Designation: ~~E797/E797M – 15~~ E797/E797M – 21

Standard Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method[1]

This standard is issued under the fixed designation E797/E797M; 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[2] provides guidelines for measuring the thickness of materials using the contact pulse-echo method at temperatures not to exceed ~~93°C [200°F].~~93 °C [200 °F].

1.2 This practice is applicable to any material in which ultrasonic waves will propagate at a constant velocity throughout the part, and from which back wall reflections can be obtained and resolved.

1.3 This practice is primarily for flat components with parallel surfaces and has limited applicability for components with non-parallel or concentric surfaces per 1.2.

1.4 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system ~~may~~are not ~~be~~necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the ~~other. Combining~~other, and values from the two systems ~~may result in non-conformance with the standard.~~shall not be combined.

1.5 *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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

E317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments
E494 Practice for Measuring Ultrasonic Velocity in Materials by Comparative Pulse-Echo Method
E543 Specification for Agencies Performing Nondestructive Testing
E1316 Terminology for Nondestructive Examinations

[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] For ASME Boiler and Pressure Vessel Code applications, see related Practice SE-797 in Section II of that Code.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard

2.2 *ASNT Documents:*[4]
Nondestructive Testing Handbook, 2nd Edition, Vol 7
SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing
ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 ~~*Aerospace Industries Association*~~ *AIA Document:*[5]
NAS-410 Certification and Qualification of Nondestructive Testing Personnel

2.4 *ISO Standard:*[6]
ISO 9712 Non-Destructive Testing—Qualification and Certification of NDT Personnel

3. Terminology

~~3.1 *Definitions: Definitions*—For definitions of terms used in this practice, refer to Terminology E1316.~~

3.1 *Definitions*—For definitions of terms used in this practice, refer to Terminology E1316.

4. Summary of Practice

4.1 Thickness (*T*), when measured by the pulse-echo ultrasonic method, is a product of the velocity of sound in the material and one half the transit time (round trip) through the material.

$$T = \frac{Vt}{2}$$

where:

T = thickness,
~~V = velocity, and~~
t = transit time.

T = Component thickness,
V = Sound velocity in the material, and
t = Sound path transit time.

4.2 The pulse-echo ultrasonic instrument measures the transit time of the ultrasonic pulse through the part.

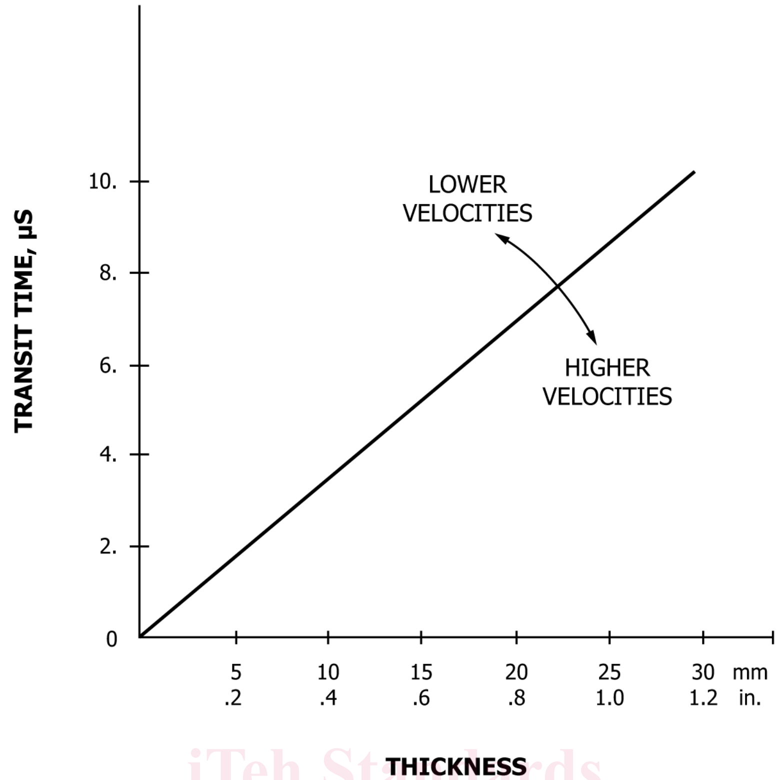
4.3 The velocity in the material being examined is a function of the physical properties of the material. It is usually assumed to be a constant for a given class of materials. Its approximate value can be obtained from Table X3.1 in Practice E494 or from the *Nondestructive Testing Handbook*, or it can be determined empirically.

