Designation: ~~E2428 – 15a~~ E2428 – 22

Standard Practice for
Calibration and Verification of Elastic Torque ~~Transducers~~Measurement Standards[1]

This standard is issued under the fixed designation E2428; 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~~ Scope*

1.1 The purpose of this practice is to specify the procedure for the calibration and verification of elastic torque ~~transducers.~~measurement standards.

~~NOTE 1—Verification by deadweight and a lever arm is an acceptable method of verifying the torque indication of a testing machine. Tolerances for weights used are tabulated in Practice E2624; methods for calibration of the weights are given in NIST Technical Note 577, Methods of Calibrating Weights for Piston Gages.[2]~~

1.2 *Units*—The values stated in SI units are to be regarded as standard. ~~Other metric and inch-pound values are regarded as equivalent when required.~~ The values given in parentheses after SI units are provided for information only and are not considered standard.

1.3 This practice is intended for the calibration of static elastic torque ~~measuring instruments.~~measurement standards. The practice is not applicable for dynamic or high-speed torque calibrations or measurements, nor can the results of calibrations performed in accordance with this practice be assumed valid for dynamic or ~~high speed~~ high-speed torque measurements.

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

1.5 *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:*[2]

E6 Terminology Relating to Methods of Mechanical Testing
E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
E2624 Practice for Torque Calibration of Testing Machines

2.2 *ASME Standard:*[3]

B46.1 Surface Texture (Surface Roughness, Waviness, and Lay)

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[1] This practice is under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.01 on Calibration of Mechanical Testing Machines and Apparatus.

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[3] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, http://www.asme.org.

[2] 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**

2.3 *BIPM* ~~*Standard*~~*Standard:*[4]
JCGM 200 International vocabulary of metrology–Basic and general concepts and associated terms (VIM)

3. Terminology

3.1 *Definitions:*

3.1.1 Refer to Terminology E6 for the definitions of calibration, metrological traceability, resolution, and verification.

3.1.2 *primary torque* ~~*standard—*~~*measurement standard, n—*~~a~~A deadweight force applied through a ~~lever arm or wheel, all displaying~~moment arm, all with metrological traceability to the International System of Units (SI).

~~3.1.1.1 *Discussion—*~~
~~for further definition of the term metrological traceability, refer to the latest revision of JCGM:200.~~

3.1.3 *secondary torque* ~~*standard—*~~*measurement standard, n—*~~an~~An instrument or mechanism, the calibration of which has been established by a comparison with ~~a~~ primary torque measurement standard(s).

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *calibration* ~~*equation—*~~*equation, n—*~~a~~A mathematical relationship between deflection and torque established from the calibration data for use with the elastic torque ~~transducer in service, sometimes called the calibration curve.~~measurement standard in service.

~~3.2.1.1 *Discussion—*~~
~~Torque transducers have torque-to-deflection relationships that can be fitted to polynomial equations.~~

~~3.2.2 *continuous-reading device*—a class of instruments whose characteristics permit interpolation of torque values between calibrated torque values.~~
~~3.2.2.1 *Discussion—*~~
~~Such instruments usually have torque-to-deflection relationships that can be fitted to polynomial equations. Departures from the fitted curve are reflected in the uncertainty (see 8.5).~~

3.2.2 ~~*creep—*~~*creep, n—*The change in ~~deflection~~indication of the elastic torque ~~transducer~~ measurement standard under constant applied torque.
3.2.2.1 *Discussion—*
Creep is expressed as a percentage of the indicated change at a constant applied torque from an initial time following the achievement of mechanical and electrical stability and the time at which the test is concluded. The stabilities of secondary torque measurement standards and primary torque measurement standards are usually adequate to measure creep during the test time interval. Creep results from a time-dependent, elastic deformation of the elastic member of the elastic torque measurement standard. In the case of elastic torque measurement standards, creep is minimized by strain gage design and process modifications to reduce the strain gage response to the inherent time-dependent elastic deformation.

~~3.2.3.1 *Discussion—*~~
~~Creep is expressed as a percentage of the output change at a constant applied torque from an initial time following the achievement of mechanical and electrical stability and the time at which the test is concluded. Valid creep tests may require the use of primary torque standards to maintain adequate stability of the applied torque during the test time interval. Creep results from a time dependent, elastic deformation of the instrument mechanical element. In the case of torque transducers, creep is adjusted by strain gage design and process modifications to reduce the strain gage response to the inherent time-dependent elastic deflection.~~

3.2.3 _*creep* ~~*recovery—*~~*recovery, n—*The ~~non-return to zero following a creep test.~~change of indicated from the elastic torque measurement standard at zero torque after the removal of the maximum applied calibration torque and initial zero-torque indication.
3.2.3.1 *Discussion—*
The zero-torque indication is taken at a time following the achievement of mechanical and electrical stability and a time equal to the time at the calibration torque. For many elastic torque measurement standards, the creep characteristic and the creep recovery characteristic are approximate mirror images.

