclude the use of a particular couplant that is found to work satisfactorily on a particular surface.

Approximate Surface Roughness Average (Ra μ in.)	Equivalent Couplant Viscosity, weight motor oil
5 to 100	SAE 10
50 to 200	SAE 20
100 to 400	SAE 30
250 to 700	SAE 40
Over 1000	cup grease

6.1.3.2 At elevated temperatures (above 125°F (52°C), heat-resistant coupling materials such as silicone oils, gels, or greases should be used. Further, intermittent contact of the search unit with the surface or auxiliary cooling of the search unit may be necessary to avoid temperature changes that affect the ultrasonic wave transmission properties of the wedge material or the characteristics of the transducer. At higher temperatures, certain couplants based on inorganic salts or thermoplastic organic materials, high-temperature wedge materials, and transducers that are not damaged by high temperatures, may be required.

6.1.3.3 Where constant coupling over large areas is needed, as in automated examination, or where severe changes in surface roughness are found, other couplings such as liquid-gap coupling will usually provide a better examination. In this case, the search unit face does not contact the examination surface but is spaced from it a distance of about 0.02 in. (0.5 mm) by integral rails or a fixture. Liquid flowing through the search unit fills the gap. The flowing liquid provides the coupling path and has the additional advantage of keeping the search unit temperature low if the examination surface is hot.

6.1.3.4 An alternative means of direct contact coupling is provided by the wheel search unit. The transducer is mounted at the required angle to a stationary axle about which rotates a liquid-filled flexible tire. A minimum amount of couplant provides ultrasonic transmission into the examination surface since the elastic tire material is in rolling contact and conforms closely to the surface.

6.1.4 *Reference Reflectors*—Reference reflectors of known dimension, artificial reflectors, or distance-amplitude relationships of known reflector sizes for a particular search unit and material may be used for standardization. The artificial reflectors may be in the form of side-drilled holes, notches, or flat-bottom holes. The reference standard and the production material should have similar velocity, attenuation, curvature, and surface finish.

7. Standardization

7.1 If quantitative information is to be obtained, vertical or horizontal linearity or both should be checked in accordance with Practice E 317 or another procedure approved by the examining agency and the customer. An acceptable linearity performance may be agreed upon between the examining agency and the customer.

7.2 Prior to examination, standardize the system in accordance with the product specification.

7.2.1 Angle-Beam Longitudinal and Shear Waves.

7.2.1.1 *Distance Standardization*—To locate reflectors accurately within the production item, a distance standardization is recommended, either in terms of the component's dimensions or the beam path. Reflections from concentric cylindrical surfaces, such as provided by some IIW blocks and the AWS distance reference block, may be used to adjust sweep range and delay. However, if the part has suitable geometry, the part provides a more reliable standardization. Where the inspection zone includes the full volume between parallel surfaces, it is recommended that at least one Vee path be marked on the screen when examining in one direction or at least one-half Vee path when examining (from surface to surface) in two directions.

7.2.1.2 *Amplitude Standardization*—Amplitude standardization (gain) is generally established on one or more reference reflectors such as side-drilled holes parallel to the major surfaces of the article being inspected and perpendicular to the sound path, flat-bottom holes drilled at the testing angle and equal radius reflectors. Surface notches can also accomplish this end under some circumstances. The reflector indication can be used to adjust the gain control in the desired level for detecting the minimum size reflector. For quantitative evaluation, distance amplitude correction may be performed electronically, by drawing a distance amplitude correction (DAC) curve on the screen, or by the use of charts and curves showing the relationship of amplitude and distance for a particular search unit and material. Unless otherwise stated, the gain should be adjusted to provide an 80 % of full screen (as long as it is within the linearity limit) maximum indication from the reference reflector.

