Designation: E2624 – 15

Standard Practice for Torque Calibration of Testing Machines [1]

This standard is issued under the fixed designation E2624; 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 covers procedures and requirements for the calibration of torque for static and quasi-static torque capable testing machines. These may, or may not, have torque indicating systems and include those devices used for the calibration of hand torque tools. Testing machines may be calibrated by one of the three following methods or combination thereof:

1.1.1 Use of standard weights and lever arms.

1.1.2 Use of elastic torque measuring devices.

1.1.3 Use of elastic force measuring devices and lever arms.

1.1.4 Any of the methods require a specific uncertainty of measurement, displaying metrological traceability to The International System of Units (SI).

NOTE 1—– for further definition of the term metrological traceability, refer to the latest revision of JCGM 200: International vocabulary of metrology — Basic and general concepts and associated terms (VIM).

1.2 The procedures of 1.1.1, 1.1.2, and 1.1.3 apply to the calibration of the torque-indicating systems associated with the testing machine, such as a scale, dial, marked or unmarked recorder chart, digital display, etc. In all cases the buyer/owner/user must designate the torque-indicating system(s) to be calibrated and included in the report.

1.3 Since conversion factors are not required in this practice, either english units, metric units, or SI units can be used as the standard.

1.4 Torque values indicated on displays/printouts of testing machine data systems—be they instantaneous, delayed, stored, or retransmitted—which are calibrated with provisions of 1.1.1, 1.1.2 or 1.1.3 or a combination thereof, and are within the ±1 % of reading accuracy requirement, comply with this practice.

1.5 The following applies to all specified limits in this standard: For purposes of determining conformance with these specifications, an observed value or a calculated value shall be rounded "to the nearest unit" in the last right-hand digit used in expressing the specification limit, in accordance with the rounding method of Practice E29, for Using Significant Digits in Test Data to Determine Conformance with Specifications.

1.6 *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:*[2]

E6 Terminology Relating to Methods of Mechanical Testing

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

E74 Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines

E2428 Practice for Calibration and Verification of Torque Transducers

2.2 *NIST Technical Notes:*

NIST Technical Note 1297 Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results[3]

2.3 *BIPM Standard:*[4]

JCGM 200 : International vocabulary of metrology — Basic and general concepts and associated terms (VIM)

3. Terminology

3.1 *Definitions:* In addition to the terms listed, see Terminology E6.

3.1.1 *accuracy*—the permissible variation from the correct value.

3.1.1.1 *Discussion*—A testing machine is said to be accurate if the indicated torque is within the specified permissible variation from the actual torque. In this practice the word "accurate" applied to a testing machine is used without numerical values. For example, "An accurate testing machine

[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.

Current edition approved Dec. 1, 2015. Published January 2016. Originally approved in 2009. Last previous edition approved in 2009 as E2624– 09. DOI: 10.1520/E2624-15.

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

[4] Available from BIPM (Bureau International des Poids et Mesures)- Pavillon de Breteuil F-92312 Sèvres Cedex FRANCE http://www.bipm.org

was used for the investigation." The accuracy of a testing machine should not be confused with sensitivity. For example, a testing machine might be very sensitive; that is, it might indicate quickly and definitely small changes in torque, but nevertheless, be very inaccurate. On the other hand, the accuracy of the results is in general limited by the sensitivity.

3.1.2 *error, n*—for a measurement or reading, the amount it deviates from a known or reference value represented by a measurement standard. Mathematically, the error is calculated by subtracting the accepted value from the measurement or reading.

3.1.2.1 *Discussion*—The word "error" shall be used with numerical values, for example, "At a torque of 3000 lbf·in., the error of the testing machine was +10 lbf·in."

3.1.3 *percent error, n*—in the case of a testing machine or device, the ratio, expressed as a percent, of an error to the known accepted value represented by a measurement standard.

3.1.4 *reference standard, n*—an item, typically a material or an instrument, that has been characterized by recognized standards or testing laboratories, for some of its physical or mechanical properties, and that is generally used for calibration or verification, or both, of a measurement system or for evaluating a test method.

3.1.4.1 *Discussion*—Torque may be generated by a length calibrated arm and calibrated masses used to produce known torque. Alternatively, torque applied to a torque measuring device to be calibrated may be measured by the use of a reference torque measurement device, that is, an elastic torque calibration device, or a length calibrated arm and an elastic force measuring device.

3.1.5 *resolution, n*—for a particular measurement device, the smallest change in the quantity being measured that causes a perceptible change in the corresponding indication.