~~3.2.4.1 *Discussion—*~~
~~Creep Recovery is expressed as a percentage difference of the output change at zero torque following a creep test and the initial~~

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[4] Available from BIPM, Pavillon de Breteuil, F-92312 Sèvres Cedex. http://www.bipm.org

~~zero torque output at the initiation of the creep test divided by the output during the creep test. The zero-torque measurement is taken at a time following the achievement of mechanical and electrical stability and a time equal to the creep test time. For many torque transducers, the creep characteristic and the creep recovery characteristic are approximate mirror images.~~

3.2.4 ~~*deflection*—~~*deflection, n—*~~the~~The difference between the ~~readings of an instrument~~ indication of the elastic torque measurement standard under applied torque and the ~~reading~~indication with ~~no~~zero applied torque.

~~3.2.5.1 *Discussion*—~~

~~The definition of deflection applies to output readings in electrical units as well as readings in units of torque.~~

3.2.5 *elastic torque measurement standard, n—*A system consisting of an elastic member combined with an electronic-indicating measurement instrument for measuring the strain of the elastic member under an applied torque.

3.2.5.1 *Discussion—*

An elastic torque measurement standard is a specific "measurement standard" as defined in JCGM 200.

3.2.5.2 *Discussion—*

An elastic torque measurement standard is commonly referred to as a torque transducer, torquemeasuring transducer, or torque cell.

3.2.6 *lower limit factor,* ~~*LLF*—~~*LLF, n—*A statistical estimate of the ~~limits of~~ measurement error ~~of~~in torque ~~values~~ computed from the calibration equation of the elastic torque ~~transducer~~ measurement standard when the elastic torque ~~transducer~~ measurement standard is calibrated in accordance with this practice.

3.2.6.1 *Discussion—*

The lower limit factor is used ~~as one factor that may establish~~ to calculate the lower torque limit of the ~~range of torque values over which the torque transducer can be used.~~ verified range of torques. Other factors evaluated in ~~the establishment of the lower~~ establishing the lower torque limit of the verified range of ~~torque values~~ torques are the resolution of the elastic torque ~~transducer~~ measurement standard and the lowest ~~nonzero~~non-zero torque applied in the calibration ~~load sequence.~~torque sequence. The lower limit factor is one component of the measurement uncertainty. As a component of measurement uncertainty, the lower limit factor is often described as the relative reproducibility error with rotation. Other measurement uncertainty components should be included in a comprehensive measurement uncertainty analysis.

3.2.6.2 *Discussion—*

The lower limit factor was termed uncertainty in ~~previous editions of~~revisions prior to E2428~~. While the lower limit factor is a component of uncertainty, other appropriate error sources should be considered in determining the measurement uncertainty of the torque transducer in service.~~-15a.

3.2.7 *mode, n—*The direction of torque, either clockwise or counter-clockwise.

3.2.8 ~~*specific torque*~~*moment arm,* ~~*device*—~~*n—*~~an alternative class of instruments not amenable to the use of a calibration equation.~~The component that couples the perpendicular line of action of the force and the center of moments to create a torque and whose length or radius length displays metrological traceability to the International System of Units (SI)

3.2.8.1 *Discussion—*

~~Such instruments, usually those in which the reading is taken from a dial indicator, are used only at the calibrated torque values. These instruments are also called limited-torque devices.~~The center of moments may be the actual point about which the force causes rotation. It may also be a reference point or axis about which the force may be considered as causing rotation.

3.2.8.2 *Discussion—*

Moment arm is synonymous with calibration beam (radius, single- or double-ended), torque arm, wheel, or lever unless specifically referenced otherwise.

~~3.2.8 *loading range*—a range of torque values within which the lower limit factor is less than the limits of error specified for the instrument application.~~

3.2.9 ~~*torque transducer*—~~*verified range of torques, n—*~~a device or system consisting of an elastic member combined with a sensing device for measuring the strain or deflection of the elastic member under an applied torque.~~The range of indicated torque for which the elastic torque measurement standard gives results within permissible variations specified.

3.3 Refer to JCGM 200 International vocabulary of metrology- Basic and general concepts and associated terms (VIM) for definitions of the terms coverage factor, expanded measurement uncertainty, indication, maximum permissible measurement error, measurement error, measurement uncertainty, measurement repeatability, measurement reproducibility, reference measurement standard, and sensitivity.

4. Significance and Use

4.1 Testing machines that apply and indicate torque are in general use in many industries. Practice E2624 has been written to provide a practice for the torque calibration and verification of these testing machines. A necessary element in Practice E2624 is the use of ~~devices~~ elastic torque measurement standards whose torque characteristics are known to be metrologically traceable to the International System of Units (SI). Practice E2428 describes how these ~~devices~~ elastic torque measurement standards are to be calibrated. The procedures are useful to users of testing machines, manufacturers and providers of elastic torque ~~measuring instruments,~~measurement standards, calibration laboratories that provide calibration services and documents of metrological traceability, ~~and~~ service organizations using ~~devices to verify testing machines.~~ elastic torque measurement standards to calibrate and verify testing machines, and testing laboratories performing general structural test measurements.

