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Standard Practice for Ultrasonic Examination of Steel with Convex Cylindrically Curved Entry Surfaces[1]

This standard is issued under the fixed designation E 1315; 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 describes the selection of single-element hard-face ultrasonic search units for which flat-entry-surface reference blocks can be used for examination of steel with convex cylindrically curved entry surfaces.

1.2 The scope of this practice includes the determination of search unit characteristics and radius of surface curvature of the material for which no gain correction is required, or, if a larger search unit is used, the computation of the additional gain required to allow standardization with a flat reference block and examination on a curved surface.

1.3 This practice is intended for use during contact examination of convexly curved steel material using round flat face, piezoelectric search units for longitudinal ultrasonic wave generation in the frequency range from 1 to 10 MHz.

1.4 *This standard does not purport to address all of the safety problems, 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 1316 Terminology for Nondestructive Examinations[2]

3. Terminology

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

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *critical radius, Rc*—Smallest radius of curvature of the material that can be examined without a correction for curvature. The critical radius is calculated from properties of the search unit, couplant and material under examination. Values of *Rc* for various conditions can be determined from the equations in Annex A1.

3.2.2 *Discussion*—For contact examination using search units with flat wearfaces on convex surfaces, the width, *W*, refers to the width of the ultrasonic beam generated by the search unit.

4. Summary of Practice

4.1 Three effects are produced by placing a flat faced search unit on a cylindrically curved convex surface:

4.1.1 *Cylindrical Plano*—A concave lens formed by the couplant defocuses the ultrasonic beam, reducing amplitude at the discontinuities.

4.1.2 Rays from the search unit strike the curved surface at non-normal incidence, producing a shear wave as well as a longitudinal wave. The shear wave extracts energy that could otherwise be used in the longitudinal component.

4.1.3 Except at the line of contact between the search unit and the curved surface, a finite varying thickness of couplant exists. This couplant layer transforms the impedance of the material undergoing examination, so that the impedance looking into the couplant no longer matches the search unit impedance. The impedance mismatch reduces the energy entering the curved surface.[3]

4.2 Of the three effects, the first two are negligible for typical search units, surface curvatures and properties of the couplant, search unit wearface and material being examined. The third effect predominates: a couplant layer $\lambda/20$ in thickness can result in an amplitude decrease of 50 % in the material being examined. Where the curvature and search unit size create a couplant thickness at diametrically opposite edges of the search unit that greatly exceeds $\lambda/20$, the ultrasound is effectively not transmitted. The effective transducer width is reduced, the total energy is reduced, and because of the reduced effective width, the beam spread increases.

5. Significance and Use

5.1 Standardization of ultrasonic equipment for examination of steel having surfaces with curved surfaces generally requires instrument standardization on reference blocks of similar

[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.06 on Ultrasonic Method.

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

[3] Substantial discussion of the basis of this practice is given in: Birchak, J. R. and Serabian, S., “Calibration of Ultrasonic Systems for Inspection from Curved Surfaces,” *Materials Evaluation*, Vol 36, January 1978, p. 39.

radius of curvature, surface finish, and material properties. A standardization procedure using flat-entry reference blocks and conventional round search units can result in equipment amplification errors if corrections are not made for the radius of curvature. This procedure restricts the ultrasonic examiner (operator) to conditions in which search units will respond the same on flat and convexly curved entry surfaces.

5.2 This practice introduces a test parameter called the critical radius of curvature, *Rc*. For surface radius, *R*, larger than *Rc*, errors due to curvature are less than 2.5 dB, and the system can be standardized directly from flat reference blocks. The ultrasonic examiner obtains *Rc* from tables (or equations) given in this practice.

5.3 When a search unit is selected so that *Rc* and *R* are equal, then even at the edge of the search unit where couplant thickness is greatest, some contribution is being made to the ultrasonic field. Standardization may be performed on a flat reference block and errors caused by cylindrical curvature will be no more than 2.5 dB.

5.4 For *R* less than *Rc*, standardization with flat reference blocks is permissible only if a gain-correction factor can be used. A correction factor is described in Annex A2 for examinations using round contact search units on cylindrically convex surfaces in the far field of the sound beam.

