



# Standard Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method<sup>1</sup>

This standard is issued under the fixed designation E 797; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This practice<sup>2</sup> provides guidelines for measuring the thickness of materials using the contact pulse-echo method at temperatures not to exceed 200°F (93°C).

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 reflections can be obtained and resolved.

1.3 The values stated in either inch-pound or SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *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 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments<sup>3</sup>

E 494 Practice for Measuring Ultrasonic Velocity in Materials<sup>3</sup>

E 1316 Terminology for Nondestructive Examinations<sup>3</sup>

### 2.2 ASNT Document:

*Nondestructive Testing Handbook*, 2nd Edition, Vol 7<sup>4</sup>

## 3. Terminology

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

## 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.

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 under test 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 E 494 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 tested, 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 (CRT (cathode ray tube), 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 calibrate*, 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 dc 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.

## 5. Significance and Use

5.1 The techniques described provide indirect measurement

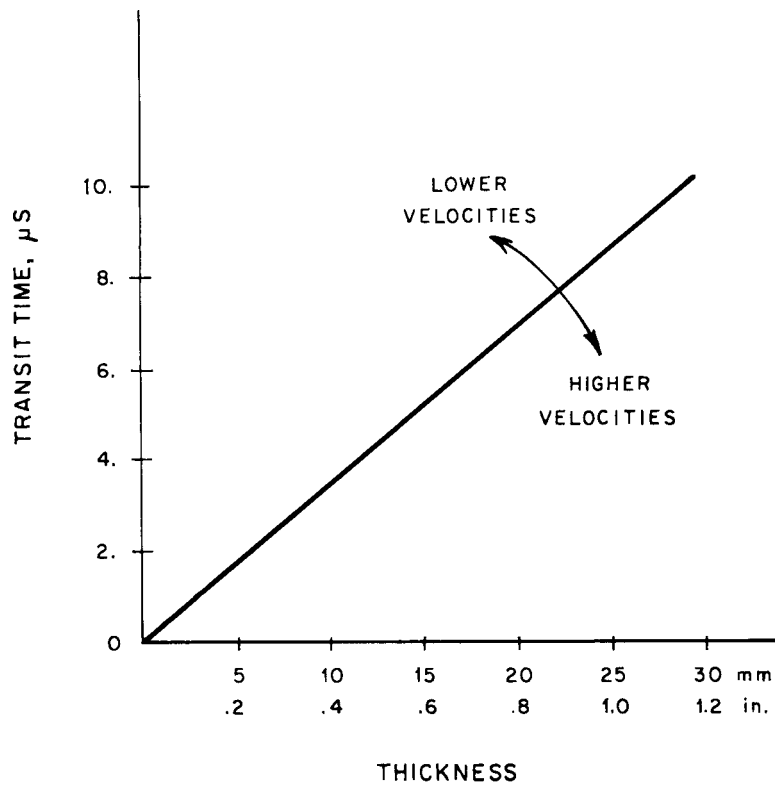
<sup>1</sup> This practice is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.06 on Ultrasonic Testing Procedure.

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<sup>2</sup> For ASME Boiler and Pressure Vessel Code applications, see related Practice SE-797 in Section II of that Code.

<sup>3</sup> *Annual Book of ASTM Standards*, Vol 03.03.

<sup>4</sup> Available from the American Society for Nondestructive Testing, 1711 Arlington Plaza, Columbus, OH 43228.



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

FIG. 1 Transit Time/Thickness Relationship

of thickness of sections of materials not exceeding temperatures of 200°F (93°C). 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.<sup>5,6</sup>

## 6. Apparatus

6.1 *Instruments*—Thickness-measurement instruments are divided into three groups: (1) Flaw detectors with CRT readout, (2) Flaw detectors with CRT and direct thickness readout, and (3) Direct thickness readout.

6.1.1 Flaw detectors with CRT readouts display time/amplitude information in an A-scan presentation. Thickness determinations are made by reading the distance between the zero-corrected initial pulse and first-returned echo (back reflection), or between multiple-back reflection echoes, on a calibrated base line of a CRT. The base line of the CRT should be adjusted for the desired thickness increments.

<sup>5</sup> Bosselaar, H., and Goosens, J.C.J., "Method to Evaluate Direct-Reading Ultrasonic Pulse-Echo Thickness Meters," *Materials Evaluation*, March 1971, pp. 45-50.