~~5. Reference Standards~~

~~5.1 Torque-measuring instruments used for the verification of the torque indication systems of testing machines may be calibrated by either primary or secondary torque standards.~~

~~5.2 Torque-measuring instruments used as secondary torque standards for the calibration of other torque-measuring instruments shall be calibrated by primary torque standards.~~

5. ~~Requirements for Torque~~ Reference Measurement Standards

5.1 Elastic torque measurement standards used for the calibration and verification of the torque-measuring systems of testing machines may be calibrated by either primary or secondary torque measurement standards.

5.2 Elastic torque measurement standards used as secondary torque measurement standards for the calibration of other elastic torque measurement standards shall be calibrated by primary torque measurement standards.

5.3 *Primary Torque Measurement Standard*—~~Torque, displaying metrological traceability to the International System of Units (SI) of length and mass, and of specific measurement uncertainty, that can be applied to torque measuring devices.~~ Weights used as primary ~~mass~~ force measurement standards shall be made of rolled, forged, or cast metal. Adjustment cavities shall be closed by threaded plugs or suitable seals. External surfaces of weights shall have a surface ~~(Roughness Average or Ra) of 3.2µm~~roughness average of 3.2 µm or less as specified in ASME B46.1.

5.3.1 ~~The~~ Calculate the force exerted by a weight in air ~~is calculated as follows:~~using the following equation:

$$F = M \times g\left(1 - \frac{d}{D}\right) \quad (1)$$

where:

F = force, N
M = true mass of the weight, kg,
g = local acceleration due to gravity, m/s^2,
d = air density (approximately 1.2 kg/m^3), and
D = density of the weight in the same units as d.

~~Force = (Mg/9.80665) (1 − (d/D)) (1)~~

~~where:~~

~~M = mass of the weight,~~
~~g = local acceleration due to gravity, m/s²,~~
~~d = air density (approximately 1.2 kg/m³),~~
~~D = density of the weight in the same units as d, and~~
~~9.80665 = the factor converting SI units of force into the customary units of force. For SI units, this factor is not used.~~

5.3.2 For the purposes of this practice, g can be calculated with sufficient uncertainty using the following formula:

$$g = 9.7803[1 + 0.0053(\sin \varnothing)^2] - 0.000001967h \quad (2)$$

where:

g = local acceleration due to gravity, m/s^2,
$\varnothing$ = latitude,
h = elevation above sea level in meters.

NOTE 1—Eq 2 corrects for the shape of the earth and the elevation above sea level. The first term, which corrects for the shape of the earth, is a simplification of the World Geodetic System 84 Ellipsoidal Gravity Formula. The results obtained with the simplified formula differ from those in the full version by less than 0.0005 %. The second term combines a correction for altitude, the increased distance from the center of the earth, and a correction for the counteracting Bouguer effect of localized increased mass of the earth. The second term assumes a rock density of 2.67 g/cm^3. If the rock density changed by 0.5 g/cm^3, an error of 0.003 % would result.

5.3.3 ~~The masses of the weights shall be determined by comparison with reference standards metrologically traceable to the International System of Units (SI) for mass. The local value of the acceleration due to gravity, calculated within 0.0001 m/s~~In some cases, a mass might not be designated in kilograms, for instance it might be denoted in pounds, and it might be desired to know the force exerted in pound-force units. In other cases, it might be desired to know the force exerted in kilogram-force units where the mass is designated in kilograms. In these cases, the force in non-SI units exerted by a weight in air is calculated as follows:

$$F_C = \frac{M \times g}{9.80665}\left(1 - \frac{d}{D}\right) \quad (3)$$

2

where:

F_C = force expressed in customary units, such as, pound-force or kilogram-force,
M = true mass of the weight, in the corresponding mass units of the force, F_C is being expressed, such as, pound or kilogram,
g = local acceleration due to gravity, m/s^2,
9.80665 = the factor converting SI units of force into non-SI units of force; this factor is equal to the value for standard gravity, 9.80665 m/s^2,
d = air density (approximately 1.2 kg/m^3), and
D = density of the weight in the same units as d.

~~(10 milligals), may be obtained from the National Geodetic Information Center, National Oceanic and Atmospheric Administration.~~

5.3.3.1 If *M*, the mass of the weight is in pounds, the force will be in pound-force units (lbf). If *M* is in kilograms, the force will be in kilogram-force units (kgf). These non-SI force units are related to the newton (N), the SI unit of force, by the following relationships:

~~NOTE 2—If *M*, the mass of the weight, is in pounds, the force will be in pound-force units (lbf). If *M* is in kilograms, the force will be in kilogram-force units (kgf). These customary force units are related to the newton (N), the SI unit of force, by the following relationships:~~

~~1 lbf = 4.44822 N~~
~~1 kgf = 9.80665 N (exact)~~

~~The newton (N) is defined as the force applied to a 1-kg mass that produces an acceleration of 1 m/s/s.~~
~~The pound-force (lbf) is defined as the force applied to a 1-lb mass that produces an acceleration of 9.80665 m/s/s.~~
~~The kilogram-force (kgf) is defined as the force applied to a 1-kg mass that produces an acceleration of 9.80665 m/s/s.~~

$$1 \text{ lbf} = 4.448222 \text{ N} \tag{4}$$

$$1 \text{ kgf} = 9.80665 \text{ N (exact)} \tag{5}$$

5.3.4 The ~~lever~~moment arm ~~or wheel~~ shall be calibrated to determine the length or radius length with a known ~~uncertainty,~~ measurement uncertainty that is metrologically traceable to the International System of Units (SI) for length. ~~The expanded uncertainty with a confidence factor of 95 % (K=2) for the torque calibrator shall not exceed 0.012 %~~ .

