Designation: E2428 – 08

Standard Practice for Calibration of Torque-Measuring Instruments for Verifying the Torque Indication of Torque Testing Machines[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 This practice is to specify procedure for the calibration of elastic torque-measuring instruments.

NOTE 1—Verification by deadweight and a lever arm is an acceptable method of verifying the torque indication of a torque 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 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.3 This practice is intended for the calibration of static or quasi-static torque measuring instruments. The practice is not applicable for high speed torque calibrations or 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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications

E2624 Practice for Torque Calibration of Testing Machines and Devices

2.2 *American National Standard:*

B46.1 Surface Texture[4]

ELASTIC TORQUE-MEASURING INSTRUMENTS

3. Terminology

3.1 *Definitions:*

3.1.1 *elastic torque-measuring device*—a device or system consisting of an elastic member combined with a device for indicating the measured values (or a quantity proportional to the measured value) of deformation of the member under an applied torque.

3.1.2 *primary torque standards*—a deadweight force applied through a lever arm or wheel, with a calibrated length or radius of a known uncertainty, that is traceable to national standards.

3.1.3 *secondary torque standard*—an instrument or mechanism, that has been calibrated by a comparison with a primary torque standard(s).

3.1.4 *torque*—a vector product of force and length, expressed in terms of N-m, lbf-in., etc.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *calibration equation*—a mathematical relationship between output of the unit under test and the applied standard torque, sometimes referred to as the calibration curve.

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 8.4).

3.2.3 *deflection*—the difference between the readings of an instrument under applied torque and the reading with no applied torque. The definition of deflection applies to output readings in electrical units as well as readings in units of torque.

[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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[2] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

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

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3.2.4 *torque range*—a range of torque values within which the uncertainty is less than the limits of error specified for the instrument application.

3.2.5 *reading*—a numerical value indicated on the scale, dial, electrical output or digital display of a torque- measuring instrument for a given torque.

3.2.6 *resolution*—the smallest change in reading or indication appropriate to the scale, dial, or display of the torque measuring instrument.

3.2.7 *specific torque device*—an alternative class of instruments not amenable to the use of a calibration equation.

3.2.7.1 *Discussion*—Such instruments, usually those in which the reading is taken from a dial indicator, are used only at the calibrated torque values.

3.2.8 *uncertainty*—a statistical estimate of the limits of error in torque values computed from the calibration equation of a torque-measuring instrument when the instrument is calibrated in accordance with this practice.

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 verification of these machines. A necessary element in Practice E2624 is the use of devices whose torque characteristics are known to be traceable to national standards. Practice E2428 describes how these devices are to be calibrated. The procedures are useful to users of torque testing machines, manufacturers and providers of torque measuring instruments, calibration laboratories that provide calibration services and documents, and service organizations using devices to verify torque testing machines.

5. Reference Standards

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

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

6. Requirements for Torque Standards

6.1 *Primary Standard*—Torque, with traceability derived from national standards of length and mass, and of specific measurement uncertainty, that can be applied to torque measuring devices. Weights used as primary mass 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 finish of 3.2m (Ra) or less as specified in ANSI B46.1.

6.1.1 The force exerted by a weight in air is calculated as follows:

$$\text{Force} = (Mg/9.80665)\,(1 - (d/D)) \quad (1)$$

where:

M = mass of the weight,
g = local acceleration due to gravity, m/s^2,
d = air density (approximately 1.2 kg/m^3),
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.

6.1.2 The masses of the weights shall be determined by comparison with reference standards traceable to the national standards of mass. The local value of the acceleration due to gravity, calculated within 0.0001 m/s^2 (10 milligals), may be obtained from the National Geodetic Information Center, National Oceanic and Atmospheric Administration.[5]

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 kilo gram-force units (kgf). These customary force units are related to the newton (N), the SI unit of force, by the following relationships:

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

The pound-force (lbf) is defined as that force which, applied to a 1-lb mass, would produce an acceleration of 32.1747 f/s/s.

6.1.3 The lever arm or wheel shall be calibrated to determine the length or radius with a known uncertainty, that is traceable to national standards of length. The expanded uncertainty with a confidence factor of 95 % (K=2) for the torque calibrator shall not exceed 0.012 % .