6. Examination Conditions

6.1 The successful application of this practice is based on several assumptions. They are as follows:

6.1.1 The examiner knows the measured search unit band center frequency and the size and shape of the transducer element. If the band center frequency is not known, the nominal frequency can be used, but accuracy may be reduced.

6.1.2 For contact examination, the viscosity of the couplant must be sufficient to completely fill the gap between the active region of the search unit wearface and the curved specimen.

6.1.3 The surface finish and material properties of the reference block are comparable to the surface finish and properties of the material being examined.

7. Apparatus

7.1 Commercially available ultrasonic equipment is applicable to this practice. No special modifications or specialized equipment are required.

8. Procedure

8.1 Select a search unit for which the critical (that is, minimum) radius of curvature is smaller than the radius of curvature of the test component.

8.2 The calculated values of *Rc* for specific search units are given in Table 1. For contact examination, *Rc* is given for search units having hard wearfaces; hard implies a wearface acoustic impedance more than four times that of the couplant.

8.3 If the combination of parameters used for the tables are not appropriate to the search unit, refer to Annex A1 and calculate the critical radius from the equations in paragraphs A2.1.1 or A2.1.2.

NOTE 1—When $Rc > R$ for all available search units, Annex A1 may be applicable.

8.4 Perform conventional instrument standardization on a flat-entry-surface reference block.

8.5 The instrument is now standardized for examination on curved surfaces having $R \geq Rc$.

9. Keywords

9.1 contact; curved surface; nondestructive examination; steel; ultrasonic examination

TABLE 1 Minimum Specimen Radius (*Rc*) for Contact Ultrasonic Examination Using Search Units with Hard Wearfaces

NOTE 1—Dimensions may be converted to centimetres by multiplying by 2.54.

NOTE 2—Calculations assume aluminum oxide wearface, glycerine couplant, steel surface, and longitudinal waves at normal incidence.

Transducer Diameter, in.	Minimum Radius of Curvature, in.			
	1 MHz Search Units	2.25 MHz Search Units	5.0 MHz Search Units	10 MHz Search Units
0.125	0.7	1.6	3.6	7.1
0.1875	1.6	3.6	8.0	16.0
0.25	2.8	6.4	14.2	28.4
0.375	6.4	14.4	31.9	63.9
0.500	11.4	25.6	56.8	114
0.750	25.6	57.5	128	256
1.000	45.5	102.3	227	455
1.125	57.5	129.5	288	575

ANNEXES

(Mandatory Information)

A1. CALCULATION OF CRITICAL RADIUS

A1.1 *Contact Examination, Hard Wearfaces*—When a large circular contact search unit is placed on a surface having a small radius of curvature, the thick couplant at the edges of the search unit causes impedance transformations. This produces impedance mismatches and reduces transmission of ultrasonic energy. The effective contact area becomes a small rectangular region in which the couplant layer is thin. For smaller search units, these edge effects become smaller. The definition of *Rc* was selected empirically so that the net reduction of search unit coupling due to edge effects equals 2.5 dB when the radius of the material examined equals the critical radius. For contact examinations within the scope of this practice:

$$Rc \simeq \frac{0.45\, f\, W^2\, (Zt/Zc)}{Vc\,(1 + Zt/Zm)} \text{ in. (cm)}$$

where:

f = frequency, Hz,
W = search unit beam diameter, in. (cm),
Zt = acoustic impedance of search unit wearface,
Zc = acoustic impedance of couplant ($Zc > Z_t/4$),
Zm = acoustic impedance of examination material, and
Vc = acoustic velocity of couplant, in./s (cm/s).

A1.2 *Material Properties*—Table A1.1 lists material properties that can be used to calculate the critical radius for examination conditions not covered in Table 1.

TABLE A1.1 Acoustic Properties of Materials

Material	Velocity (cm/s × 10^5)	Velocity (in./s × 10^5)	Acoustic Impedance (g/cm^2 s × 10^5)
Couplants	*Vc*	*Vc*	*Zc*
Glycerine	1.9	0.75	2.5
Motor Oil (SAE 30)	1.7	0.66	1.5
Water	1.5	0.59	1.5
Kerosene	1.3	0.52	1.1
Search Unit Wear Surface Materials			*Zt*
Aluminum Oxide	8.76	3.45	31.2
Quartz	5.8	2.3	15
Polymethyl methacrylate	2.7	1.1	3.2
Examination Material			
Steel	5.9	2.3	46
Steel (Shear Wave)	3.2	1.3	25

A2. APPLYING CORRECTION FACTORS TO THE CONTACT ULTRASONIC EXAMINATION OF STEEL HAVING CONVEX CYLINDRICALLY CURVED ENTRY SURFACES

A2.1 *Introduction*—This method uses correction factors to transfer ultrasonic system sensitivity levels from a flat-entry-surface reference block to a cylindrically curved specimen. This procedure is recommended only if the operator does not have a suitable contact search unit available with *Rc* less than *R*.