5.3.5 The expanded measurement uncertainty for the primary torque measurement standard shall not exceed 0.012 % of applied torque, with an approximate coverage factor of 95 % (*k*=2).

5.4 *Secondary Torque Measurement Standards*—~~Secondary~~ A secondary torque measurement standard is typically ~~a torque transducer~~ an elastic torque measurement standard used with a machine for applying ~~torque, or a~~ torque. An alternative is a force-multiplying system that uses a mechanical or hydraulic mechanism to apply or multiply a ~~force.~~force to a moment arm.

~~6.2.1 The multiplying ratio of a force multiplying system used as a secondary torque standard shall be measured at not less than ten points over its range with an accuracy of 0.06 % of ratio or better. Some systems may show a systematic change in ratio with increasing force. For these cases the ratio at intermediate points may be obtained by linear interpolation between measured values. Deadweights used with multiplying-type secondary torque standards shall meet the requirements of 6.1 and 6.1.2. The force exerted on the system shall be calculated from the relationships given in 6.1.1. The force multiplying system shall be checked annually by elastic force measuring instruments used within their class AA loading ranges to verify the forces applied by the system are within acceptable ranges defined by this standard. Changes exceeding 0.06 % of applied force shall be cause for re-verification of the force multiplying system.~~

~~$LLF_c = \sqrt{LLF_1^2+LLF_2^2+...+LLF_n^2}$ (2)~~

~~*where:*~~

~~LLF_C = Lower limit factor of the combination, and~~
~~$LLF_{1, 2, ... n}$ = Lower limit factor of the individual instruments~~

5.4.1 ~~Torque transducers~~ Elastic torque measurement standards used as secondary torque measurement standards shall be calibrated by primary torque measurement standards and used only over the Class AA ~~loading range~~ verified range of torques in this practice (see ~~8.6.2.1~~7.4.1.2).

5.4.2 Other types of torque measurement standards may be used and shall be calibrated. The expanded ~~uncertainty with a confidence factor of 95% (K=2)~~ measurement uncertainty shall not exceed ~~0.06%~~ 0.06 % of the applied ~~torque.~~ torque, with an approximate coverage factor of 95 % (*k*=2).

~~7. Calibration~~

~~7.1 *Basic Principles*—The relationship between the applied torque and the deflection of a torque transducer is, in general, not linear. As the torque is applied, the shape of the elastic element changes, progressively altering its resistance to deformation. The result is that the slope of the torque-deflection curve changes gradually and continuously over the entire range of the instrument. This characteristic curve is a stable property of the instrument that is changed only by a severe overload or other similar cause.~~

~~7.1.1 Superposed on this curve are local variations of instrument readings introduced by imperfections in the torque transducer. Examples of imperfections include instabilities in excitation voltage, voltage measurement, or ratio-metric voltage measurement in a torque transducer. Some of these imperfections are less stable than the characteristic curve and may change significantly from one calibration to another.~~

~~7.1.2 *Curve Fitting*—To determine the torque-deflection curve of the torque transducer, known torque values are applied and the resulting deflections are measured throughout the range of the torque transducer. A polynomial equation is fitted to the calibration data by the least squares method to predict deflection values throughout the loading range. Such an equation compensates effectively for the nonlinearity of the calibration curve. The standard deviation determined from the difference of each measured deflection value from the value derived from the polynomial curve at that torque provides a measure of the error of the data to the curve fit equation. A statistical estimate, called the Lower Limit Factor, LLF, is derived from the calculated standard deviation and represents the width of the band of these deviations about the basic curve with a probability of 95%. The LLF is, therefore, an estimate of one source of uncertainty contributed by the torque transducer when torque values measured in service are calculated by means of the calibration equation. Actual errors in service are likely to be different if torque values are applied under mechanical and environmental conditions differing from those of calibration. Other sources of uncertainty could increase the uncertainty of measurement of the torque transducer in service.~~

~~NOTE 3—While it is the responsibility of the calibration laboratory to calibrate the torque transducer in accordance with the requirements of this practice it is the responsibility of the user to determine the uncertainty of the torque transducer in service.~~

~~7.1.3 *Curve Fitting using polynomials of greater than 2nd degree*—The use of calibration equations of the 3rd, 4th, or 5th degree is restricted to devices having a resolution of 1 increment of count per 50000 or greater active counts at the maximum calibration torque. Annex A1 specifies the procedure for obtaining the degree of the best fit calibration equation for these devices. Equations of greater than 5th degree shall not be used.~~