3.1.5.1 *Discussion*—Resolution may depend on the value (magnitude) of the quantity being measured.

3.1.5.2 *Discussion*—For paper charts or analog indicators, the resolution should not be assumed to be better (smaller) than 1⁄10 of the spacing between graduations. For digital devices, the best resolution potentially achievable is the smallest difference between two different readings given by the display.

3.1.5.3 *Discussion*—For both analog and digital devices, the actual resolution can be significantly poorer than described above, due to factors such as noise, friction, etc.

3.1.6 *torque, n*—a moment (of forces) that produces or tends to produce rotation or torsion.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *calibrated range of torque—in the case of testing machines*, the range of indicated torque for which the testing machine gives results within the permissible variations specified.

3.2.2 *calibration torque*—a torque with metrological traceability derived from standards of mass and length and of specific uncertainty of measurement, which can be applied to torque measuring devices.

3.2.3 *capacity range—in the case of testing machines*, the range of torque for which it is designed.

3.2.3.1 *Discussion*—Some testing machines have more than one capacity range, that is, multiple ranges.

3.2.4 *correction—in the case of testing machines*, the difference obtained by subtracting the indicated torque from the reference value of the applied torque.

3.2.5 *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.

3.2.5.1 *Discussion*—The instrumentation for the elastic devices may be either an electrical or a mechanical device, that is, a scale or pointer system.

3.2.6 *expanded uncertainty*—a statistical measurement of the probable limits of error of a measurement, NIST Technical Note 1297 treats the statistical approach including the expanded uncertainty.

3.2.7 *lower torque limit of calibration range*—the lowest value of torque at which a torque measuring system can be calibrated.

3.2.8 *parasitic torque*—Forces that bypass the torque axis and can cause errors in determining the value of the torque.

3.2.8.1 *Discussion*—Usually the result of off axis loading (bending moments) caused by cables, conduit, or hydraulic lines attached to objects that are in the torque path and cause subsequent errors in the measured torque.

3.2.9 *permissible variation (or tolerance)— in the case of testing machines*, the maximum allowable error in the value of the quantity indicated.

3.2.9.1 *Discussion*—It is convenient to express permissible variation in terms of percentage of error. The numerical value of the permissible variation for a testing machine is so stated hereafter in these practices.

3.2.10 *torque-capable testing machine*—a testing machine or device that has provision for applying a torque to a specimen.

4. Significance and Use

4.1 Testing machines that apply and indicate torque are used in many industries, in many ways. They may be used in a research laboratory to measure material properties, and in a production line to qualify a product for shipment. No matter what the end use of the machine may be, it is necessary for users to know the amount of torque that is applied, and that the accuracy of the torque value is traceable to the SI. This standard provides a procedure to verify these machines and devices, in order that the indicated torque values may be traceable. A key element to having metrological traceability is that the devices used in the calibration produce known torque characteristics, and have been calibrated in accordance with Practice E2428.

4.2 This standard may be used by those using, those manufacturing, and those providing calibration service for torque capable testing machines or devices and related instrumentation.

5. Calibration Devices

5.1 *Calibration by Standard Weights and Lever Arms*—Calibration by the application of standard weights using a lever arm to the torque sensing mechanism of the testing machine, where practicable, is the most accurate method. Its limitations are: *(1)* the small range of torque that can be calibrated, *(2)* the non-portability of any high capacity standard weights and *(3)* analysis of all parasitic torque components.

5.2 *Calibration by Elastic Calibration Devices*—The second method of calibration of testing machines involves measurement of the elastic strain or rotation under the torque of a torque transducer or a force transducer/lever arm combination. The elastic calibration devices are less constrained than the standards referenced in 5.1. The design of fixtures and interfaces between the calibration device and the machine are critical. When using elastic torque or force measuring devices, use the devices only over their Class A loading ranges as determined by Practice E2428 for elastic torque measuring devices or Practice E74 for elastic force measuring devices.

6. Requirements for Torque Standards

6.1 *Weights and Lever Arms*—Weights and lever arms with traceability derived from standards of mass, force, length and of specific measurement uncertainty may be used to apply torque to testing machines. Weights used as force standards shall be made of rolled, forged, or cast metal. The expanded uncertainty, with a confidence factor of 95% (k=2), for the weight values shall not exceed 0.1 %.

6.1.1 The force exerted by a mass in air is determined by:

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

where:

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

NOTE 2—Neglecting air buoyancy can cause errors on the order of 0.01% to 0.05% depending on the metal the weight is fabricated from. If it is neglected, it should be considered in any uncertainty analysis.