4.4 One or more reference blocks are required having known velocity, or of the same material to be examined, and having thicknesses accurately measured and in the range of thicknesses to be measured. It is generally desirable that the thicknesses be "round numbers" rather than miscellaneous odd values. One block should have a thickness value near the maximum of the range of interest and another block near the minimum thickness.

4.5 The display element (A-scan display, meter, or digital display) of the instrument must be adjusted to present convenient values of thickness dependent on the range being used. The control for this function may have different names on different instruments, including *range, sweep, material standardize*, or *velocity*.

4.6 The timing circuits in different instruments use various conversion schemes. A common method is the so-called time/analog conversion in which the time measured by the instrument is converted into a proportional d-c voltage which is then applied to the readout device. Another technique uses a very high-frequency oscillator that is modulated or gated by the appropriate echo indications, the output being used either directly to suitable digital readouts or converted to a voltage for other presentation. A relationship of transit time versus thickness is shown graphically in Fig. 1.

[4] Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, http://www.asnt.org.
[5] Available from Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, http://www.aia-aerospace.org.
[6] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.



NOTE 1—Slope of velocity conversion line is approximately that of steel.

FIG. 1 Transit Time/Thickness Relationship

5. Significance and Use

5.1 The techniques described provide indirect measurement of thickness of sections of materials not exceeding temperatures of ~~93°C [200°F].~~ 93 °C [200 °F]. Measurements are made from one side of the object, without requiring access to the rear surface.

5.2 Ultrasonic thickness measurements are used extensively on basic shapes and products of many materials, on precision machined parts, and to determine wall thinning in process equipment caused by corrosion and erosion.

5.3 Recommendations for determining the capabilities and limitations of ultrasonic thickness gages for specific applications can be found in the cited references.[7,8]

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this practice.

6.2 *Personnel Qualification:*

6.2.1 If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, NAS-410, ISO 9712, 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.

6.3 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Specification E543. The applicable edition of Specification E543 shall be specified in the contractual agreement.

[7] Bosselaar, H., and Goosens, ~~J.C.J.,~~ J. C. J., "Method to Evaluate Direct-Reading Ultrasonic Pulse-Echo Thickness Meters," *Materials Evaluation*, March 1971, pp. 45–50.

[8] Fowler, K.A., Elfbaum, ~~G.M.,~~ G. M., Husarek, V., and Castel, J., "Applications of Precision Ultrasonic Thickness Gaging," *Proceedings of the Eighth World Conference on Nondestructive Testing*, Cannes, France, Sept. 6–11, 1976, Paper 3F.5.

6.4 *Procedures and Techniques*—The procedures and techniques to be utilized shall be as specified in the contractual agreement.

6.5 *Surface Preparation*—The pre-examination surface preparation criteria shall be specified in the contractual agreement.

7. Apparatus

7.1 *Instruments*—Thickness-measurement instruments are divided into three groups: (*1*) ~~Flaw~~flaw detectors with an A-scan display readout, (*2*) ~~Flaw~~flaw detectors with an A-scan display and direct thickness readout, and (*3*) ~~Direct~~direct thickness readout.

7.1.1 Flaw detectors with A-scan display readouts display time/amplitude information. Thickness determinations are made by reading the distance between the zero-corrected (pulse triggered or delay controlled) initial pulse and first-returned echo (back wall reflection), or between multiple-back ~~reflection echoes,~~wall reflections, on a standardized base line of the A-scan display. The base line of the A-scan display should be adjusted for the desired thickness increments.

7.1.2 Flaw detectors with numeric readout are a combination pulse ultrasound flaw detection instrument with an A-scan display and additional circuitry that provides digital thickness information. The material thickness can be electronically measured and presented on a digital readout. The A-scan display provides a check on the validity of the electronic measurement by revealing measurement variables, such as internal discontinuities, or echo-strength variations, which might result in inaccurate readings.

7.1.3 Thickness readout instruments are modified versions of the pulse-echo instrument. The elapsed time between the initial pulse and the first echo or between multiple echoes is converted into a meter or digital readout. The instruments are designed for measurement and direct numerical readout of specific ranges of thickness and materials.