~~NOTE 4—For some torque transducers, use of a polynomial fit higher than the second degree may result in a lower LLF. Over-fitting should be avoided. Equations of greater than 5th degree cannot be justified due to the limited number of increments in the calibration protocol. Errors caused by round-off may occur if calculations are performed with insufficient precision. A torque transducer not subjected to repair, overloading, modifications, or other significant influence factors that alter its elastic properties or its sensing characteristics will likely exhibit the same degree of best fit on each succeeding calibration as was determined during its initial calibration using this procedure. A torque transducer not subjected to the influence factors outlined above which exhibits continued change of degree of best fit with several successive calibrations may not have sufficient performance stability to allow application of the curve fitting procedure of Annex A1.~~

~~7.2 *Selection of Calibration Torque Values*—A careful selection of the different torque values to be applied in a calibration is essential to provide an adequate and unbiased sample of the full range of the deviations discussed in 7.1 and 7.1.1. For this reason, the selection of the calibration torque values is made by the standardizing laboratory. An exception to this, and to the recommendations of 7.2.1 and 7.2.4, is made for specific torque measurement devices, where the selection of the torque values is dictated by the needs of the user.~~

~~7.2.1 *Distribution of Calibration Torque Values*—Distribute the calibration torque values over the full range of the torque transducer, providing, if possible, at least one calibration torque for every 10 % interval throughout the range. It is not necessary, however that these torques be equally spaced. Calibration torque values at less than one tenth of capacity are permissible and tend to give added assurance to the fitting of the calibration equation. If the lower limit of the loading range of the device (see 8.6.1) is anticipated to be less than one tenth of the maximum torque applied during calibration, then torque values should be applied at or below this lower limit. The smallest torque applied shall be equal to or below the theoretical lower limit of the instrument as defined by the values: 400 × resolution for Class A loading range and 1667 × resolution for Class AA loading range. In torque transducer calibration with electrical instruments capable of linearizing the output signal, whenever possible, select calibration torques other than those at which the linearity corrections were made.~~

~~7.2.2 *Resolution Determination*—The resolution of a digital instrument is considered to be one increment of the last active number on the numerical indicator, provided that the reading does not fluctuate by more than plus or minus one increment when no torque is applied to the instrument. If the readings fluctuate by more than plus or minus one increment, the resolution will be equal to half the range of fluctuation.~~

~~7.2.3 *Number of Calibration Torque Values*—A total of at least 30 torque applications per mode, clockwise or counter clockwise, is required for a calibration and, of these, at least 10 must be at different torque values. Apply each torque value at least twice during the calibration in both the clockwise and counter clockwise direction, as applies.~~

~~7.2.4 *Specific Torque Devices (Limited Torque Devices)*—Because these devices are used only at the calibrated torque values, select those torque values which would be most useful in the service function of the instrument. Coordinate the selection of the calibration torque values with the submitting organization. Apply each calibration torque at least three times in order to provide sufficient data for the calculation of the standard deviation of the observed deflections about their average values.~~

~~7.3 *Temperature Equalization:*~~

~~7.3.1 Allow the torque measurement system sufficient time to adjust to the ambient temperature in the calibration machine prior to calibration in order to assure stable instrument response.~~

~~7.3.2 The recommended value for room temperature calibrations is 23°C.~~

~~7.3.3 During the calibration, monitor and record the temperature as close to the torque transducer as possible. It is recommended that the test temperature not change more than ±1°C during calibration, but in no case shall it change more than ±2°C.~~

~~7.4 *Procedural Order in Calibration*—Immediately before starting the calibration, pre-load the torque-measuring instrument to the maximum torque to be applied at least two times. Pre-loading is necessary to reestablish a stable minimum torque output value and to condition the transducer for stable performance. This is particularly necessary following a change in the mode of loading, as from clockwise to counter clockwise. Some instruments may require more than two pre-loads to achieve stability in zero- torque indication.~~

~~NOTE 5—Overload or proof load tests are not required by this practice. An essential part of the manufacturing process for a torque transducer should be the application of a series of overloads to at least 10 % in excess of rated capacity. This should be done before the instrument is released for calibration or service. For performance verification following overload within the safe overload range of the instrument, it is recommended that an overload test encompassing the anticipated range of overload be conducted.~~

~~7.4.1 After pre-loading, apply the calibration torque value, approaching each torque value from a lesser value of torque. Torque values shall be applied and removed slowly and smoothly, without inducing shock or vibration to the torque-measuring instrument. The time interval between successive applications or removals of torque values, and in obtaining readings from the torque-measuring instrument, shall be as uniform as possible. If a calibration torque is to be followed by another calibration torque of lesser magnitude, reduce the applied torque on the instrument to zero before applying the second calibration torque.~~

~~7.4.2 For any torque transducer, the errors observed at corresponding torque values taken first by increasing the torque to any given test torque and then by decreasing the torque to that test torque may not agree. Torque transducers are usually used under increasing torque, but if a torque transducer is to be used under decreasing torque, it shall be calibrated under decreasing torque with decreasing torque values. Use the procedures for calibration and analysis of data given in Sections 7 and 8 except where otherwise noted. When a torque transducer is calibrated with both increasing and decreasing torque, it is recommended that the same torque increments be applied, but required that separate calibration equations are developed.~~