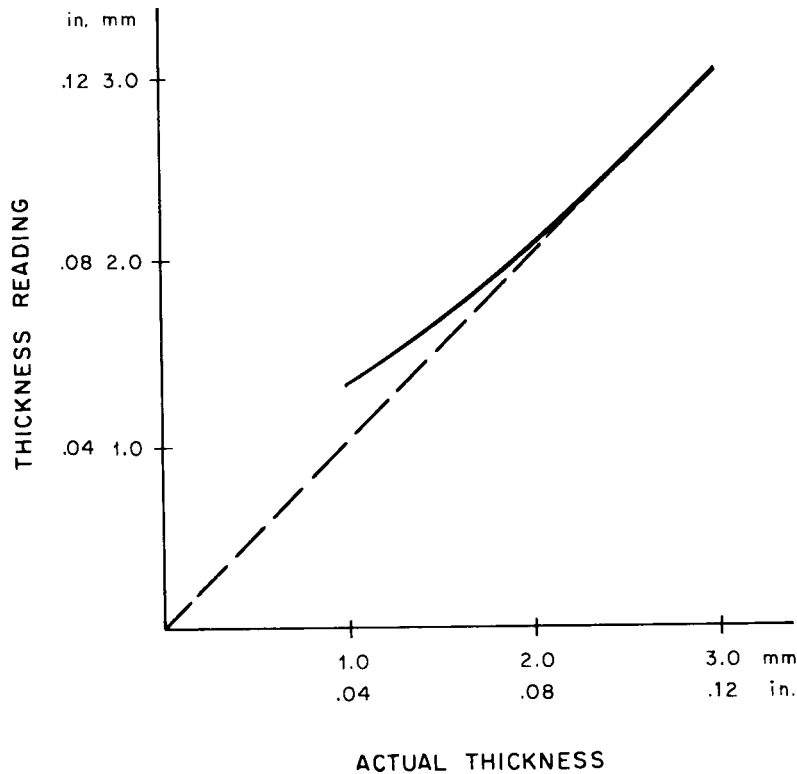
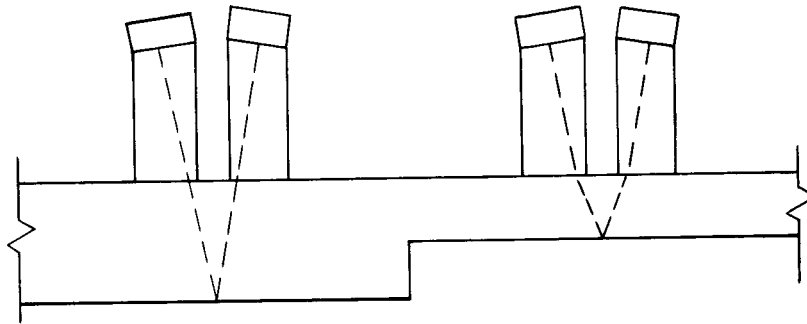
<sup>6</sup> Fowler, K.A., Elfbaum, G.M., Husarek, V., and Castel, J., "Applications of Precision Ultrasonic Thickness Gaging," *Proceedings of the Eighth World Conference on Nondestructive Testing*, Cannes, France, Sept. 6-11, 1976, Paper 3F.5.

6.1.2 Flaw detectors with numeric readout are a combination pulse ultrasound flaw detection instrument with a CRT and additional circuitry that provides digital thickness information. The material thickness can be electronically measured and presented on a digital readout. The CRT 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.

6.1.3 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.

6.2 *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.) For optimum performance, it is often necessary that the instrument and search units be matched.

6.3 *Calibration Blocks*—The general requirements for appropriate calibration blocks are given in 4.4, 7.1.3, 7.2.2.1,



(a) Proportional sound path increases with decrease in thickness.

(b) Typical reading error values

**FIG. 2 Dual Transducer Nonlinearity**

7.3.2, and 7.4.3. Multi-step blocks that may be useful for these calibration procedures are described in Appendix X1 (Figs. X1.1 and X1.2).

**7. Procedure—Calibration and Adjustment of Apparatus**

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

7.1.1 *Conditions*—The display start is synchronized to the initial pulse. All display elements are linear. Full thickness is displayed on CRT.

7.1.2 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 test blocks providing a minimum of two thicknesses that span the thickness range be used to check the full-range accuracy.

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

7.1.4 The readings should then be checked and adjusted on test blocks with thickness of lesser value to improve the overall accuracy of the system.

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

7.2.1 *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.

7.2.2 In most instruments, if the material calibrate 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 calibrated with the delay line search unit, the following technique is recommended:

7.2.2.1 Use at least two test 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.

7.2.2.2 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 calibrate 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 calibrate control to decrease the thickness range. A certain amount of over correction is usually recommended. Reposition the search unit sequentially on both 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.

7.2.3 An alternative technique for delay line search units is a variation of that described in 7.2.2. A series of sequential adjustments are made, using the “delay” control to provide correct readings on the thinner test 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.