6.2 *Secondary Standards*—Secondary torque standards may be either elastic torque-measuring instruments used with a machine for applying torque, or a mechanical or hydraulic mechanism to apply or multiply a deadweight force.

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 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.

6.2.2 Elastic torque-measuring instruments used as secondary standards shall be calibrated by primary standards and used only over the Class AA loading range (see 8.5.2.1).

6.2.3 Other types of torque standards may be used and shall be calibrated. The expanded uncertainty with a confidence factor of 95% (K=2) shall not exceed 0.06% of the applied torque.

7. Calibration

7.1 *Basic Principles*—The relationship between the applied torque and the deflection of an elastic torque-measuring

[5] Available from National Oceanic and Atmospheric Administration (NOAA), 14th St. and Constitution Ave., NW, Room 6217, Washington, DC 20230, http://www.noaa.gov.

instrument 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 uniformly over the entire range of the instrument. This characteristic of full-scale non-linearity is a stable property of the instrument that is changed only by a severe overload or other similar cause.

7.1.1 *Localized Non-linearities*—Superimposed on this curve are localized non-linearities introduced by the imperfections in the torque indicating system of the instrument. Examples of these imperfections include voltage and sensing instabilities. Some of these imperfections are less stable than the full-scale non-linearity and may change from one calibration to another.

7.1.2 *Curve Fitting*—A second degree polynomial fitted to the observed calibration data using the method of least squares, predicts the deflection values for applied torque throughout the loading range of the elastic torque measuring instrument (see 8.4). Such an equation compensates effectively for the full-scale non-linearity, allowing the localized non-linearities to appear as deviations. A statistical estimate, called the uncertainty, is made of the width of the band of these deviations about the basic curve. The uncertainty is an estimate of the limits of error contributed by the instrument when torque values measured in service are calculated using the calibration equation. Actual errors in service will vary for torque values applied under loading and environmental conditions differing from those of the calibration.

7.1.3 *Curve Fitting for High Resolution Devices*—Annex A1 recommends a procedure for obtaining the degree of the best-fit calibration curve for these devices.

NOTE 3—Experimental work by several calibration laboratories in fitting higher than second degree polynomials to the observed data indicated that, for some devices, use of a higher degree equation may result in a lower uncertainty than derived from the second degree fit (ASTM RR:E28-1009). Over-fitting should be avoided. Equations of greater than 5th degree should not be used due to the limited number of torque increments in the calibration protocol. Numerical errors may occur if calculations are performed with insufficient precision. A device used to measure torque not subjected to repair, overloading, modifications, or other significant influence factors which alter its elastic properties, or its sensing characteristics, will likely exhibit the same degree of best fit on each succeeding calibration using this procedure. A device 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 instrument, providing, if possible, at least one calibration torque for every 10 % interval throughout the range. It is not necessary, however that these torque values 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 8.5.1) is anticipated to be less than one tenth of the maximum torque applied during calibration, then the torque values should be applied at or below this lower limit. In no case should the smallest torque applied be below the theoretical lower limit of the instrument as defined by the values: 400 × resolution for Class A loading range and 2000 × resolution for Class AA loading range.

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 (73.4°F) but other temperatures may be used.

7.3.3 During the calibration, monitor and record the temperature as close to the elastic device 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 4—Overload or proof load tests are not required by this practice. It must be emphasized that an essential part of the manufacturing process for a torque-measuring instrument should be the application of a series of overloads to at least 10 % in excess of rated capacity. This must 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.

NOTE 5—For any torque-measuring instrument, 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-measuring instruments are usually used under increasing torque, but if a torque-measuring instrument is to be used under decreasing torque, it should 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-measuring device is calibrated with both increasing and decreasing torque, it is recommended that the same torque increments be applied, but that separate calibration equations are developed.

7.4.2 The standardizing 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 non-return to zero 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 instrument 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 producing a better appraisal of the performance of the instrument. 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 cell 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.