~~7.4.3 The calibration laboratory shall decide whether or not a zero-torque reading is to be taken after each calibration torque value. Factors such as the stability of the zero-torque reading, the presence of noticeable creep following the application of torque loads, and the expected use are factors to be considered. It is pointed out, however, that a lengthy series of incremental torque values applied without returning to zero reduces the amount of sampling of the torque transducer performance. The operation of removing all torque from the instrument permits small readjustments at the torque reacting surfaces, increasing the amount of random sampling and thus potentially producing a better appraisal of the performance of the torque transducer. It is recommended that not more than five incremental torque values be applied without return to zero. This is not necessary when the instrument is calibrated with decreasing torque; however, any return to zero prior to application of all the individual torque increments must be followed by application of the maximum torque before continuing the sequence.~~

~~7.5 *Randomization of Loading Conditions*—Shift the position of the instrument in the calibration machine before repeating any series of torque values. Rotate the torque transducer in the mounting fixtures by amounts such as one-third, one quarter, or one-half turn, and shift and realign any keyed connectors. If the calibration is done in both clockwise and counter clockwise directions, perform a part of the counter clockwise calibration, do the clockwise calibration, then finish the counter clockwise calibration afterward. Introduce variations in any other factors that normally are encountered in service, as for example, disconnecting and reconnecting electrical cables. Allow sufficient time for the instrument to reach temperature stability if power is removed or cabling is removed and then reconnected.~~

~~NOTE 6—A situation to be avoided is rotating the torque-measuring instrument from 0° to 180° to 0° during calibration, since the final position duplicates the first, and reduces the randomization of loading conditions.~~

~~NOTE 7—Depending on their design, torque transducers vary in sensitivity to mounting conditions, parasitic forces or moments due to misalignment. A measure of this sensitivity may be to simulate these factors such as *(a)* using fixtures of varying stiffness or hardness, *(b)* applying the appropriate torque for bolting fixtures with different torque ratings, or *(c)* mounting in various orientations with angular or eccentric misalignment, and so forth. Such factors can sometimes be significant contributors to measurement uncertainty and should be reflected in comprehensive measurement uncertainty analyses.~~

~~NOTE 8—It is recommended that during the calibration of torque transducers that use a square drive, four rotations of the torque transducer should occur resulting in four calibration runs per mode.~~

6. Calibration

6.1 *Basic Principles*—The relationship between the applied calibration torque and the deflection of an elastic torque measurement standard is, in general, not linear. As the calibration torque is applied, the shape of the elastic member changes, progressively altering its resistance to deformation. The result is that the slope of the torque-deflection curve changes gradually and continuously over the entire range of the elastic torque measurement standard. This characteristic curve is a stable property of the elastic torque measurement standard that is changed only by a severe overload or other similar cause.

6.1.1 Superposed on this curve are local variations introduced by imperfections in the elastic torque measurement standard. Examples of imperfections include instabilities in excitation voltage, voltage measurement, or ratio-metric voltage measurement in an elastic torque measurement standard. Some of these imperfections are less stable than the characteristic curve and can change significantly from one calibration to another.

6.1.2 *Curve Fitting*—To determine the torque-deflection curve of the elastic torque measurement standard, known calibration torque values are applied and the resulting deflections are measured throughout the verified range of torques of the elastic torque measurement standard. A polynomial equation is fitted to the calibration data by the least squares method to predict deflection throughout the verified range of torques. Such an equation compensates effectively for the nonlinearity of the calibration results. The standard deviation determined from the difference of each measured deflection from the value derived from the polynomial curve at that calibration torque provides a measure of the error of the measurement data to the calibration equation. A statistical estimate, called the lower limit factor, *LLF*, is derived from the calculated standard deviation and represents the width of the band of these deviations about the basic curve with a probability of approximately 95 %. The *LLF* is, therefore, an estimate of one source of measurement uncertainty contributed by the elastic torque measurement standard when calibration torque values measured in service are calculated by means of the calibration equation. Actual measurement errors in service are likely to be different if calibration torque values are applied under mechanical and environmental conditions differing from those of calibration. Other sources of measurement errors could increase the measurement uncertainty of the elastic torque measurement standard in service. The calibration laboratory shall calibrate the elastic torque measurement standard in accordance with the requirements of this practice, and the user shall determine the measurement uncertainty of the elastic torque measurement standard in service.

6.1.3 *Curve Fitting Using Polynomials of Greater Than 2nd Degree*—Calibration equations of the 3rd, 4th, or 5th degree shall only be used with elastic torque measurement standards having a resolution of 1 increment of count per 50000 or greater active counts at the maximum calibration torque value. Annex A1 specifies the procedure for obtaining the degree of the best-fit calibration equation. Equations of greater than 5th degree shall not be used.