### 7.3 Case III—Dual Search Units:

7.3.1 The method described in 7.2 (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 transit time is no longer linearly proportional to thickness, and the condition deteriorates toward the low thickness end of the range. The variation is also shown schematically in Fig. 2(a). Typical error values are shown in Fig. 2(b).

7.3.2 If measurements are to be made over a very limited range near the thin end of the scale, it is possible to calibrate the instrument with the technique in Case II using appropriate thin test 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.

7.3.3 If a wide range of thicknesses is to be measured, it may be more suitable to calibrate as in Case II using test 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.

7.3.4 For a direct-reading panel-type meter display, it is

convenient to build these corrections into the display as a nonlinear function.

### 7.4 Case IV—Thick Sections:

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

7.4.2 Direct contact search unit and initial pulse synchronization are used. The display start is delayed as described in 7.4.4. All display elements should be linear. Incremental thickness is displayed on the CRT.

7.4.3 Basic calibration of the sweep will be made as described in Case I. The test block chosen for this calibration should have a thickness that will permit calibrating the full-sweep distance to adequate accuracy, that is, about 10 mm (0.4 in.) or 25 mm (1.0 in.) full scale.

7.4.4 After basic calibration, 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 calibration 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 echo of the basic calibration block, equivalent to 50 mm (2.0 in.), is aligned with the 0 reference on the CRT. The sixth back echo should then occur at the right edge of the calibrated sweep.

7.4.5 This calibration can be checked on a known block of the approximate total thickness.

7.4.6 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.).

## 8. Technical Hazards

8.1 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.

8.2 *Material Properties*—The instrument should be calibrated on a material having the same acoustic velocity and attenuation as the material to be measured. Where possible, calibration should be confirmed by direct dimensional measurement of the material to be examined.

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

### 8.4 Geometry:

8.4.1 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.

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

8.5 High-temperature materials, up to about 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). Thus, if the instrument was calibrated on a piece of similar material at 20°C (68°F), and if the reading was obtained with a surface temperature of 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.

8.6 *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 E 317.

8.7 *Back 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 reflection from the measured material is different from the amplitude of the back reflection from the calibration blocks, the thickness readout may read to a different half cycle in the wavetrain, thereby producing an error. This may be reduced by:

8.7.1 Using calibration blocks having attenuation characteristics equal to those in the measured material or adjusting back reflection amplitude to be equal for both the calibrating blocks and measured material.

8.7.2 Using an instrument with automatic gain control to produce a constant amplitude back reflection.

8.8 *Readouts*—CRT displays are recommended where reflecting surfaces are rough, pitted, or corroded.

8.8.1 Direct-thickness readout, without CRT, presents hazards of misadjustment and misreading under certain test conditions, especially thin sections, rough corroded surfaces, and rapidly changing thickness ranges.

8.9 *Calibration Standards*—Greater accuracy can be obtained when the equipment is calibrated on areas of known thickness of the material to be measured.

8.10 Variations in echo signal strength may produce an error equivalent to one or more half-cycles of the RF frequency, dependent on instrumentation characteristics.

## 9. Procedure Requirements

9.1 In developing the detailed procedure, the following items should be considered:

9.1.1 Instrument manufacturer's operating instructions.

9.1.2 Scope of materials/objects to be measured.

9.1.3 Applicability, accuracy requirements.

9.1.4 Definitions.

9.1.5 Requirements.

9.1.5.1 Personnel.

9.1.5.2 Equipment.

9.1.5.3 Procedure qualification.

9.1.6 Procedure.

9.1.6.1 Measurement conditions.

9.1.6.2 Surface preparation and couplant.

9.1.6.3 Calibration and allowable tolerances.

9.1.6.4 Scanning parameters.

9.1.7 Report.

9.1.7.1 Procedure used.

9.1.7.2 Calibration record.

9.1.7.3 Measurement record.

## 10. Report

10.1 Record the following information at the time of the measurements and include it in the report:

10.1.1 Inspection procedure.

10.1.1.1 Type of instrument.

10.1.1.2 Calibration blocks, size and material type.

10.1.1.3 Size, frequency, and type of search unit.

10.1.1.4 Scanning method.

10.1.2 Results.

10.1.2.1 Maximum and minimum thickness measurements.

10.1.2.2 Location of measurements.

10.1.3 Personnel data, certification level.

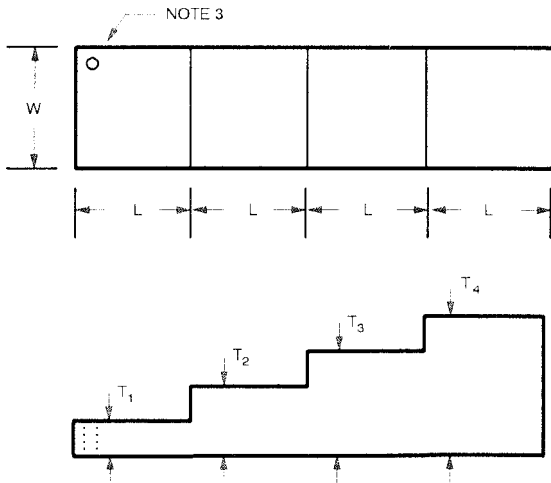
## 11. Keywords

11.1 contact testing; nondestructive testing; pulse-echo; thickness measurement; ultrasonics

