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## Standard Practice for Measuring the Change in Length of Fasteners Using the Ultrasonic Pulse-Echo Technique<sup>1</sup>

This standard is issued under the fixed designation E 1685; 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 covers a procedure for measuring changes in length of threaded fasteners using conventional ultrasonic; pulse-echo bolt-measuring instrumentation which has been properly calibrated.

1.2 This procedure is normally intended for metal bolting 0.25 in. (6.4 mm) or more in nominal diameter with effective length-to-diameter ratios of 2:1 or greater.

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 6 Terminology Relating to Methods of Mechanical Testing<sup>2</sup>

<sup>1</sup> This practice is under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.13 on Residual Stress Measurement.

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

E 1544 Practice for Construction of a Stepped Block and Its Use to Estimate Errors Produced by Speed-of-Sound Measurement Systems for Use on Solids<sup>2</sup>

### 3. Terminology

3.1 The definitions in this practice are in accordance with Terminology E 6 and Section I of Terminology E 1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *change in length*—physical change in length of a threaded fastener due to a change in tension within the fastener.

3.2.2 *effective length*—the length of a bolt that is responsive to stress.

3.2.2.1 *Discussion*—This quantity lies somewhere between the overall length of the bolt and the grip length. It is usually estimated as the grip length plus one half the thickness of the head and one half the thickness of the nut.

3.2.3 *longitudinal wave*—those waves in which the particle motion of the material is in the same direction as the wave propagation.

3.2.4 *pulse-echo bolt-measuring equipment*—an assembly of ultrasonic instruments designed specifically to measure changes in the lengths of bolts. See Appendix X1.

3.2.5 *reference length*—the ultrasonic time of flight in the test specimen multiplied by a reference propagation velocity.

3.2.6 *reference propagation velocity*—the velocity of propagation of the ultrasonic wavefront in a calibration test block or in the bolts whose changes of length are being measured.

3.2.7 *time of flight*—the measured time interval between the launching of an ultrasonic pulse at the start of a path of travel and the reception of the pulse at the end of the path.

### 4. Summary of Practice

4.1 This practice describes a procedure for determining the change in length of a threaded fastener due to a change in tension in the fastener. Measurements of the ultrasonic time of flight are made before and after the fastener tension is changed, and a calculation of the change in length is made from the change in the time of flight.

4.1.1 Brief bursts of ultrasound (pulses) are generated by applying high-voltage electrical signals to an electroacoustic transducer having a resonant frequency in the 5 to 10-MHz range. The pulses enter the bolt through the transducer/bolt interface, travel to the far end of the bolt, and reflect back (echo) to the transducer. The time of flight required for the signal to make its round-trip is measured electronically. By measuring the change in the time of flight due to a change in tension within the bolt, the equipment can determine the change in the length of the bolt due to the change in tension. Compensation for the direct effect of stress on the propagation velocity in the bolt is automatically done by a computer or microprocessor within the equipment.

4.2 This procedure is used on fasteners as they are tightened within their elastic limits; or on previously tightened fasteners as they are loosened. The latter can have been tightened past yield.

### 5. Significance and Use

5.1 The techniques described provide for the indirect measurement of change in length of a fastener. Such measurements are made from one end of the specimen without requiring access to the rear surface.

5.2 The equipment is field portable and should be used in the manner prescribed by the manufacturer. Common uses include monitoring changes in length of fasteners and as a tool for industrial quality control. Current applications include fasteners used in turbines, petrochemical pressure vessels, aircraft, automotive manufacturing, general bolting within the nuclear industry, structural steel connections, laboratory testing, and so forth.

### 6. Apparatus

6.1 *Pulse-Echo Instrument*—For ultrasonic measurements of the change in length of bolts, any longitudinal-wave pulse-echo ultrasonic instrument capable of reporting calculated changes in length is acceptable provided that its accuracy and precision satisfy the requirements set forth in Annex A1. The major components of suitable instruments are as follows:

6.1.1 *Pulser/transmitter*, a means of generating electrical pulses to excite an acoustic transducer.

6.1.2 *Receiver/detector*, a means of amplifying and detecting the returning back-wall echo.

6.1.3 *Time-base Controller*, a means of measuring changes in ultrasonic time of flight.

6.1.4 *Acoustic Transducer*, a means of sending and receiving ultrasonic waves. Experience has shown that transducers with resonances in the 5 to 10-MHz frequency range are usually satisfactory. In general, select an acoustic transducer having an element of the largest diameter available while not exceeding the minimum body diameter of the bolt.

6.2 *Other Apparatus:*

6.2.1 *Couplant*—For longitudinal pulse-echo measurements, a liquid is required to couple ultrasound between the transducer and the fastener. Of the couplants commonly used, where applicable a 50/50 glycerine/water mix often provides optimal results. Light oil or standard commercially available ultrasonic couplants are also satisfactory.