8. Calculation and Analysis of Data

8.1 *Deflection*—Calculate the deflection values for the torque-measuring instrument as the differences between the measured readings of the instrument under applied torque and the averages of the zero-torque readings taken before and after each application of torque. If a series of incremental force readings has been taken without return to zero, a series of interpolated zero torque readings may be used for the calculations. In calculating the average zero-torque readings and deflections, express the values to the nearest unit in the same number of places as estimated in reading the instrument scale. Follow the instructions for the rounding method given in Practice E29.

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

$$\text{Deflection} = A_0 + A_1\tau + A_2\tau^2 + \ldots A_5\tau^5 \qquad (2)$$

where:

τ = torque, and
A_0 through A_5 = coefficients.

A 2nd degree equation is recommended with coefficients A_3, A_4, and A_5, equal to zero. Other degree equations may be used. For example the coefficients A_2 through A_5 would be set equal to zero for a linearized torque cell.

8.2.1 For high resolution devices (see 7.1.3), the procedure of Annex A1 may be used to obtain the best fit calibration curve. After determination of the best fit polynomial equation, fit the pooled calibration data to a polynomial equation of that degree per 8.2, and proceed to analyze the data per 8.3 – 8.5.2.2.

8.3 *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:

$$\text{Standard Deviation } s_m = \sqrt{\frac{d_1^{\,2} + d_2^{\,2} + \ldots + d_n^{\,2}}{n - m - 1}} \qquad (3)$$

where:

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

NOTE 6—The departures of the observed deflections from the calibration equation values are not random but arise partly from the localized non-linearities, discussed in 7.1.1. As a consequence, the distributions of the residuals from the least squares fit may not follow the normal curve of error and the customary estimates based on the statistics of random variables may not be strictly applicable.

8.4 *Uncertainty*—For the purposes of this practice, uncertainty is defined as two (2.0) times the standard deviation. If the calculated uncertainty is less than the instrument resolution, the uncertainty is then defined as that value equal to the resolution. Express the uncertainty in torque units, using the average ratio of torque to deflection from calibration data.

8.5 *Loading Range*—The range of torques within which the uncertainty of a torque-measuring instrument does not exceed the maximum permissible limits of error specified as a fraction or percentage of torque. Since the uncertainty for the instrument is of constant torque amplitude throughout the entire range of the instrument, it will characteristically be less than the specified percentage of torque at instrument capacity but will begin to exceed the specified percentage at some point in the lower range of the instrument, as illustrated in Fig. 1. The loading range shown in the figure thus extends from the point, A, where the uncertainty and error limit lines intersect, up to the instrument capacity. The loading range shall not include torques outside the range of torques applied during the calibration.

8.5.1 *Lower Limit of the Torque Loading Range*—Calculate the lower end of the loading range for a specified percentage limit of error, *P*, as follows:

$$\text{Lower Limit} = (100 \times \text{uncertainty})/(P) \quad (4)$$

8.5.2 *Standard Torque Loading Ranges*—Two standard torque-loading ranges are listed as follows, but others may be used where special needs exist:

8.5.2.1 *Class AA*—For instruments used as secondary reference standards, the uncertainty of the instrument must not exceed 0.06 % of the torque. The lower torque limit of the instrument is 1667 times the uncertainty, in torque units, obtained from the calibration data.

NOTE 7—For example, an instrument calibrated using primary torque standards applied on a certified lever arm at a known distance had a calculated uncertainty of 0.338 N-m. The lower torque limit for use as a Class AA device is therefore 0.338 × 1667 = 563.446 N-m. The uncertainty will be less than 0.06 % of torque for torques greater than this lower torque limit to the capacity of the instrument.