APPENDIX

(Nonmandatory Information)

X1. Typical Multi-Step Thickness Gage Calibration Blocks



NOT TO SCALE

TABLE OF DIMENSIONS

U.S. Customary Block, in.		Metric Block 4A, mm		Metric Block 4B, mm		
Legend	Dimension	Tolerance	Dimension	Tolerance	Dimension	Tolerance
T <sub>1</sub>	0.250	0.001	6.25	0.02	5.00	0.02
T <sub>2</sub>	0.500	0.001	12.50	0.02	10.00	0.02
T <sub>3</sub>	0.750	0.001	18.75	0.02	15.00	0.02
T <sub>4</sub>	1.000	0.001	25.00	0.02	20.00	0.02
L	0.75	0.02	20.0	0.5	20.0	0.5
W	0.75	0.05	20.0	1.0	20.0	1.0

NOTE 1—Material to be as specified.

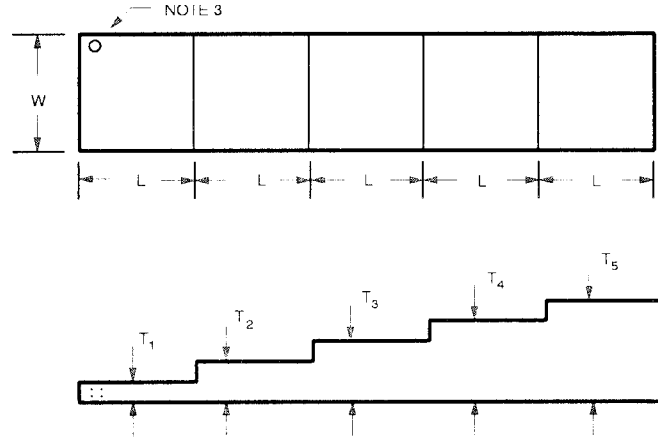
NOTE 2—Surface finish: “T” faces Ra 32 μin. (0.8 μm) max. Other surfaces Ra 63 μin. (1.6 μm) max.

NOTE 3—Location for optional 1/16 in. (1.5 mm) diameter through hole used for block support during plating; center 1/16 in. (1.5 mm) from block edges.

NOTE 4—All “T” dimensions to be after any required plating or anodizing.

NOTE 5—In order to prevent sharp edges, minimize plating buildup, or remove in-service nicks and burrs, block edges may be smoothed by beveling or rounding, provided that the corner treatment does not reduce the edge dimension by more than 0.020 in. (0.5 mm).

FIG. X1.1 Typical Four-Step Thickness Calibration Blocks



NOT TO SCALE

TABLE OF DIMENSIONS

U.S. Customary Block, in.		Metric Block 5A, mm		Metric Block 5B, mm		
Legend	Dimension	Tolerance	Dimension	Tolerance	Dimension	Tolerance
T <sub>1</sub>	0.100	0.001	2.50	0.02	2.00	0.02
T <sub>2</sub>	0.200	0.001	5.00	0.02	4.00	0.02
T <sub>3</sub>	0.300	0.001	7.50	0.02	6.00	0.02
T <sub>4</sub>	0.400	0.001	10.00	0.02	8.00	0.02
T <sub>5</sub>	0.500	0.001	12.50	0.02	10.00	0.02
L	0.75	0.02	20.0	0.5	20.00	0.5
W	0.75	0.05	20.0	1.0	20.00	1.0

NOTE 1—Material to be as specified.

NOTE 2—Surface finish: “T” faces Ra 32 μin. (0.8 μm) max. Other surfaces Ra 63 μin. (1.6 μm) max.

NOTE 3—Location for optional 1/16 in. (1.5 mm) diameter through hole used for block support during plating; center 1/16 in. (1.5 mm) from block edges.

NOTE 4—All “T” dimensions to be after any required plating or anodizing.

NOTE 5—In order to prevent sharp edges, minimize plating buildup, or remove in-service nicks and burrs, block edges may be smoothed by beveling or rounding, provided that the corner treatment does not reduce the edge dimension by more than 0.020 in. (0.5 mm).

FIG. X1.2 Typical Five-Step Thickness Calibration Blocks

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 **E 797**

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