A2.2 *Significance and Use*—This procedure applies to contact examination using circular search units for which the specimen radius of curvature, *R*, is smaller than the critical radius listed in Table 1 or derived in Annex A2. The correction factor is defined to be the extra gain required to compensate for curvature after standardization on a flat reference block. The correction factor shown in Figure applies only to flaw detection in the far field of the sound beam.

A2.3 *Examination Conditions:*

A2.3.1 The successful application of this method is based on several assumptions that have either been experimentally confirmed or are relatively easy to implement. They are as follows:

A2.3.1.1 The examiner (operator) knows the measured operational parameters of search unit center frequency and width or diameter. If the frequency has not been measured, the nominal frequency may be used but perhaps with reduced accuracy.

A2.3.1.2 The surface finish and material properties of the reference block are similar to the surface finish and properties of the material being examined.

A2.3.1.3 The search unit wear surface is flat and has not been shaped to the contour of the examination material.

A2.3.1.4 Correction factors apply only to examinations using the far field of the search unit.

A2.4 *Standardization*—Fig. A2.1 shall be used to obtain the appropriate correction factor for any cylindrically convex surface. The normalized curvature (*R/Rc*) must be calculated first.

A2.5 *Procedure:*

A2.5.1 Use Table 1 to determine the critical radius for the particular search unit diameter and frequency to be used for the examination. If the combination of parameters used in the table

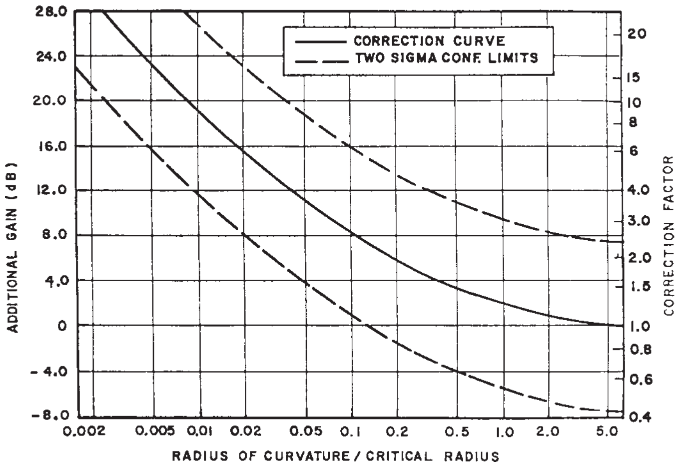

FIG. A2.1 Correction Factor (Extra Gain After Standardization on Flat Surface) for Examination of Cylindrically Convex Surfaces (Far Field Only)

are not appropriate to the search unit, refer to Table A1.1 and calculate the critical radius from the equations in paragraphs A1.1.1 or A1.1.2.

A2.5.2 Calculate the ratio of material radius to critical radius (*R/Rc*).

A2.5.3 Determine from Fig. A1.1 the correction factor (*C*) from the normalized curvature (*R/Rc*). The factor (*C*) is the amount of receiver gain that must be added to equate curved surface standardization to flat-surface standardization.

A2.5.4 Adjust the ultrasonic instrument gain to obtain the desired response from the flat surfaced steel block reflector(s). Add the amount of gain (*C*) determined in A2.5.3. The instrument is now adjusted to the appropriate amplification for examination on the curved surface of radius, *R*.

A2.6 *Precision of Method*—The correction curve of Fig. A1.1 was determined empirically. The two sigma confidence limits determined from nearly 2500 measurements are shown as dotted lines on Fig. A2.1. The use of a Vee-block holder, to maintain a diameter of the search unit as the line of contact with the cylindrically curved surface, will reduce the scatter.