6.1.2 For the purposes of this standard, g can be calculated with a sufficient uncertainty using the following formula.

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

where:

$\varnothing$ = latitude
h = elevation above sea level in meters.

NOTE 3—Formula 2 corrects for the shape of the earth and elevation above sea level. The correction 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 by less than 0.0005%. The term that corrects for altitude, corrects for an increased distance from the center of the earth and the counter-acting Bouguer effect of localized increased mass of the earth. The formula assumes a rock density of 2.67 g/cc. If the rock density changed by 0.5 g/cc, an error of 0.003 % would result.

6.2 The force in customary units exerted by a weight in air is calculated as follows:

$$F_c = \frac{Mg}{9.80665}\left(1 - \frac{d}{D}\right) \quad (3)$$

where:

F_c = force expressed in customary units, that is, pound force or kilogram force
M = true mass of the weight
g = Local acceleration due to gravity, m/s^2
d = air density (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 customary units of force; this factor is equal to the value of standard gravity. 9.80665 m/s^2

NOTE 4—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:

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

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

6.2.1 For use in verifying testing machines, corrections for local values of gravity and air buoyancy to weights calibrated in pounds can be made with sufficient accuracy using the multiplying factors from Table 1. Alternatively the following formula may be used to find the multiplying factor, *MF*. Multiply *MF* times the mass of the weight given in pounds to obtain the value of force in pounds-force, corrected for local gravity and air buoyancy.

$$MF = \frac{9.7803\left[1 + 0.0053\ (\sin \varnothing)^2\right] - 0.000001967h}{9.80665} \times 0.99985 \quad (6)$$

TABLE 1 Unit Force Exerted by a Unit Mass in Air at Various Latitudes

Latitude, °	Elevation Above Sea Level, ft (m)					
	–30 to 150 (–100 to 500)	150 to 460 (500 to 1500)	460 to 760 (1500 to 2500)	760 to 1070 (2500 to 3500)	1070 to 1470 (3500 to 4500)	1470 to 1670 (4500 to 5500)
20	0.9978	0.9977	0.9977	0.9976	0.9975	0.9975
25	0.9981	0.9980	0.9980	0.9979	0.9979	0.9978
30	0.9985	0.9984	0.9984	0.9983	0.9982	0.9982
35	0.9989	0.9988	0.9988	0.9987	0.9986	0.9986
40	0.9993	0.9993	0.9992	0.9992	0.9991	0.9990
45	0.9998	0.9997	0.9997	0.9996	0.9996	0.9995
50	1.0002	1.0002	1.0001	1.0001	1.0000	0.9999
55	1.0007	1.0006	1.0006	1.0005	1.0005	1.0004

where:

$\varnothing$ = latitude
h = elevation above sea level in metres.

NOTE 5—Equation 6 and Table 1 correct for the shape of the earth, elevation above sea level, and air buoyancy. The correction 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 by less than 0.0005%. The term that corrects for altitude, corrects for an increased distance from the center of the earth and the counter-acting Bouguer effect of localized increased mass of the earth. The formula assumes a rock density of 2.67 g/cc. If the rock density changed by 0.5 g/cc, an error of 0.003 % would result. The largest inaccuracy to be expected, due to extremes in air pressure and humidity when using steel weights, is approximately 0.01%. If aluminum weights are used, errors on the order of 0.03% can result.

6.2.2 Standard weights are typically denominated in a unit of mass. When a standard weight has been calibrated such that it exerts a specific force under prescribed conditions, it must be recognized that the weight will exert that force only under those conditions. When used in other fields of gravity, it is necessary to correct the calibrated force value by multiplying the force value by the value for local gravity and dividing by the value of gravity for which the weight was calibrated. Any required air buoyancy corrections must also be taken into account.

6.3 The lever arm or wheel shall be calibrated to determine the length or radius within a known uncertainty, that is traceable to SI. The expanded uncertainty, with a confidence factor of 95% (k=2), for the measured length of the calibration lever arm shall not exceed 0.1 %.

6.4 Elastic torque-measuring instruments may be used as secondary standards and shall be calibrated by primary standards. Practice E2428 defines the calibration of elastic torque-measuring instruments. Practice E74 defines the calibration of elastic force-measuring instruments.

7. Selection of Applied Torques

7.1 Determine the upper and lower limits of the torque range of the testing machine to be calibrated. In no case shall the calibrated range of torque include torques below 200 times the resolution of the torque indicator.