7.1.4 Time-base linearity is required so that a change in the thickness of material will produce a corresponding change of indicated thickness. If an A-Scan display is used as a readout, its horizontal linearity can be checked by using Practice E317.

7.2 *Search Units*—Most pulse-echo type search units (straight-beam contact, delay line, and dual element) are applicable if flaw detector instruments are used. If a thickness readout instrument has the capability to read thin sections, a highly damped, high-frequency search unit is generally used. High-frequency (10 MHz or higher) delay line search units are generally required for thicknesses less than about 0.6 mm [0.025 in.]. Measurements of materials at high temperatures require search units specially designed for the application. When dual element search units are used, their inherent nonlinearity usually requires special corrections for thin sections. (See Fig. 2 and Fig. X2.1.) For optimum performance, it is often necessary that the instrument and search units be matched.

7.3 *Standardization Blocks*—The general requirements for appropriate standardization blocks are given in 4.4, 8.1.3, 8.2.2.1, 8.3.2, and 8.4.3. Multi-step blocks that may be useful for these standardization procedures are described in Appendix X1 (Figs. X1.1 and X1.2).

8. Standardization of Apparatus

8.1 *Case I—Direct Contact, Single-Element Search Unit:*

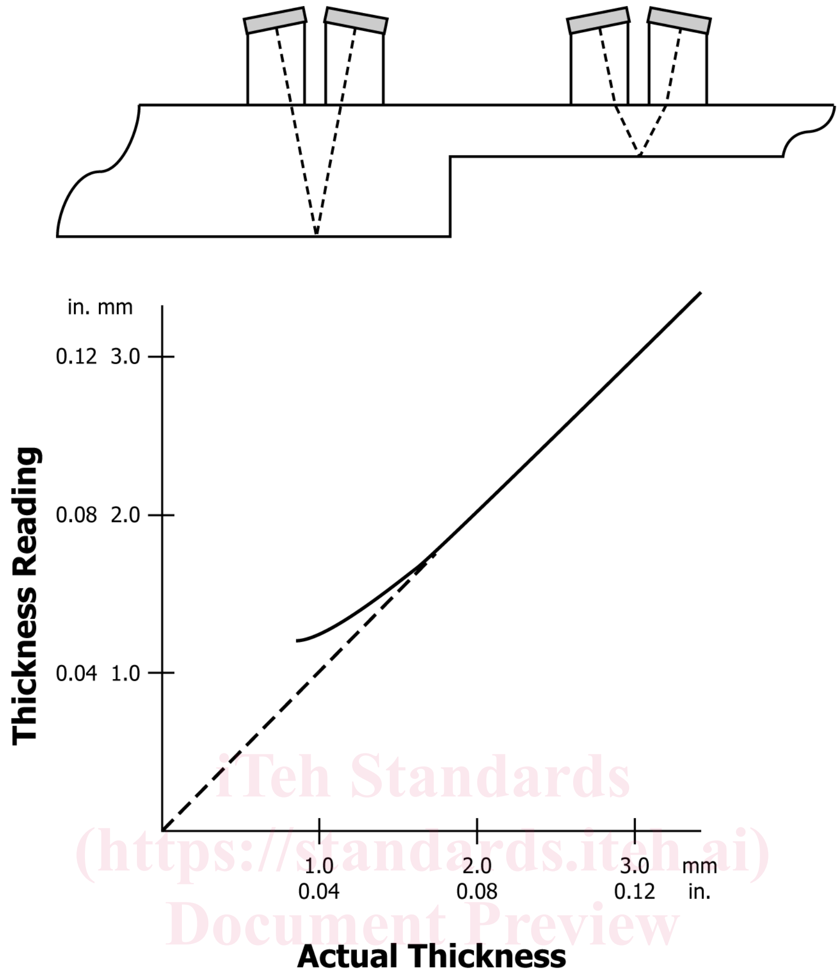
8.1.1 *Conditions*—The display start is synchronized to the initial pulse. All display elements are linear. Full thickness is displayed on the A-scan display.

8.1.2 Under these conditions, we can assume that the velocity conversion line effectively pivots about the origin (Fig. 1). It may be necessary to subtract the wear-plate time, requiring minor use of delay control. It is recommended that standardization blocks providing a minimum of two thicknesses that span the thickness range be used to check the full-range accuracy.

8.1.3 Place the search unit on a standardization block of known thickness with suitable couplant and adjust the instrument controls (material standardization, range, sweep, or velocity) until the display presents the appropriate thickness reading.