7.2.1.3 Often the same reference reflector can be used for both distance and amplitude standardization. An example for low-attenuation material using a single side-drilled hole at a depth of $T/4$ is shown in Fig. 16. Move the reflector through the beam to $1/8$, $3/8$, $5/8$, $7/8$, and $9/8$ of the Vee path. Adjust delay to place indication 1 at sweep division 1. Adjust range to place indication 9 at sweep division 9. Since these controls interact, repeat the delay and range adjustments until indications 1 and 9 are placed at sweep divisions 1 and 9. Adjust gain to provide an 80 % of full-screen indication from the highest of the 1, 3, 5, 7, or 9 indications. At this gain, mark the maximum amplitudes on the screen from the reflector at 1, 3, 5, 7, and 9. Connect these points for the distance amplitude correction (DAC) curve or compensate electronically if equivalency can be demonstrated. Corner reflections from the hole to the surface may be observed at about 4 and 8 divisions on the sweep. These indications will not be used in the distance amplitude correction (DAC) curve. Measure position of the reflector on the surface from the front of the search unit (or the beam centerline projection on the side of the wedge) to the surface projection of the hole. Since the depth to the hole is known, the standardization provides means for estimating the position, depth, and relative response of an unknown reflector.

7.2.2 Surface-Beam Rayleigh Waves.

7.2.2.1 *Distance Standardization*—Since this is a surface examination technique, an abrupt change in surface geometry is necessary for use as a reference for distance standardization

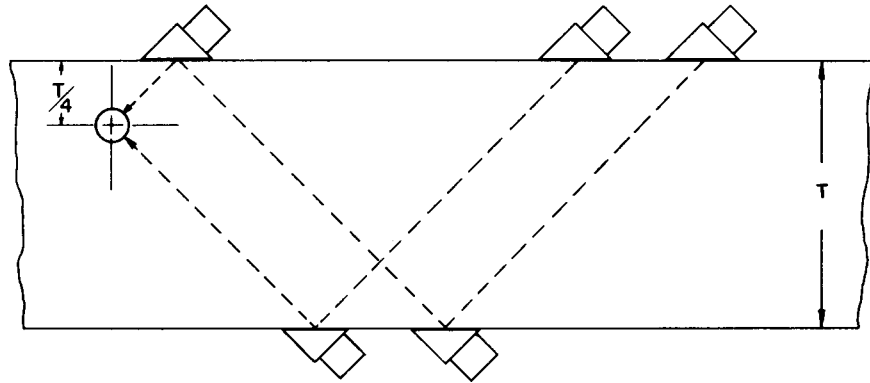
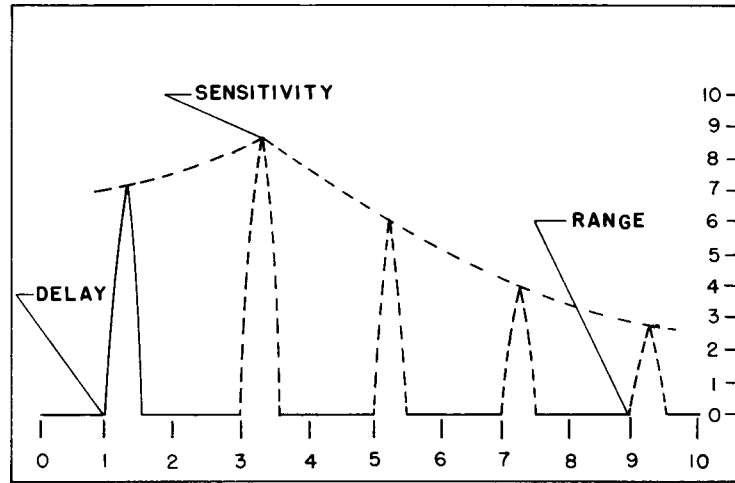


FIG. 16 Standardization

(that is, corner, square notch, etc.). The sweep (time trace) on screen should be standardized for distance from the search unit to the reference reflector.

7.2.2.2 *Amplitude Standardization*—Depth of penetration of Rayleigh waves is frequency-dependent. The ordering data shall state the maximum allowable depth discontinuity that can then be used as the reference reflector. The examination frequency (f) should approximately equal the Rayleigh wave velocity (VR) in the material divided by four times the standardization reference reflector depth (d) as follows:

$$f \cong \frac{VR}{4(d)}$$

NOTE 2—Example: The reference reflector depth is 0.013 in. (0.33 mm) in a material having a Rayleigh wave velocity (VR) of 0.118 in./ μ s (3.00 mm/ μ s):

$$f \cong \frac{VR}{4(d)}$$

$$f \cong \frac{0.118 \text{ in./}\mu\text{s}}{4(0.013 \text{ in.})}$$

$$f \cong 2.27 \text{ cycles/}\mu\text{s.}$$

or 2.27 MHz. This frequency will produce a beam with sufficient depth of penetration to give higher amplitudes from reflectors with greater depths.