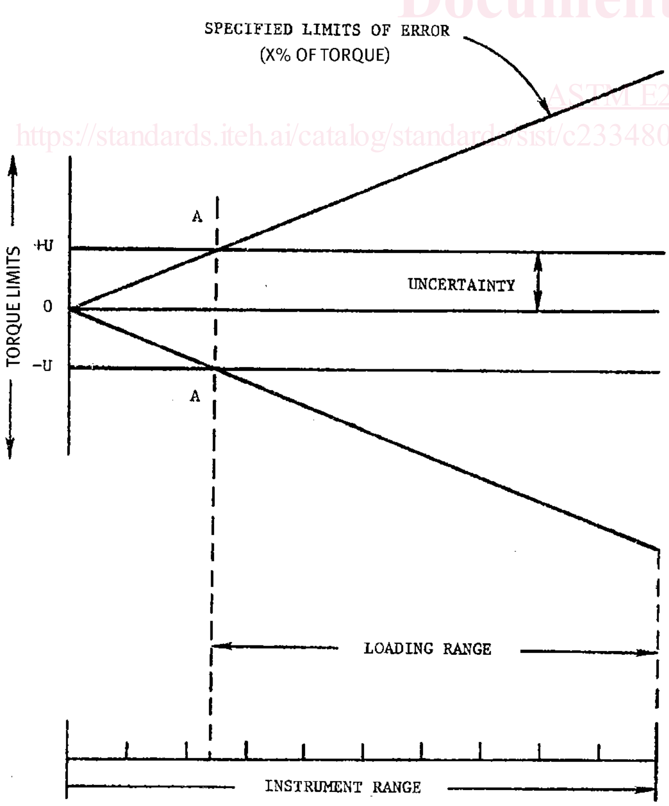

FIG. 1 Relationship of Loading Range to Instrument Uncertainty and Specified Limits of Error

8.5.2.2 *Class A*—For instruments used to verify torque testing machines in accordance with Practice E2624, the uncertainty of the instrument must not exceed 0.25 % of the torque. The lower torque limit of the instrument is 400 times the uncertainty, in torque units, obtained from the calibration data.

NOTE 8—In the example of Note 7, the lower torque limit for use as a Class A device is 0.338 × 400 = 135.581 N-m. The uncertainty will be less than 0.25 % of torque for torque values greater than this lower torque limit up the capacity of the instrument.

NOTE 9—The term "torque loading range" used in this practice is parallel in meaning to the same term in Practice E2624. It is the range of torque values over which it is permissible to use the instrument in verifying a torque testing machine or other similar device. When a torque loading range other than the two standard ranges given in 8.5.1 is desirable, the appropriate limit of error should be specified in the applicable method of test.

8.5.3 *Precision and Bias*—The magnitudes of uncertainty (see 8.4) and lower limit of torque loading ranges (see 8.5.2) which determine compliance to this standard are derived quantities based on statistical analysis of the calibration data. The calculated uncertainty is 2 times the standard deviation. As a function of probability, this limit of uncertainty means that, with 95 % probability, the error will not exceed the value of uncertainty.

8.6 *Specific Torque Devices*—Any torque-measuring device may be calibrated as a specific torque device. These instruments are used only at the calibrated torque values and the curve-fitting and analytical procedures of 8.2 – 8.4 are replaced by the following procedures:

8.6.1 *Calculation of Nominal Torque Deflection*—From the calibration data, calculate the average value of the deflections corresponding to the nominal torque. If the calibration torque values applied differ from the nominal value of the torque values, as may occur in the case of a calibration by secondary standards, adjust the observed deflections to values corresponding to the nominal torque values by linear interpolation, provided that the torque differences do not exceed ±1 % of the torque capacity. The average value of the nominal torque deflection is the calibrated value for that torque.

8.6.2 *Standard Deviation for a Specific Torque Device*—Calculate the range of the nominal torque deflections for each calibration torque as the difference between the largest and smallest deflections for the torque value. Multiply the average value of the ranges for all the calibration torques by the appropriate factor from Table 1 to obtain the estimated standard deviation of an individual deflection about the mean value.

TABLE 1 Estimates of Standard Deviation from the Range of Small Samples

Number of Observations at Each Torque	Multiplying Factor for Range
3	0.591
4	0.486
5	0.430
6	0.395

8.6.3 *Uncertainty for Specific Torque Devices*—The uncertainty for a specific torque device is defined as 2 times the standard deviation, plus the resolution. Convert the uncertainty into torque units by means of a suitable factor and round to the number of significant figures appropriate to the resolution. The uncertainty is expressed as follows:

$$\text{Uncertainty} = (2s + r)\tau_1 \qquad (5)$$

where:

s = standard deviation,
r = resolution, and
τ_1 = average ratio of torque to deflection from the calibration data.