8.1.4 The readings should then be checked and adjusted on standardization blocks with thickness of lesser value to ~~improve~~verify the overall accuracy of the system.

8.2 *Case II—Delay Line Single-Element Search Unit:*



(*a*) Proportional sound path increases with decrease in thickness.
(*b*) Typical reading error values.

FIG. 2 Dual Transducer Nonlinearity

8.2.1 *Conditions*—When using this search unit, it is necessary that the equipment be capable of correcting for the time during which the sound passes through the delay line so that the end of the delay can be made to coincide with zero thickness. This requires a so-called "delay" control in the instrument or automatic electronic sensing of zero thickness.

8.2.2 In most instruments, if the material standardize circuit was previously adjusted for a given material velocity, the delay control should be adjusted until a correct thickness reading is obtained on the instrument. However, if the instrument must be completely standardized with the delay line search unit, the following technique is recommended:

8.2.2.1 Use at least two standardization blocks. One should have a thickness near the maximum of the range to be measured and the other block near the minimum thickness. For convenience, it is desirable that the thickness should be "round numbers" so that the difference between them also has a convenient "round number" value.

8.2.2.2 Place the search unit sequentially on one and then the other block, and obtain both readings. The difference between these two readings should be calculated. If the reading thickness difference is less than the actual thickness difference, place the search unit on the thicker specimen, and adjust the material standardize control to expand the thickness range. If the reading thickness difference is greater than the actual thickness difference, place the search unit on the thicker specimen, and adjust the material standardize control to decrease the thickness range. A certain amount of over correction is usually recommended. Reposition the search unit sequentially on both ~~blocks,~~blocks and note the reading differences while making additional appropriate corrections. When the reading thickness differential equals the actual thickness differential, the material thickness range is correctly adjusted. A single adjustment of the delay control should then permit correct readings at both the high and low end of the thickness range.

8.2.3 An alternative technique for delay line search units is a variation of that described in 8.2.2. A series of sequential adjustments are made, using the "delay" control to provide correct readings on the thinner standardization block and the "range" control to correct the readings on the thicker block. Moderate over-correction is sometimes useful. When both readings are "correct" the instrument is adjusted properly.

8.3 *Case III—Dual Search Units:*

8.3.1 The method described in 8.2 (Case II) is also suitable for equipment using dual search units in the thicker ranges, above 3 mm [0.125 in.]. However, below those values there is an inherent error due to the ~~Vee path that the sound beam travels. The~~ breakdown in the small angle approximation. Thus the transit time is no longer linearly proportional to thickness, and the ~~condition deteriorates toward the low thickness end of the range.~~ nonlinearity increases with decreasing thickness. The variation is also shown schematically in Fig. 2(*a*) and Fig. X2.1(*a*). Typical error values are shown in Fig. 2(*b*) and expanded in Fig. X2.1(*b*).

NOTE 1—Many simple, direct read, dual element search units may not see appreciable variation in thickness readings for standardization blocks at the high and low ends of the range to be measured. This is especially true if the measurement range is within the measurement variation of the device.

8.3.2 If measurements are to be made over a very limited range ~~near the thin end of the scale,~~of thicknesses near or below 3 mm [0.125 in], it is possible to standardize the instrument with the technique in Case II using appropriate thin standardization blocks. This will produce a correction curve that is approximately correct over that limited range. Note that it will be substantially in error at thicker measurements.

8.3.3 If a wide range of thicknesses is to be measured, it may be more suitable to standardize as in Case II using standardization blocks at the high end of the range and perhaps halfway toward the low end. Following this, empirical corrections can be established for the very thin end of the range.

8.3.4 For a direct-reading panel-type meter display, it is convenient to build these corrections into the display as a nonlinear function.

8.3.5 For cylindrical components with concentric surfaces, best results are often achieved when the sound propagation path is aligned axially to the component.

8.4 *Case IV—Thick Sections:*

8.4.1 *Conditions*—For use when a high degree of accuracy is required for thick sections.

8.4.2 Direct contact search unit and initial pulse synchronization are used. The display start is delayed as described in 8.4.4. All display elements should be linear. Incremental thickness is displayed on the A-scan display.

8.4.3 Basic standardization of the sweep will be made as described in Case I. The standardization block chosen for this standardization should have a thickness that will permit standardizing the full-sweep distance to adequate accuracy, that is, about 10 mm [0.4 in.] or 25 mm [1.0 in.] full scale.