7.2 If the lower limit of the torque range is greater or equal to one-tenth the upper limit, calibrate the testing machine by applying at least five test torque values, at least two times, with the difference between any two successive torque value applications being no larger than one-third the difference between the selected maximum and minimum test torque values. Minimum torque values may be one-tenth the maximum torque values. Applied torque values on the second run are to be approximately the same as those on the first run. Report all values, including the indicator reading, after removal of torques. Include indicator resolution for the minimum torque value.

NOTE 6—When calibration is done using lever arms and weights, the combination of standard weights and lever arms may not exactly correspond to the desired upper and lower torques to be applied to the testing machine. In this case torque values that differ from the desired value by ±2.5 % are acceptable.

7.3 When the lower limit of a calibrated torque range is less than 10 % of the capacity of the range, or where the resolution of the torque indicator changes automatically and extends or selects ranges without the influence of an operator, verify the torque range by applying at least two successive series of torque values, arranged in overlapping decade groups, such that the maximum torque value in one decade is the minimum torque value in the next higher decade. Starting with the selected minimal torque value in each decade, there are to be at least five torque applications, in an approximate ratio of 1:1, 2:1, 4:1, 7:1, 10:1 or 1:1, 2.5:1, 5:1, 7.5:1, 10:1, unless the maximum torque value is reached prior to completing all torque application ratios. The decade's minimum torque must be a torque 200 or more times the resolution of the torque indicator in each decade. Report all torque values and their percent errors. Include the resolution of the torque indicator for each decade. See 3.1.6 and Appendix X1, which contains a non-mandatory method for determining resolution.

NOTE 7—Example: If full scale is 5000 lbf·in. and the minimal torque resolution is 0.04 lbf·in., the minimum calibrated torque would be 8 lbf·in. (0.04 × 200). Instead of decades of 8, 80 and 800 lbf·in., three decades of 10, 100 and 1000 lbf·in. could be selected to cover the torque application range. Suitable calibration test torque values would then be approximately 10, 20, 40, 70, 100, 200, 400, 700, 1000, 2000, 4000, 5000 lbf·in. Note that the uppermost decade would not be a complete decade and would be terminated with the maximum torque value in the range. If the alternate distribution of torques is used, the verification torques selected would be 10, 25, 50, 75, 100, 250, 500, 750, 1000, 2500, 3750, 5000 lbf·in.

7.4 Report the resolution of each decade and the percent error for each test torque value of the two runs. The largest reported error of the two sets of the test runs is the maximum error for the torque range.

7.5 Approximately 30 seconds after removing the maximum torque in a range, record the return to zero indicator reading. This reading shall be 0.0 ± either the resolution, 0.1 % of the maximum torque just applied, or 1 % of the lowest calibrated torque in the range, whichever is greater.

8. Extraneous Factors

8.1 For the purpose of determining the calibrated torque range of a testing machine, apply all torque values such that the resultant torque is as nearly along the axis of the torque sensing device as is possible. Care should be given to minimize any concentricity or angular misalignment.

8.2 Where a lever arm is to be used, ensure that there is minimal angular misalignment to the reaction point of applied torque values and the centerline of the torque sensing device. The lever arm shall be designed so that it will withstand the loading applied during calibration without deflections that will change it's effective length. It shall be supported in such a manner to minimize bending around the centerline of the torque sensing device. The support shall be designed so as to minimize all parasitic forces from being applied to the torque transducer.

8.3 Where a reference torque transducer is to be used for torque calibration of a testing machine, ensure that there is minimum misalignment of the transducers or load train variables that could exert bias within the setup.

8.4 *Temperature Considerations:*

8.4.1 Where the torque measuring device(s) are electrical, connect the force/torque transducer, indicator, interface, etc.

using the appropriate cabling used in the actual machine setup. Turn on power and allow the components to warm up for a period of time recommended by the manufacturer. In the absence of any recommendations, allow at least 15 minutes for the components to be energized.

8.4.2 Position a temperature measurement device in close proximity of the machine being calibrated. Allow the force/torque measuring devices and all relevant parts of the measuring system equipment to reach thermal stability.

9. System Calibration

9.1 A testing machine shall be calibrated as a system with the torque sensing and indicating devices (see 1.2 and 1.4) in place and operating as in actual use.

9.2 System calibration is invalid if the torque sensing devices are removed and calibrated independently of the testing machine.

9.3 A calibration consists of at least two runs of torque contained in the torque range(s) selected. See 7.2 and 7.3.

9.3.1 If the initial run produces values within the requirements of Section 10, the data may be used "as found" for run one of the two required for the new calibration certificate.