NOTE 2—For some elastic torque measurement standards, use of a polynomial fit higher than the second degree can result in a lower *LLF* than that derived from the second-degree fit (ASTM RR:E28-1009)[5]. Equations of greater than 5th degree cannot be justified due to the limited number of increments in the calibration protocol. Errors caused by round-off can occur if calculations are performed with insufficient digits of resolution. An elastic torque measurement standard not subjected to repair, overloading, modifications, or other significant influence factors that alter its elastic properties or its sensing characteristics will likely exhibit the same degree of best fit on each succeeding calibration as was determined during its initial calibration using this procedure. An elastic torque measurement standard not subjected to the influence factors outlined above that exhibits continued change of degree of best fit with several successive calibrations could have insufficient performance stability to allow application of the curve-fitting procedure of Annex A1.

6.2 *Selection of Calibration Torque Values*—A careful selection of the different calibration torque values to be applied in a calibration is essential to provide an adequate and unbiased sample of the full range of the deviations discussed in 6.1 and 6.1.1. For this reason, the calibration laboratory shall select the calibration torque values.

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[5] ~~Available from National Oceanic and Atmospheric Administration (NOAA), 14th St. and Constitution~~Supporting data have been filed at the ASTM International Headquarters and may be obtained by requesting Research Report RR:E28-1009~~Ave., NW, Room 6217, Washington, DC 20230, http://www.noaa.gov.~~. Contact ASTM Customer Service at service@ASTM.org.

6.2.1 *Distribution of Calibration Torque Values*—Distribute the calibration torque values over the full range of the elastic torque measurement standard. If possible, at least one calibration torque value should be applied for every 10 % interval throughout the range. It is not necessary, however, that these calibration torques be equally spaced. Calibration torque values less than one tenth of capacity may be used and tend to give added assurance to the fitting of the calibration equation. If the lower torque limit of the verified range of torques of the elastic torque measurement standard (see 7.4.1) is anticipated to be less than one tenth of the maximum calibration torque applied during calibration, then calibration torque values should be applied at or below this lower torque limit. The smallest calibration torque value applied shall be less than or equal to the theoretical lower torque limit of the elastic torque measurement standard. The smallest calibration torque value applied is defined by the values: 400 × resolution for Class A verified range of torques and 1667 × resolution for Class AA verified range of torques. In elastic torque measurement standard calibration with an electronic-indicating measurement instrument capable of linearizing the indicated signal, whenever possible, select calibration torque values other than those at which the linearity corrections were made.

6.2.2 *Resolution Determination*—The resolution of an electronic-indicating measurement shall be one increment of the last active number on the electronic-indicating measurement instrument of the elastic torque measurement standard. If the indication fluctuates by more than plus or minus one increment, the resolution shall be equal to half the range of fluctuation when zero-torque is applied to the elastic torque measurement standard.

6.2.3 *Number of Calibration Torque Values:*

6.2.3.1 A total of at least 30 calibration torque applications per mode, clockwise or counterclockwise.

6.2.3.2 At least 10 calibration torque values shall be at different calibration torque values.

6.2.3.3 Apply each calibration torque value at least twice during the calibration in both the clockwise and counterclockwise direction, as applies.

6.3 *Temperature Considerations:*

6.3.1 Allow the elastic torque measurement standard enough time to adjust to the ambient temperature in the calibration machine prior to calibration to ensure stable response.

6.3.2 The ambient temperature during calibration should be 23 °C, although other temperatures may be used.

6.3.3 During the calibration, monitor and record the temperature as close to the elastic torque measurement standard as possible. The temperature should not change more than ±1 °C during calibration.

6.4 *Procedural Order in Calibration:*

6.4.1 Immediately before starting the calibration, slowly and smoothly apply the maximum calibration torque value in the calibration sequence to the elastic torque measurement standard. The maximum calibration torque value may be applied multiple times to help achieve stability in zero-torque indication.

NOTE 3—Exercising to the maximum calibration torque reestablishes a stable minimum calibration torque indication and conditions the elastic torque measurement standard for stable performance. Exercising is particularly important following a change in the mode, as from clockwise to counterclockwise. Some elastic torque measurement standards achieve stability in zero-torque indication only after two exercise cycles.

NOTE 4—Overload or proof load tests are not required by this practice.

6.4.2 After the exercise cycles, apply the calibration torque values.

6.4.3 For ascending calibration torque, approach each calibration torque value from a lesser magnitude of torque.

6.4.3.1 Calibration torque values shall be applied and removed slowly and smoothly, without inducing shock or vibration to the elastic torque measurement standard.

6.4.3.2 The time interval between successive applications or removals of calibration torque values, and in obtaining indications from the elastic torque measurement standard, shall be as uniform as possible.

6.4.3.3 If a calibration torque value is to be followed by another calibration torque value of lesser magnitude, reduce the applied calibration torque on the elastic torque measurement standard to zero torque before applying the subsequent calibration torque value.

6.4.4 If an elastic torque measurement standard is to be used under decreasing calibration torque, it shall be calibrated under decreasing torque with decreasing calibration torque values. Use the procedures for calibration and analysis of data given in Sections 6 and 7. When an elastic torque measurement standard is calibrated with both increasing and decreasing calibration torque, the same calibration torque increments shall be applied, and separate calibration equations shall be developed.

NOTE 5—For any elastic torque measurement standard, the measurement errors observed at corresponding calibration torque values taken first by increasing the torque to any given calibration torque value and then by decreasing the calibration torque value to that calibration torque value do not always agree. Elastic torque measurement standards are usually used under increasing torque.