8.6.4 *Precision Torque*—A specific torque device does not have a torque loading range as specified in 8.5, since it can be used only at the specific torque values for which it was calibrated. The use is restricted, however, to those calibrated torque values that would be included in a torque loading range calculated in 8.5 – 8.5.2.2.

9. Influence of Temperature on Torque-Measuring Instruments

9.1 Torque cells usually have temperature compensating circuits built in by the manufacturer. It is the responsibility of the user to verify that errors due to temperature are not significant, or are properly addressed in the measurement uncertainty analysis.

10. Time Interval Between Calibration and Stability Criteria

10.1 All torque-measuring instruments and systems shall meet the range, accuracy, resolution, and stability requirements of this standard, and shall be suitable for their intended use.

10.2 Torque measuring instruments and systems used as secondary standards or 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 recalibration interval. New devices shall be calibrated at an interval not exceeding 1 year to determine stability per 10.2.1.

10.2.1 Torque measuring instruments shall demonstrate changes in the calibration values over the range of use during the recalibration interval of less than 0.032 % of reading for torque measuring instruments and systems used over the Class AA loading range and less than 0.16 % of reading for those instruments and systems used over the Class A loading range. See Note 10.

10.2.2 Devices not meeting the stability criteria of 10.2.1 shall be recalibrated at intervals that shall ensure the stability criteria are not exceeded during the recalibration interval. See Note 10.

NOTE 10—The above stability criteria provide minimum requirements for establishing calibration intervals for torque measuring instruments and systems used as secondary torque standards and those used for the verification of the torque indication of testing machines. Users working with smaller measurement uncertainty limits should evaluate the uncertainty and stability of their instruments and systems to determine appropriate stability criteria suitable for the intended use and stated uncertainties. For secondary standards, it is recommended that cross-checking be performed at periodic intervals using other standards to help ensure that standards are performing as expected.

10.3 *Calibration Following Repairs or Overloads*—A torque-measuring instrument or force multiplying system shall be calibrated whenever the calibration of the device might be suspect. Any instrument sustaining an overload that produces a permanent shift in the zero torque or force reading amounting to 1 % or more of the instrument capacity shall be calibrated before further use.

NOTE 11—Certain indicators used with electrical torque transducers can zero-out or tare-out significant offsets at zero torque. These operations can circumvent the requirement of 10.3. A means of establishing a true zero reference is required in order to assure that the zero balance of calibration has not been shifted by an amount greater than 1 %.

11. Substitution of Electronic Torque Indicating Devices Used with Elastic Members

11.1 It may be desirable to treat the calibration of the elastic member and the torque indicating device separately, thus allowing for the substitution or repair of the torque indicating device without the necessity for repeating an end-to-end system calibration. When such substitution or repair is made, the user assumes the responsibility to assure that the accuracy of the torque measurement system is maintained. Substitution of the torque indication device shall not extend the system calibration/verification date. The following conditions shall be satisfied when substituting a metrologically significant element of the torque indicating measurement system.

11.2 The indicating device used in the initial calibration and the device to be substituted shall each have been calibrated and their measurement uncertainties determined. The indicator to be substituted shall be calibrated over the full range of its intended use including both positive and negative values if the system is used in clockwise and counter clockwise mode. The calibrated range shall include a point less than or equal to the output of the torque transducer at the lower torque limit and a point equal to or greater than the output of the torque transducer at the maximum applied torque. A minimum of five points shall be taken within this range. The measurement uncertainty of each device shall be less than or equal to one third of the uncertainty for the torque measurement system over the range from the lower torque limit to the maximum torque.

11.3 The measurement uncertainty of the torque indicating device shall be determined by one of the methods outlined in Appendix X1. It is recommended that a transducer simulator capable of providing a series of input mV/V steps over the range of measurement and with impedance characteristics similar to that of the torque transducer be employed as a check standard to verify calibration of the torque indicating device and in establishing the measurement uncertainty. The measurement uncertainty of the transducer simulator shall be less than or equal to one tenth of the uncertainty for the torque measurement system.

11.4 Excitation voltage amplitude, frequency, and waveform shall be maintained in the substitution within limits to assure that the effect on the calibration is negligible. It is a user responsibility to determine limits on these parameters through