9.3.2 If the initial run produces any values which are outside of these requirements, the "as found" data may be reported and may be used in accordance with applicable quality control programs. Calibration adjustments shall be made to the torque indicator system(s), after which the two required runs shall be conducted and reported in the new calibration certificate.

9.3.3 Calibration adjustments may be made to improve the accuracy of the system. They shall be followed by the two required runs, and issuance of a new calibration certificate.

9.3.4 The indicated torque of a testing machine that exceeds the permissible variation and that cannot be properly adjusted, shall not be corrected either by calculation or by the use of a calibration diagram in order to obtain torque values within the required permissible variation.

9.4 In the calibration of a testing machine, approach the torque value to be calibrated by increasing the torque from a lower value.

9.4.1 For any testing machine the errors observed at a given torque value taken first by increasing the torque to any given torque value and then by decreasing the torque to that same value, may not agree. If a testing machine is to be used under decreasing torque mode, it shall be calibrated under decreasing torque as well.

9.5 Testing machines that are used to apply torque in both clockwise and counterclockwise directions shall be calibrated in both directions.

9.6 Before commencing with the procedure, condition the system to the loads that will be applied during calibration by exercising the torque measuring device to the maximum calibration torque. Care should be given to the way a testing machine is used in determining the appropriate procedure for exercising a given machine.

9.6.1 If the testing machine is to be used in a single direction, exercise the system three times to the maximum torque in that direction prior to calibrating.

9.6.2 If the testing machine is to be used in both clockwise and counter clockwise directions exercise the system to the maximum torque three times in the appropriate mode prior to calibrating that mode.

9.6.3 If a testing system is to be used through zero (applying positive torque values and then negative torque values without the ability to exercise the system), exercise the system to maximum positive torque once and then to the maximum negative torque. Repeat this process three times, zeroing the indicated torque at zero applied torque. Start the positive torque calibration after the third application of the maximum negative calibration torque.

9.7 Remove all applied torque and set the machine's torque indication device to read zero.

9.8 Zero the reading of the calibration apparatus.

9.9 *Calibration by Use of Standard Weights:*

9.9.1 Place standard weights meeting the requirements of 6.1 on the calibration weight pan suspended from the calibration lever arm. Apply the weights in increments and remove in the reverse order. Apply the weights symmetrically maintaining a force vector perpendicular to the moment arm radius. Record the applied torque value and the indicated torque value for each test torque value applied, and the error and the percent error calculated from this data.

NOTE 8—Care should be given to ensure that the applied forces are applied at the lever arm's calibrated length.

9.10 *Calibration by Use of Elastic Calibration Devices:*

9.10.1 *Temperature Equalization:*

9.10.1.1 When using an elastic calibration device to verify the torque values of a testing machine, place the device near to, or preferably in, the testing machine a sufficient length of time before the test to assure that the indication of the calibration device is stable.

9.10.1.2 During the calibration, measure the temperature of the elastic device within ±2°F or ±1°C by placing a calibrated thermometer as close to the device as possible.

9.10.1.3 Elastic calibration devices not having an inherent temperature-compensating feature must be corrected mathematically for the difference between ambient temperature and the temperature to which its calibration is referenced. Temperature-correction coefficients should be furnished (if applicable) by the manufacturer of the calibration device.

9.10.1.4 Place the elastic calibration device in the testing machine so that it is aligned properly with the torque sensing device of the unit under test. If an elastic torque measuring device is used for calibration, position its centerline so that it coincides with the centerline of the torque sensing device of the unit under test. If an elastic-force measuring device is used for calibration, align its sensing axis so that it is perpendicular to the associated lever arm. Each elastic calibration device shall be used within its Class A torque range and identified with the calibration readings for which it is used.

9.10.1.5 To ensure a stable zero, flex the elastic device from zero torque to the maximum torque at which the device will be used as described in 9.6. Allow sufficient time for stability.

9.10.1.6 There are two methods for using elastic calibration devices. Select the method to be used and use only that method through out the calibration of the test machine:

(1) Follow-the-Torque Method—The torque on the elastic calibration device is followed until the torque reaches a nominal graduation on the torque-readout scale of the testing machine. Record the torque on the elastic calibration device.

(2) Set-the-Torque Method—The nominal torque is preset on the torque calibration standard, and the testing machine torque readout is read when the nominal torque on the torque calibration standard is achieved.

9.10.1.7 After selecting suitable torque increments, obtain zero readings for both the machine and elastic device, and apply the torques slowly and smoothly without over shooting the intended torques during all calibration measurements.