7.2.3 *Lamb Waves* (may be produced in sheet or tubing).

7.2.3.1 *Distance Standardization*—If the angle of incidence of a sound beam is adjusted (by using a variable-angle contact search unit or by varying the angle in an immersed examination) so that the wave front intersection velocity of the incident longitudinal wave is equal to the phase velocity of a particular type and mode of a Lamb wave, the Lamb wave can be generated in the sheet or tube. The phase velocities of the various modes of the asymmetrical and symmetrical waves depend upon the frequency of the ultrasonic wave and the thickness of the material. Therefore, it is necessary that the reference standard be similar to the item under examination. The desired reference discontinuity may be either a thickness differential or a discontinuity reflector. The Lamb wave travels at its group velocity, which is different for each mode and is different from the phase velocity. The sweep (time trace) on the screen should be standardized for distance from the search unit to the reference reflector.

7.2.3.2 *Amplitude Standardization*—The ordering data shall state the maximum allowable discontinuity that can then be used as the reference standard. A suitable Lamb-wave type and mode shall be chosen in order to obtain a reference indication from the reference reflector.

8. Procedure

8.1 Angle-beam examinations are generally performed by using the angle-beam longitudinal wave or the angle-beam shear wave technique.

8.2 *Angle-Beam Longitudinal Wave*—When the geometry of the part or orientation of the flaws requires a beam angle of 1 to 40°, angle-beam longitudinal waves should be used. Angle-beam shear waves between 1 and 40° generally should not be used because a higher amplitude angle-beam longitudinal wave may coexist and confuse the examination. In the 1 to 40° beam angle range, angle-beam longitudinal waves will give higher amplitudes than the coexisting lower angle shear waves. Three subgroups may be identified within this group: single transducer; parallel beam, dual transducer; and crossed beam, dual transducer search units.

8.2.1 *Single-Transducer Search Units*— When the angle of the major reflecting face of the expected flaw is known, the examination beam angle should be perpendicular to that face. Scan the material so that the beam is perpendicular to the major face of the flaw in areas where the flaw may be present.

8.2.1.1 The beam angle for detecting fatigue cracks in solid shafts from the end, as shown in Fig. 17, may be computed as follows:

$$\phi_2 = \arctan \frac{A + B}{C}$$

Perform the examination by directing the beam through the shaft centerline to the suspected crack area while moving the search unit around the examination circle.

8.2.1.2 The beam angle for detecting fatigue cracks in hollow shafts from the end, as shown in Fig. 18, may be computed as follows:

