INTERNATIONAL

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Standard Practice for Calibration and Verification of Elastic Torque 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*

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

1.2 *Units*—The values stated in SI units are to be regarded as standard. 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 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 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, health, and 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)

2.3 *BIPM 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 measurement standard, n*—A deadweight force applied through a moment arm, all with metrological traceability to the International System of Units (SI).

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

3.2 *Definitions of Terms Specific to This Standard:*

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

3.2.2 *creep, n*—The change in indication of the elastic torque 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

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[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.

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

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

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

gage design and process modifications to reduce the strain gage response to the inherent time-dependent elastic deformation.

3.2.3 *creep recovery, n*—The 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 *deflection, n*—The difference between the indication of the elastic torque measurement standard under applied torque and the indication with zero applied 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, torque-measuring transducer, or torque cell.

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

3.2.6.1 *Discussion*—The lower limit factor is used to calculate the lower torque limit of the verified range of torques. Other factors evaluated in establishing the lower torque limit of the verified range of torques are the resolution of the elastic torque measurement standard and the lowest non-zero torque applied in the calibration 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 revisions prior to E2428-15a.

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

3.2.8 *moment arm, n*—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*—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.

3.2.9 *verified range of torques, n*—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 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 elastic torque measurement standards are to be calibrated. The procedures are useful to users of testing machines, manufacturers and providers of elastic torque measurement standards, calibration laboratories that provide calibration services and documents of metrological traceability, service organizations using elastic torque measurement standards to calibrate and verify testing machines, and testing laboratories performing general structural test measurements.

5. 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*—Weights used as primary 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 of 3.2 µm or less as specified in ASME B46.1.

5.3.1 Calculate the force exerted by a weight in air 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.

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,
Ø = 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 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:

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

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.

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:

$$1\ \text{lbf} = 4.448222\ \text{N} \quad (4)$$

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

5.3.4 The moment arm shall be calibrated to determine the length or radius length with a known measurement uncertainty that is metrologically traceable to the International System of Units (SI) for length.

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

5.4.1 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 verified range of torques in this practice (see 7.4.1.2).

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

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.

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.

[5] Supporting data have been filed at the ASTM International Headquarters and may be obtained by requesting Research Report RR:E28-1009. Contact ASTM Customer Service at service@ASTM.org.

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 counterclockwise) 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:

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

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:

$$E_{zr} = \frac{T_{300} - T_{izr}}{T_c} \quad (7)$$

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

6.7.6 *Creep Recovery Maximum Permissible Measurement Error*—For elastic torque measurement standards calibrated for use over the following verified ranges of torques, the creep recovery maximum permissible measurement error of the indication at the applied calibration torque value are
Class AA: ±0.02 %
Class A: ±0.05 %.

6.7.7 The creep recovery test should be repeated if the zero-return error exceeds 50 % of the creep recovery maximum permissible measurement error limits. If the zero-return measurement error in the second creep-recovery test exceeds 50 % of the creep recovery maximum permissible measurement error limits, either repair, replace, or use Method *(b)* as defined in 6.6.2.

7. Calculation and Analysis of Data

7.1 *Calibration Equation*—Fit a polynomial equation of the following form to the calibration torque and deflection obtained in the calibration using the method of least squares:

$$D = A_0 + A_1 + A_2\tau^2 + ...A_5\tau^2 \quad (8)$$

where:

D = Deflection ,
τ = calibration torque, and
A_0 through A_5 = coefficients

A 2nd degree equation should be used with coefficients A_3, A_4, and A_5, equal to zero. Other degree equations may be used.

NOTE 9—For example, the coefficients A_2 through A_5 would be set equal to zero for a linearized elastic torque measurement standard.

7.1.1 The procedure of Annex A1 shall be used to obtain the maximum degree of the best-fit polynomial equation statistically supported by the calibration data set. Perform the calculation with a polynomial equation fitted to the average data at each applied calibration torque value following the method of Annex A1. After determination of the degree of the best-fit polynomial equation, fit the polynomial equation of that degree, or a lower degree, to the entire calibration data set (not the average data set) in accordance with 7.3, and proceed to analyze the data in accordance with 7.4.

7.2 *Standard Deviation*—Calculate a standard deviation from the differences between the individual values observed in the calibration and the corresponding values taken from the calibration equation. Calculate the standard deviation as follows:

$$s_m = \sqrt{\frac{d_1^2 + d_2^2 ... + d_n^2}{n - m - 1}} \quad (9)$$

where:

s_m = standard deviation
d_1, d_2, etc. = differences between the fitted curve and the n observed values from the calibration data,
n = number of deflections, and
m = the degree of polynomial fit

NOTE 10—The departures of the observed deflections from the calibration equation values are not purely random but arise partly from the localized variation and elastic torque measurement standard resolution, discussed in 6.1.1. Consequently, the distributions of the residuals from the least squares fit might not follow the normal curve of error, and the customary estimates based on the statistics of random variables might not be strictly applicable.

7.3 *Determination of Lower Limit Factor, LLF*—Calculate the *LLF* as 2.0 times the standard deviation. If the calculated *LLF* is less than the elastic torque measurement standard resolution, define the *LLF* as that value equal to the resolution. Express the *LLF* in torque units, using the average ratio of torque to deflection from the calibration data.

7.4 *Verified Range of Torques*—Calculate the verified range of torques of the elastic torque measurement standard as follows.