<sup>2</sup> Annual Book of ASTM Standards, Vol 03.01.

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

6.2.2 *Oscilloscope*—For optimal adjustment of the apparatus, the use of an oscilloscope is necessary. The oscilloscope must have two input channels, two traces, external triggering, and a dual time base with delayed sweep capability. Its bandwidth should be at least 35 MHz or its equivalent.

6.2.2.1 Pulse-echo instruments with built-in oscilloscope display capabilities must have sampling speeds equivalent to at least ten times the transducer frequency for satisfactory signal display.

6.2.3 *Standard Reference Blocks*, for periodic recalibration of the pulse-echo instrument.

6.2.3.1 A glass or metallic reference block of known length and appropriate surface roughness, shape, thickness, and parallelism is recommended. Acceptable standards include a glass block, two metal bars of unequal length, and single bars of known acoustic velocity. The path length of the standard must be determined by a technique of higher accuracy. See Practice E 1544. Calibration of standards should be traceable to NIST.

## 7. Procedure

7.1 The performance of the pulse-echo instrument should be verified or adjusted to a reference standard in accordance with the manufacturer's specifications. See Annex A2.

7.1.1 In noncritical applications, where uncertainties smaller than  $\pm 15\%$  of the change in length are not required, an instrument calibrated on one bolt of a given material can be used on other bolts of the same material but having different shapes.

7.1.2 At the other extreme, if the instrument is to be used on bolts in critical, safety-related applications or where uncertainties of  $\pm 1$  to  $3\%$  are required, or both, consideration should be given to recalibration on a statistically significant sample of each new lot of bolts.

7.2 *Fastener Preparation*—For reliable ultrasonic measurements the fastener must have suitable finish and geometry requirements. One end must be accessible for transducer placement. This end must, for at least the diameter of the transducer, be flat and perpendicular to the axis of the bolt. A machined surface with a finish of 125 RMS or better is recommended, exclusive of indented grade markings. Raised grade markings must be removed. (See Note 1.) If the end is recessed it must have a flat spot face. The reflector end of the fastener must have a flat surface parallel to the other end. The amount of axial runout on the end is dependent on fastener size and the accuracy requirement. An area as small as  $\frac{1}{8}$  in. (3 mm) in diameter may be sufficient. The ends of bolts with through center holes may be prepared adjacent to the holes, with the transducer locations marked.

NOTE 1—Grade markings should not be moved indiscriminately. Documentation of grade marking removals should be created and maintained.

7.3 Measure average fastener temperature within  $1^\circ\text{C}$ , in accordance with instructions in the instrument operating manual.

7.4 *Transducer Placement*:

7.4.1 Apply a suitable acoustic couplant to allow adequate sound transmission. Glycerine or some other high-viscosity couplant is recommended if the fastener has indented grade markings or if its surface has a few pits.

NOTE 2—The coupling surface must be wiped clean each time couplant is applied. The amount of couplant to be used should be sufficient to wet the transducer face but not excessive. Consistent amounts must be used for successive or repetitive readings.

7.4.2 Place the transducer on the flat surface of the bolt to be measured. To minimize possible impact damage to the wearplate portion of the transducer, it should be set down on its edge and then carefully rotated to a flat position. The transducer is seated by light, back-and-forth finger movements to squeeze out excess couplant and to obtain the shortest, most stable, length display, or the largest echo signal on the oscilloscope. Repeat this process several times to ensure repeatability.

7.4.3 For repeatable readings the transducer must always be returned to the same position during the measurement process. This location may be marked on the end of the fastener, and the identification/serial number can be noted for a relative position. See Appendix X2.

7.5 Obtain the reference length of the fastener in either the untensioned or tensioned condition. Record the reference length for future comparisons.

NOTE 3—The untensioned condition must be physically loose.

7.6 If the reference length was determined in the untensioned condition, tighten the fastener. If the reference length was determined in the tensioned condition, unload the fastener.

7.7 Measure the change in length of the fastener and record the value.

7.8 Additional measurements may be made at any time in the future by following 7.1, 7.3, 7.4, and 7.7, and using the reference length as measured in accordance with 7.5.

## 8. Report

8.1 If a report is required, the following data should be included:

8.1.1 Type of material measured.

8.1.2 The calibration factors in use by the test equipment. These must include the stress factor, the material velocity, and the temperature factor. See Annex A2.

8.1.3 Transducer size, frequency, and serial number.

8.1.4 Model and serial numbers of the pulse-echo instrument and reference blocks, if applicable.

8.1.5 Initial reference length (in inches or millimetres) and the temperature at the time of measurement.

8.1.6 Change-in-length measurement (in inches or millimetres) and the temperature at the time of measurement.

## 9. Keywords

9.1 bolts; change-in-length measurements; clamping force; fasteners; residual stress measurements; ultrasonics.