9.10.1.8 Ensure that the uses of the maximum torque indicators, recorders, or other accessory devices do not cause errors which exceed the acceptable tolerances of 10.1.

9.10.1.9 Record the indicated torque of the testing machine and the applied torque from the elastic calibration device (temperature corrected as necessary), as well as the error and percentage of error calculated from the readings.

10. Basis of Calibration

10.1 The percent error for torque values within the calibrated range of the testing machine shall not exceed ±1.0 %. The algebraic difference between errors of two applications of same torque (repeatability) shall not exceed 1.0 % (see 7.1 and 7.3).

10.2 The certificate of the calibration of a testing machine will state within what range of torque values it may be used, rather than reporting a blanket acceptance or rejection of the machine. For testing machines that possess multiple-capacity ranges, the range of torque values of each range must be stated.

10.3 In no case shall the calibrated range of torque be stated as including torque values below 200 times the resolution of the machine's torque indicator (see 3.1.6).

10.4 In no case shall the calibrated range of torque values be stated as including torque outside the range of torque values applied during the calibration test.

10.5 Testing machines may be more or less accurate than the allowable ±1.0 % of reading error, or more or less repeatable than 1.0 % of reading, which is the Practice E2624 calibration basis. Buyers/owners/users or product specification groups might require or allow larger or smaller error systems. Systems with accuracy errors larger than ±1.0 % of reading or repeatability errors larger than 1.0 % of reading do not comply with Practice E2624.

11. Time Interval Between Calibrations

11.1 It is recommended that testing machines be calibrated annually or more frequently if required. In no case shall the time interval exceed 18 months except for machines in which a long-time test runs beyond the 18 month period. In such cases, the machine shall be calibrated after completion of the test.

11.2 Testing machines shall be calibrated immediately after repairs (this includes new or replacement parts, or mechanical or electrical adjustments) that may in any way affect the operation of the torque indicating device or the values displayed.

11.2.1 Examples of new or replacement parts that may not affect the proper operation of a torque indicating system, are: printers, computer monitors, keyboards, and modems.

11.3 Calibration is required immediately after a testing machine is relocated (except for machines that are designed to be moved from place to place in normal use) and whenever there is a reason to doubt the accuracy of the torque indicating system, regardless of the time interval since the last calibration.

12. Report

12.1 *Calculating Results:*

12.1.1 *Error*—calculate the error E, as follows:

$$E = A - B \tag{7}$$

where:

A = Torque indicated by the testing machine being verified,
B = Applied torque, N·m (lbf·in.), as determined by the reference device.

12.1.2 *Percentage of error*—calculate the percentage of error, E_p as follows:

$$E_p = ((A - B)/B) \times 100 \tag{8}$$

where:

A = Torque indicated by the testing machine being verified,
B = Applied torque, N·m (lbf·in.), as determined by the reference device.

12.2 *Reporting Results:*

12.2.1 Reports should include the following information:

12.2.1.1 Name of the calibrating agency,

12.2.1.2 Date of calibration,

12.2.1.3 Testing machine description, serial number, and location,

12.2.1.4 Method of calibration used,

12.2.1.5 Manufacturer, serial number, calibrated range of torque, and calibration date of devices used in calibration,

12.2.1.6 Statement of how, by whom, and when the calibration of the apparatus used in verifying the testing machine was done,

12.2.1.7 Class A range of torques, in accordance with Practice E2428, for each calibration device,

12.2.1.8 Temperature of the calibration device and a statement that computed torque values have been temperature corrected as necessary,

12.2.1.9 Identification of the torque-indicating systems that were calibrated (for testing machines having more than one type of indicating system),

12.2.1.10 The testing machine error and percent error for each torque-indicating system at each torque value and the maximum algebraic error difference (repeatability) for each torque range and torque-indicating system calibrated,

12.2.1.11 The uncertainty of the applied torque values, as required. Appendix X2 is an example a method which may be used to calculate and state uncertainties and/or errors, 12.2.1.12 Calibrated range of torque of each torque- indicating system of the testing machine,

12.2.1.13 Results obtained on the return-to-zero reading for each range (see 7.5),

12.2.1.14 Statement that calibration has been performed in accordance with Practice E2624. It is recommended that calibration be performed in accordance with the latest published issue of Practice E2624.

12.2.2 Names of calibration personnel and witnesses (if required).

12.3 The certificate shall be error free, and contain no alteration of data, dates, etc.

13. Keywords

13.1 calibration; resolution; torque range

APPENDIXES

(Nonmandatory Information)

X1. DETERMINING RESOLUTION OF THE TORQUE INDICATOR

X1.1 The resolution of a torque capable testing machine in general is a complex function of many variables including applied torque range, electrical and mechanical components, electrical and mechanical noise, and application software.