8.4.4 After basic standardization, the sweep must be delayed. For instance, if the nominal part thickness is expected to be from 50 to 60 mm [2.0 to 2.4 in.], and the basic standardization block is 10 mm [0.4 in.], and the incremental thickness displayed will also be from 50 to 60 mm [2.0 to 2.4 in.], the following steps are required. Adjust the delay control so that the fifth back wall echo of the basic standardization block, equivalent to 50 mm [2.0 in.], is aligned with the 0 reference on the A-scan display. The sixth back wall echo should then occur at the right edge of the standardized sweep.

8.4.5 This standardization can be checked on a known block of the approximate total thickness.

8.4.6 The reading obtained on the unknown specimen must be added to the value delayed off screen. For example, if the reading is 4 mm [0.16 in.], the total thickness will be 54 mm [2.16 in.].

9. Technical Hazards

9.1 Dual search units may also be used effectively with rough surface conditions. In this case, only the first returned echo, such as from the bottom of a pit, is used in the measurement. Generally, a localized scanning search is made to detect the minimum remaining wall.

9.2 *Material Properties*—The instrument should be standardized on a material having ~~the same~~ acoustic ~~velocity~~velocities and ~~attenuation as~~ attenuations as similar as possible to the material to be measured. The tolerance shall be controlled by the procedure (6.4) unless otherwise specified by the contractual agreement. Note that the properties of components made of the same alloy can vary significantly. Where possible, standardization should be confirmed by direct dimensional measurement of the material to be examined.

9.3 *Scanning*—The maximum speed of scanning should be stated in the procedure. Material conditions, type of equipment, and operator capabilities may require slower scanning.

9.4 *Geometry:*

9.4.1 Highest accuracy can be obtained from materials with parallel or concentric surfaces. In many cases, it is possible to obtain measurements from materials with nonparallel surfaces. However, the accuracy of the reading may be limited and the reading obtained is generally that of the thinnest portion of the section being interrogated by the sound beam at a given instant. The maximum deviation from parallel is generally less than the half angle beam spread. This equation is generally expressed with K = 1.22, which corresponds to zero amplitude. A more practical value may be K = 0.87, which corresponds to -20 dB in the reflection field.

$$\phi \le \sin^{-1}(K\ V/f_c\ D) \quad (1)$$

where:

ϕ = Angular deviation from parallel,
V = Sound velocity in the material,
f^c = Center frequency of the transducer,
D = Diameter of the transducer, and
K = Beam spread constant.

9.4.2 Relatively small-diameter curves often require special techniques and equipment. When small diameters are to be measured, special ~~procedures including additional specimens may~~procedures, which may include additional specimens, shall be required to ensure accuracy of setup and readout.

9.5 High-temperature materials, up to about ~~540°C [1000°F],~~540 °C [1000 °F], can be measured with specially designed instruments with high-temperature compensation, search unit assemblies, and couplants. Normalization of apparent thickness readings for elevated temperatures is required. A rule of thumb often used is as follows: The apparent thickness reading obtained from steel walls having elevated temperatures is high (too thick) by a factor of about 1 % per ~~55°C [100°F].~~55 °C [100 °F]. Thus, if the instrument was standardized on a piece of similar material at ~~20°C [68°F],~~20 °C [68 °F], and if the reading was obtained with a surface temperature of ~~460°C [860°F],~~460 °C [860 °F], the apparent reading should be reduced by 8 %. This correction is an average one for many types of steel. Other corrections would have to be determined empirically for other materials.

~~9.6 *Instrument*—Time-base linearity is required so that a change in the thickness of material will produce a corresponding change of indicated thickness. If a CRT is used as a readout, its horizontal linearity can be checked by using Practice E317.~~

9.6 *Back Wall Reflection Wavetrain*—Direct-thickness readout instruments read the thickness at the first half cycle of the wavetrain that exceeds a set amplitude and a fixed time. If the amplitude of the back wall reflection from the measured material is different from the amplitude of the back wall reflection from the standardization blocks, the thickness readout may read to a different half cycle in the wavetrain, thereby producing an error. This may be reduced by:

9.6.1 Using reference blocks having attenuation characteristics equal to those in the measured material or adjusting back wall reflection amplitude to be equal for both the standardizing blocks and measured material.