## ANNEXES

### (Mandatory Information)

#### A1. INSTRUMENT RESOLUTION

A1.1 Pulse-echo bolt-measuring instruments are designed to measure and report the change in a fastener's length to the nearest 0.0001 or 0.00001 in. (0.0025 or 0.00025 mm). To do this it must be able to resolve 0.00005 or 0.000005 in. (0.0012 or 0.00012 mm). This degree of precision is required because a typical bolt tightened to its yield point will stretch only about 0.003 in./in. (0.003 mm/mm) of grip length.

#### A2. INSTRUMENT CALIBRATION

A2.1 Calibration is essential for the correct use of a pulse-echo bolt-measuring instrument, and this involves a number of steps. First, the ability of the instrument to measure times of flight accurately must be determined by using it to measure several dimensions on a reference block.

A2.2 Next, a sample (one in routine applications, several for critical applications) of the actual fasteners whose changes in length are to be measured is loaded in a tensile testing machine or tightened in a load cell. The resulting change in length of the sample is measured with the pulse-echo instrument and with another calibrated instrument such as the extensometer on the testing machine. If the bolt-measuring instrument is to be used on fasteners at various temperatures, additional tests involving an oven or cold chamber are also required.

A2.3 In order to calibrate a pulse-echo bolt-measuring instrument, factors must be used to change the actual measured time of flight to a bolt elongation measurement. These factors are dependent on the properties of the bolt material.

A2.3.1 *Stress Factor*—The elongation (or delta length) must be corrected for the effect of stress on sound velocity. (Sound speed decreases through a metal bolt when it is elongated by an axial load.) The correction factor is commonly termed the stress factor and may be expressed in units of in./s/psi or m/s/Pa.

A2.3.2 *Material Velocity*—The time of flight is converted to a length measurement using the longitudinal wave velocity in the unstressed material. This is commonly called the material velocity and may be expressed in units of in./s or m/s.

A2.3.3 *Temperature Factor*—The change in length of a bolt is also affected by temperature, and this is accommodated by using a ratio which corrects for both the physical and the ultrasonic length changes. This ratio is commonly called the temperature factor and may be expressed in units of in./s/° F or m/s/° C.

A2.3.3.1 Different commercial pulse-echo bolt-measuring instruments use different techniques to compensate for these effects. The manufacturer's calibration procedures should be used. Once the calibration factors have been established for a given fastener material and shape the instrument may be recalibrated for that fastener using reference blocks only.

**APPENDIXES****(Nonmandatory Information)****X1. PULSE-ECHO BOLT-MEASURING INSTRUMENT VERSUS PULSE-ECHO THICKNESS GAGE**

X1.1 There are some similarities between a pulse-echo bolt-measuring instrument and the more common pulse-echo thickness gage; but there are also some important differences which make the thickness gage inappropriate for fastener measurements. The time of flight of the ultrasonic wavefront is affected not only by the change in length of a fastener as it is tightened but, even more, by the change in stress level within the fastener (which affects the ultrasonic velocity). A computer or microprocessor within the pulse-echo bolt-measuring instrument, having been fed the instrument calibration and application data (that is, the effective length), can compensate for the change in the time of flight caused by the increase in path length of the fastener. Thickness gages do not have this capability.

X1.2 The bolt-measuring instrument is also designed to ignore echoes from such things as the underside of a bolt head or the bolt threads. Further, it is designed to measure the change in length of a fastener with the precision typically required in automotive, aerospace, or similar applications (that is, bolts having lengths of a few inches or less). See Annex A1. for further information.

**X2. TROUBLE SHOOTING**

X2.1 *Non-Repeatable Initial Length Readings*—The causes are usually associated with improper coupling of the transducer and fastener.

X2.1.1 Fastener surface finish irregularities.

X2.1.2 Lack of parallelism between the ends of the fastener.

X2.1.3 Too much or too little couplant has been used, or excess couplant has not been squeezed out of the transducer-fastener interface (see Note 1-2).

X2.1.4 Dirt on the transducer face.

X2.1.5 Loose cable connections or a bad cable, usually the ground wire.

X2.1.6 Transducer not being returned to the same location.

X2.1.7 Fastener temperature changes not automatically compensated.

X2.2 *Non-Repeatable Change-in-Length Readings*—The causes are usually related to bolt bending or weakening of the signal strength due to stress.

X2.2.1 Bolt bending is related to nonparallelism of the head and nut bearing surfaces.

X2.2.2 Weakening of signal strength is related to a stress-induced increase in the acoustic attenuation of the material. As the signal diminishes, the gate may jump from peak to peak or may be entirely lost. This will show on the oscilloscope or the instrument's built-in display screen.

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