6.5 *Randomization of Calibration Torque Application Condition:*

6.5.1 During the calibration, maintain the torque measurement axis of the elastic torque measurement standard coincident with the torque axis of the calibration machine.

6.5.2 Rotate the position of the elastic torque measurement standard in the calibration machine by amounts such as one third, one quarter, or one half turn and realign any keyed connectors before repeating any series of calibration torque applications.

6.5.3 Introduce variations in any other factors that normally are encountered in service, as for example, disconnecting and reconnecting electrical cables.

6.5.4 Allow sufficient time for the elastic torque measurement standard to reach temperature stability if power is removed or cabling is removed and then reconnected.

6.5.5 In a two-mode calibration (clockwise and counter-clockwise) perform a part of the calibration in one mode.

6.5.5.1 Switch modes and continue the calibration.

6.5.5.2 Finish the calibration in the initial mode.

6.5.5.3 Modes may be changed at each rotational position.

NOTE 6—Depending on their design, elastic torque measurement standards vary in sensitivity to mounting conditions, parasitic forces, or moments due to misalignment. A measure of this sensitivity can be made by imposing conditions to simulate these factors such as *(a)* using fixtures of varying stiffness or hardness, *(b)* applying the appropriate torque for bolting fixtures with different torque ratings, or *(c)* mounting in various orientations with angular or eccentric misalignment, and so forth. Such factors can sometimes be significant contributors to measurement uncertainty and should be reflected in comprehensive measurement uncertainty analyses.

6.5.6 During the calibration of elastic torque measurement standards that use a square drive, rotate the elastic torque measurement standard to each position resulting in four calibration runs per mode.

6.6 *Deflection Calculation*—The method selected for treatment of zero should reflect anticipated usage of the elastic torque measurement standard. The calculation shall *(a)* use the initial zero value only or *(b)* a value derived from indications taken before and after the application of a calibration torque or series of calibration torque values.

6.6.1 *Method (a):*

6.6.1.1 Calculate the deflection as the difference between the indication at the applied calibration torque and the indication at initial zero torque.

6.6.1.2 Perform a creep recovery test per the criteria of 6.7 to ensure that the zero-return characteristic of the elastic torque measurement standard does not result in excessive measurement error.

6.6.2 *Method (b):*

6.6.2.1 When it is elected to return to zero after each applied calibration torque, the average of the two zero values shall be used to determine the deflection.

6.6.2.2 When a series of applied calibration torque values are applied before return to zero calibration torque, a series of interpolated zero torque indications may be used for the calculations. In calculating the average zero torque indications, express the values to the nearest unit in the same number of places as estimated in the indication of the electronic-indicating measurement instrument scale. Follow the instructions for the rounding method given in Practices E29.

6.7 *Determination of Creep Recovery*—Perform a creep recovery test to ensure that the creep characteristic of the elastic torque measurement standard does not have a significant effect on calculated deflections when method *(a)* is used to determine deflections.

NOTE 7—Creep affects the calculation of deflection. A large non-return to zero following calibration torque application during calibration is a demonstration of excessive creep.

NOTE 8—Creep and creep recovery are generally stable properties of an elastic torque measurement standard unless the elastic torque measurement standard is overloaded, has experienced moisture or other contaminant incursion, or is experiencing fatigue failure.

6.7.1 *Method (a)*—Perform the creep recovery test for elastic torque measurement standards that are new, that have never had a creep recovery test performed, that have had major repairs, that are suspected of having been overloaded, or that show excessive non-return to zero following calibration.

6.7.2 *Method (b)*—The creep recovery test is not required since method *(b)* is used to determine deflections on an elastic torque measurement standard both during calibration and subsequent use.

6.7.3 Perform the creep recovery test as follows:

6.7.3.1 Exercise the elastic torque measurement standard to the maximum calibration torque value at least two times.

6.7.3.2 Allow the zero-return indication to stabilize and record the value of the initial zero-return indication T_{izr}.

6.7.3.3 Apply the maximum applied calibration torque used in calibration of the elastic torque measurement standard and hold as constant as possible for 300 s, and then record the indication of the elastic torque measurement standard, T_c.

6.7.3.4 Remove the applied calibration torque as smoothly but as quickly as possible, and record the indication at 30 s, T_{30}, and at 300 s, T_{300}.

6.7.4 Calculate the creep recovery error, E_{cr}, as follows:

$$E_{cr} = \frac{100 \times (T_{30} - T_{izr})}{T_c} \tag{6}$$

where:

E_{cr} = creep recovery error
T_{30} = indication 30 s after zero torque is achieved
T_{izr} = initial zero-return indication
T_c = indication at maximum calibration torque applied

6.7.5 A zero-return error shall be calculated as follows:

$$E_{zr} = \frac{T_{300} - T_{izr}}{T_c} \tag{7}$$

where:

E_{zr} = zero-return error
T_{300} = final zero-return indication 300 s after the applied calibration torque is removed
T_{izr} = iinitial zero-return indication
T_c = indication at maximum calibration torque applied