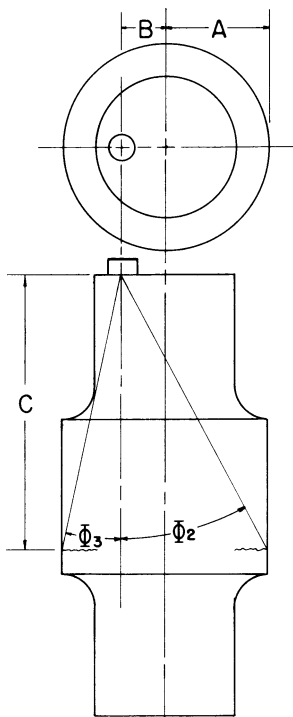


FIG. 17 Shaft

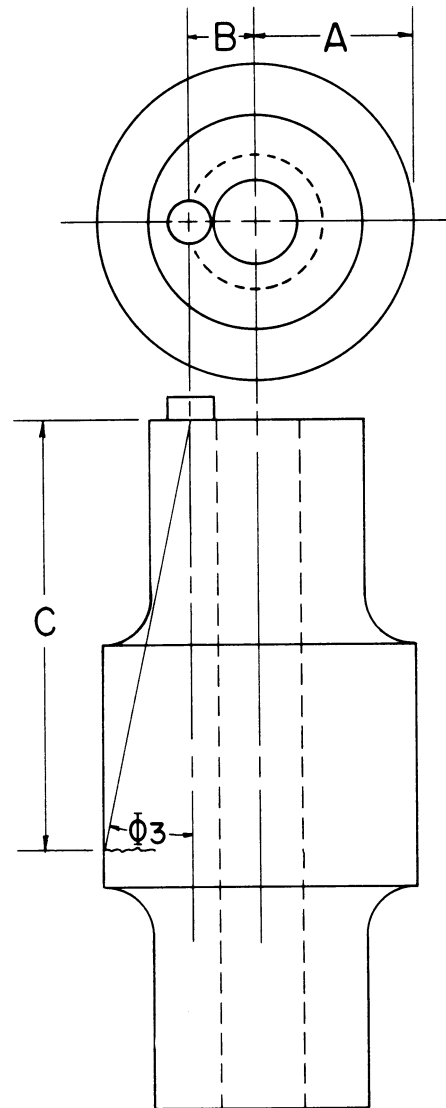


FIG. 18 Shaft

$$\phi_3 = \arctan \frac{A - B}{C}$$

Perform the examination by directing the beam from the end of the shaft to the suspected crack area while moving the search unit around the examination circle.

8.2.2 *Parallel-Beam, Dual-Transducer Search Units*— When metal paths to the reflector are short, separate transmitter and receiver search units or dual-transducer search units may be used to eliminate wedge noise. In the dual-transducer search unit, the transmitter transducer and wedge are separated from the receiver transducer and wedge by material that reduces crosstalk. The beam directions of the transmitter and receiver will be essentially parallel. Except for operation of the instrument in the through transmission mode, application of these search units is similar to that described in 8.2.1.

8.2.3 *Crossed-Beam, Dual-Transducer Search Units*— These search units are assembled so that the beams cross directly under the examination surface and provide improved near-surface resolution. The range of depth that can be examined with these search units depends on the transducer size and

beam angle. Except for improved near-surface resolution, possibly limited depth range, the extra care required for depth standardization, and operation of the instrument in the through transmission mode, application of these search units is similar to straight-beam examination as described in Practice E 114.

8.3 *Angle-Beam Shear Wave*—Angle-beam shear wave examinations are generally performed using the single transducer search unit technique. The principles involved in this technique are illustrated in Fig. 16. The side of the drilled hole provides a cylindrical reflector similar to a slag inclusion. Other flaws and flaw orientations are possible. It is imperative, therefore, that a study be made of the anticipated flaws to determine the most likely orientation so that the ultrasonic beam may be directed to produce reflections. Often a number of beam directions or a rotational aiming of the beam will be needed if flaw orientation can be random. Inclusions of voids that are rough, irregular, or spherical provide multidirectional reflections and require less aiming of the beam. Cracks due to stress, incomplete fusion welds, etc., can be expected to be at right angles to the stress or to lie in the plane of the weld preparation face. Materials that have been rolled, forged, or otherwise formed in the solid state may exhibit cracks at right angles to the stress (direction of flow) or laminations in a plane parallel to the examination surface.

8.4 *Scanning*—Manipulate the search unit with respect to the specimen such that the ultrasonic beam interrogates the entire volume of the specimen requiring examination. Unless otherwise stated, identify the peak indications only.

9. Examination Data Record

9.1 The following data should be recorded during each examination.

9.1.1 Part identification and date of examination.

9.1.2 Operator's name and (if certified) level.

9.1.3 Instrument description, make, model, and serial number.

9.1.4 *Setup*—Couplant, cable length, cable type, and manual/automatic scanning.

9.1.5 *Search Unit Description*—Type, frequency, transducer size, wedge, and beam mode of vibration.

9.1.6 Reference standards and standardization data required to duplicate the examination.

9.1.7 Indication information as required by the applicable specification or results of the examination (number, identity or probable type, size, and location of discontinuities).

10. Interpretation of Results

10.1 Reflector position and amplitude should be determined at reference gain.

10.2 Reflections may be caused by the geometry of the part, for example, corners, surface concavity or convexity, and other surface contours which reflect ultrasonic waves to the search unit. Geometric indications should be identified.

10.3 Advance agreement should be made between the supplier and purchaser regarding the interpretation of the results of the examination and what data will be stored. Indications that are not identified as geometric and that exceed the rejection level shall be rejected unless it is agreed by the customer or determined from the part drawing that the defects will not remain in the finished part.

11. Report

11.1 The report shall include the information agreed upon between the purchaser and the manufacturer.

12. Keywords

12.1 angle beam; contact ultrasonic method; lamb waves; longitudinal waves; nondestructive examination; Rayleigh waves; shear waves; ultrasonic examination

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