7.4.1 *Lower Torque Limit of the Verified Range of Torques*—Calculate the lower torque limit, T_{ll}, of the verified range of torques as a percent of indication, P, and class of the verified range of torques as:

$$T_{ll} = \frac{100 \times LLF}{P} \quad (10)$$

where:

T_{ll} = lower torque limit
LLF = lower limit factor
P = percent of indication

7.4.1.1 For Class A verified range of torques P=0.25 %.

7.4.1.2 For Class AA verified range of torques P=0.06 %.

7.4.1.3 The lower torque limit should be 2 % (1/50) or greater of capacity of the elastic torque measurement standard.

7.4.1.4 When a verified range of torques other than the two standard ranges given in 7.4.1.1 and 7.4.1.2 is desirable, the appropriate lower torque limit error should be specified in the applicable method of test.

7.4.2 The verified range of torques shall not include calibration torque values outside the range of calibration torque values applied during calibration. If the lower torque limit is less than the lowest non-zero calibration torque value applied, the lower torque limit of the verified range of torques is equal to the lowest calibration torque value applied.

NOTE 11—For example, an elastic torque measurement standard calibrated using primary torque measurement standards applied on a moment arm at a known distance had a calculated *LLF* of 0.338 N-m. The lower torque limit for the Class AA verified range of torques is therefore T_{ll} =100×*LLF*/0.06=563 N-m. The *LLF* will be less than the lower torque limit error of ±0.06 % of torque for calibration torques greater than this lower torque limit to the maximum calibration torque value of the elastic torque measurement standard.

7.4.3 For elastic torque measurement standards used to verify testing machines in accordance with Practices E2624, or similar applications, the lower limit factor of the elastic torque measurement standard shall not exceed 0.25 % of torque.

NOTE 12—The term "verified range of torques" used in these practices is parallel in meaning to the same term in Practices E2624. It is the range of calibration torque values over which it is permissible to use the elastic torque measurement standard in a calibrating a testing machine or other similar device

8. Temperature Requirement for Elastic Torque Measurement Standard During Use

8.1 *Temperature of Calibration*—the elastic torque measurement standard should be calibrated at 23 °C, although other temperatures may be used (see 6.3).

8.2 *Maximum permissible measurement error due to temperature effect*—If an elastic torque measurement standard is used at a temperature other than the temperature at which it was calibrated, the user shall ensure that the measurement error due to temperature, as a percent of indication, does not exceed:
Class AA ± 0.01 %
Class A ± 0.06 %.

NOTE 13—When the *LLF* for either Class AA or Class A verified range of torques is added as root-sum-squares with values for maximum permissible measurement error due to temperature given in 8.2, the effect on the maximum permissible measurement error due to temperature is negligible. Such a combination of measurement error sources is valid in the case of independent measurement error sources.

NOTE 14—Temperature effects can cause significant measurement errors in both temperature-compensated and uncompensated elastic torque measurement standards.

9. Time Interval Between Calibration and Stability Criteria

9.1 The elastic torque measurement standards shall meet the range, maximum permissible measurement errors, resolution, and stability requirements of this standard, and shall be suitable for the intended use.

9.2 Elastic torque measurement standards used as secondary torque measurement standards for the verification of torque indication of testing machines shall be calibrated at intervals not exceeding two years after demonstration of stability supporting the adopted calibration interval. New elastic torque measurement standards shall be calibrated at an interval not exceeding 1 year to determine stability per 9.2.1.

9.2.1 During recalibration, the elastic torque measurement standards shall, over the range of use, only demonstrate changes in calibration values of less than 0.032 % of indication for elastic torque measurement standards used over the Class AA verified range of torques and less than 0.16 % of indication for those elastic torque measurement standards used over the Class A verified range of torques.

9.2.2 Elastic torque measurement standards not meeting the stability criteria of 9.2.1 shall be calibrated at intervals that shall ensure the stability criteria are not exceeded during the calibration interval.

NOTE 15—The above stability criteria provide minimum requirements for establishing calibration intervals for elastic torque measurement standards.

9.2.3 Users specifying verified range of torques other than Class AA or Class A should determine stability criteria appropriate to the instruments employed.

9.2.4 Secondary torque measurement standards should be cross-checked at periodic intervals using other standards to help ensure that secondary torque measurement standards are performing as expected.

9.3 *Calibration Following Repairs or Overloads*—An elastic torque measurement standard shall be calibrated whenever the calibration of the elastic torque measurement standards might be suspect. Any elastic torque measurement standard sustaining an overload that produces a permanent shift in the zero-torque indication amounting to 1 % or more of the capacity of the elastic torque measurement standards shall be calibrated before further use.

9.3.1 A means of establishing a true zero reference should be developed to ensure that the zero-torque indication during calibration has not been shifted by an amount greater than 1 % of the elastic torque measurement standard capacity.

10. Substitution of Electronic Indicating Instruments Used for Elastic Torque Measurement Standards

10.1 The elastic member and the electronic-indicating measurement instrument may be calibrated separately. This allows for the substitution or repair of the electronic-indicating measurement instrument without the necessity for repeating an end-to-end elastic torque measurement standard calibration. When such substitution or repair is made, the user shall ensure that the measurement performance of the elastic torque measurement standard is maintained. Substitution of the electronic-indicating measurement instrument shall not extend the elastic torque measurement standard calibration date. The following conditions shall be satisfied when substituting a metrologically significant element of the electronic-indicating measurement instrument.

10.1.1 The electronic-indicating measurement instrument used in the initial calibration and the electronic-indicating measurement instrument to be substituted shall each have been calibrated and their measurement uncertainties determined. The electronic-indicating measurement instrument to be substituted shall be calibrated with metrological traceability to the SI over the full range of its intended use including both positive and negative values if the system is used in clockwise and counterclockwise modes. The calibrated range shall include a point less than or equal to the indication of the elastic torque measurement standard at the lower torque limit and a point equal to or greater than the indication of the elastic torque measurement standard at the maximum applied calibration torque. A minimum of five points shall be taken within this