X1.2 A variety of methods may be used to check the resolution of the system. Some suggested procedures are as follows.

X1.3 *Procedure for Analog-Type Torque Indicators*:

X1.3.1 Typically these devices are not auto-ranging. The resolution should be checked at the lowest calibrated torque in each torque range (typically 10 % of the torque range).

X1.3.2 Divide the pointer width by the distance between two adjacent graduation marks at the torque where the resolution is to be ascertained to determine the pointer to graduation ratio. If the distance between the two adjacent graduation marks is less than 0.10 in. (2.5 mm) and the ratio is less than 1:5, use 1:5 for the ratio. If the distance between the two adjacent graduation marks is greater than or equal to 0.10 in. (2.5 mm) and the ratio is less than 1:10, use 1:10 for the ratio. If the ratio is greater than those given in these exceptions, use the ratio determined. Typical ratios in common usage are 1:1, 1:2, 1:5, and 1:10.

X1.3.3 Multiply the ratio determined above by the torque represented by one graduation to determine the resolution.

X1.3.4 Apply as constant a torque as possible where the resolution is to be ascertained to minimize the fluctuation of the torque indicator. It is recommended that the fluctuation be no more than twice the resolution determined in the previous step.

X1.4 *Procedure for Non-Auto-Ranging Digital-Type Torque Indicators*:

X1.4.1 The resolution should be checked at the lowest calibrated torque in each torque range (typically 10 % of the torque range).

X1.4.2 Apply a clockwise or counter clockwise torque to a specimen approximately equal to that at which the resolution is to be ascertained, and slowly change the applied torque. Record the smallest change in torque that can be ascertained as the resolution. Applying the torque values to a compliant element, such as a spring or an elastomer, makes it easier to slowly change the applied torque.

X1.4.3 Next apply a constant torque at the torque value where the resolution is to be ascertained to ensure that the torque indicator does not fluctuate by more than twice the resolution determined in the previous step. If the indicator fluctuates by more than twice the resolution, the resolution shall be equal to one-half the range of the fluctuation.

X1.5 *Procedure for Auto-Ranging-Digital Type Torque Indicators*:

X1.5.1 This procedure is the same as that for non-auto-ranging digital torque indicators except that the resolution is checked at the lowest calibrated torque in each decade or at other torques to ensure that the indicator resolution is 200 times smaller than the torques. Some examples are as follows.

X1.5.1.1 A 60 000 lbf·in. capacity machine is to be calibrated from 240 lbf·in. up to 60 000 lb·in. The resolution should be determined at 240, 2400, and 24 000 lbf·in.

X1.5.1.2 A 1000 lbf·in. capacity machine is to be calibrated from 5 lbf·in. up to 1000 lbf·in. The resolution should be determined at 5, 50, and 500 lbf·in.

X2. SAMPLE UNCERTAINTY ANALYSIS FOR TORQUE

X2.1 The measurement uncertainty determined using this appendix is the measurement uncertainty of the errors reported during verification of a testing machine by standard weights and lever arm. It is not the measurement uncertainty of the testing machine or test results using the testing machine.

X2.2 The torque equation is:

$$T = rF\sin\Theta \quad (X2.1)$$

where:

T = applied torque,
r = the distance between the point of rotation and the applied force,
F = applied force, and
Θ = angle between the direction of the applied force and the arm of radius r.

X2.3 In this example the measurement uncertainty of the reported errors of a testing machine determined during a verification using Practice E2428 is a combination of multiple components and can be expressed as follows:

$$u_T^2 = (F\sin\Theta)^2 u_r^2 + (r\sin\Theta)^2 u_F^2 + (rF\cos\Theta)^2 u_\Theta^2 \quad (X2.2)$$

where:

u_T = the standard uncertainty of T,
u_r = the standard uncertainty of r,
u_F = the standard uncertainty of F, and
u_Θ = the standard uncertainty of Θ.

X2.4 So the standard uncertainty or 1 sigma value is:

$$u_T = \sqrt{(F\sin\Theta)^2 u_r^2 + (r\sin\Theta)^2 u_F^2 + (rF\cos\Theta)^2 u_\Theta^2} \quad (X2.3)$$

X2.5 So the expanded uncertainty U is:

$$U = k_{u_T} \quad (X2.4)$$

where:

k = characteristic constant, or coverage factor for XX.XX percent confidence.

X2.6 A problem arises for θ=90° because $rF\cos\theta=0$, so the contribution of u_θ appears to disappear. However θ does contribute to the standard uncertainty. Assuming u_θ equals some constant C and provided that 0°<θ<90°, then θ=90°±C or 90°-C<θ<90°+ C. Given the fact that sin 90°+C=sin 90°-C, the torque value at either angle yields a value $T=rF\sin(90°- C)$. So the % error becomes:

$$\%\ ERROR = \frac{rF\sin(90° - C) - rF\sin 90°}{rF\sin 90°} \times 100 \quad (X2.5)$$

which simplifies to:

$$\%\ ERROR = [rF\sin(90° - C) - 1] \times 100 \quad (X2.6)$$

X2.6.1 This result can be used to replace $(rF\cos\theta)^2 u^2_\theta$ in the above u_T equation or used later when combining other uncertainties.

X2.7 The following addresses issues surrounding temperature. The relationship between the length of the arm r and the temperature t is:

$$r_{t_2} = r_{t_1}[1 + \alpha(t_2 - t_1)] \quad (X2.7)$$

where:

r_{t_2} = the length of the arm at the time of the torque measurement,
r_{t_1} = the length of the arm r at the time of its calibration,
α = thermal expansion coefficient for the arm material,
t_2 = the temperature at the time of the torque measurement, and
t_1 = the temperature at the time of the arm r calibration.

X2.8 So it follows that the uncertainty of the length of the arm at any temperature t yields:

$$U_r = r_t^{\alpha U_t} \quad (X2.8)$$

where:

U_r = the uncertainty of the arm r at the time of the torque measurement, and
U_t = the uncertainty of the temperature measurement.

X2.8.1 Assuming r_{t_2}=20 in., α=6.5ppm/°F for steel and U_t=1°F, U_r=0.00013 in., or 0.00065 %. Using the standard uncertainties and the RSS method of combining them, yields an even lower contribution to the expanded uncertainty.

X2.9 The uncertainty of the weights is such that they are not impacted by the laboratory environmental conditions.

X2.10 The uncertainty due to repeatability during the verification can be assessed by evaluating the differences between the two runs of data.

X2.10.1 For each force verification point, find the sum of the squares of the differences in error between the first and second run of that verification point and the four verification points closest to that verification point. Divide that sum by ten and take the square root of the result to obtain an estimate of the uncertainty due to repeatability during the verification process.

NOTE X2.1—The sum is divided by ten because there are five pairs of readings used, and the variance of each pair is equal to the difference divided by two.

NOTE X2.2—Example: The repeatability contribution to the uncertainty of a 2.25 N·m capacity testing machine is to be determined at 40 percent of the range. See Table X2.1 for results of two calibration runs.

The uncertainty component due to repeatability at 40% of range, u_{rep} is calculated as follows:
The repeatability at 40% of range and the four closest torques to 40% of range are 0.00% of 0.2241 N·m, 0.00% of 0.448199 N·m, 0.00% of 0.8964 N·m, 0.06% of 1.58115 N·m and 0.09% of 2.2161 N·m which respectively are 0.00, 0.00, 0.00, 0.000949 and 0.001994 N·m. Therefore:

$$u_{rep} = \sqrt{\frac{0.00^2 + 0.00^2 + 0.00^2 + 0.000949^2 + 0.001994^2}{10}}$$
$$= 0.00070\text{N}\cdot\text{m}$$

TABLE X2.1 Calibration Runs

Percent of Range	Run 1 Indicated	Run 1 Applied	Run 1 Error %	Run 2 Indicated	Run 2 Applied	Run 2 Error %	% Repeatability
1	0.025	0.0249	0.40	0.025	0.0249	0.40	0.00
2	0.050	0.0497999	0.40	0.050	0.0497999	0.40	0.00
4	0.087	0.0871501	-0.17	0.087	0.0871501	-0.17	0.00
7	0.162	0.16185	0.09	0.162	0.16185	0.09	0.00
10	0.225	0.2241	0.40	0.225	0.2241	-0.40	0.0044
20	0.449	0.448199	0.18	0.449	0.448199	0.18	0.00
40	0.897	0.8964	0.07	0.897	0.8964	0.07	0.00
70	1.582	1.58115	0.05	1.583	1.58115	0.12	0.06
100	2.215	2.2161	-0.05	2.217	2.2161	0.04	0.09

X2.11 The uncertainty due to friction involving the knife edges and fixtures can't be quantified; however they are believed to be extremely small relative the other uncertainties therefore considered insignificant and not included in the assessment.