American Association State
Highway and Transportation Officials Standards
AASHTO No: T67

Standard Practices for Force Verification of Testing Machines[1]

This standard is issued under the fixed designation E4; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 These practices cover procedures for the force verification, by means of standard calibration devices, of tension or compression, or both, static or quasi-static testing machines (which may, or may not, have force-indicating systems). These practices are not intended to be complete purchase specifications for testing machines. Testing machines may be verified by one of the three following methods or combination thereof:

1.1.1 Use of standard weights,

1.1.2 Use of equal-arm balances and standard weights, or

1.1.3 Use of elastic calibration devices.

NOTE 1—These practices do not cover the verification of all types of testing machines designed to measure forces, for example, the constant-rate-of-loading type which operates on the inclined-plane principle. This type of machine may be verified as directed in the applicable appendix of Specification D76/D76M.

1.2 The procedures of 1.1.1 – 1.1.3 apply to the verification of the force-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 force-indicating system(s) to be verified and included in the report.*

1.3 *Units*—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.

1.3.1 Other customary force units may be used with this standard such as the kilogram-force (kgf) which is often used with hardness testing machines

1.4 Forces indicated on displays/printouts of testing machine data systems—be they instantaneous, delayed, stored, or retransmitted—which are verified with provisions of 1.1.1, 1.1.2, or 1.1.3, and are within the ±1 % accuracy requirement, comply with Practices E4.

1.5 *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]

D76/D76M Specification for Tensile Testing Machines for Textiles
E6 Terminology Relating to Methods of Mechanical Testing
E74 Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines
E467 Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System

3. Terminology

3.1 For definitions of terms used in this practice, refer to Terminology E6.

3.2 *Definitions:*

3.2.1 *elastic calibration device, n*—a device for use in verifying the force readings of a testing machine consisting of an elastic member(s) to which forces may be applied, combined with a mechanism or device for indicating the magnitude (or a quantity proportional to the magnitude) of deformation under force.

3.2.2 *portable testing machine (force-measuring type), n*—a device specifically designed to be moved from place to place and for applying a force (load) to a specimen.

3.2.3 *testing machine (force-measuring type), n*—a mechanical device for applying a force to a specimen.

3.3 *Definitions of Terms Specific to This Standard:*

[1] These practices are 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 May 15, 2016. Published June 2016. Originally approved in 1923. Last previous edition approved in 2015 as E4 – 15. DOI: 10.1520/E0004-16.

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

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

3.3.1 *accuracy, n*—the specified permissible variation from the reference value.

3.3.1.1 *Discussion*—A testing machine is said to be accurate if the indicated force is within the specified permissible variation from the actual force. In these methods the word "accurate" applied to a testing machine is used without numerical values, for example, "An accurate testing machine 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 force, but nevertheless, be very inaccurate. On the other hand, the accuracy of the results is in general limited by the sensitivity.

3.3.2 *calibration, n— in the case of force testing machines*, the process of comparing the force indication of the machine under test to that of a standard, making adjustments as needed to meet error requirements.

3.3.3 *capacity range, n*—in the case of testing machines, the range of forces for which it is designed.

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

3.3.4 *correction, n*—in the case of a testing machine, the difference obtained by subtracting the indicated force from the correct value of the applied force.

3.3.5 *error (or the deviation from the correct value), n*—in the case of a testing machine, the difference obtained by subtracting the force indicated by the calibration device from the force indicated by the testing machine.

3.3.5.1 *Discussion*—The word "error" shall be used with numerical values, for example, "At a force of 300 kN [60 000 lbf], the error of the testing machine was + 67 N [+ 15 lbf]."

3.3.6 *force, n*—in the case of testing machines, a force measured in units such as pound-force, newton, or kilogram-force.

3.3.6.1 *Discussion*—The newton is that force which acting on a 1-kg mass will give to it an acceleration of 1 m/s^2. The pound-force is that force which acting on a [1-lb] mass will give to it an acceleration of 9.80665 m/s^2 [32.1740 ft/s^2]. The kilogram-force is that force which acting on a 1-kg mass will give to it an acceleration of 9.80665 m/s^2[32.1740 ft/s^2].

3.3.7 *percent error, n*—in the case of a testing machine, the ratio, expressed as a percent, of the error to the correct value of the applied force.

3.3.7.1 *Discussion*—The test force, as indicated by the testing machine, and the applied force, as computed from the readings of the verification device, shall be recorded at each test point. The error, *E*, and the percent error, *E*p, shall be calculated from these data as follows:

$$E = A - B \tag{1}$$

$$E_p = [(A - B)/B] \times 100$$

where:

A = force indicated by machine being verified, N [or lbf], and

B = correct value of the applied force, N [or lbf], as determined by the calibration device.

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

3.3.8.1 *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.

3.3.9 *resolution of the force indicator, n*—smallest change of force that can be estimated or ascertained on the force indicating apparatus of the testing machine, at any applied force. Appendix X1 describes a method for determining resolution.

3.3.10 *resolution of analog type force indicators (scales, dials, recorders, etc.), n*—the resolution is the smallest change in force indicated by a displacement of a pointer, or pen line.

3.3.10.1 *Discussion*—The resolution is calculated by multiplying the force corresponding to one graduation by the ratio of the width of the pointer or pen line to the center to center distance between two adjacent graduation marks. The typical ratios used are 1:1, 1:2, 1:5, or 1:10. A spacing of 2.5 mm [0.10 in.] or greater is recommended for the ratio of 1:10. A ratio less than 1:10 should not be used.

3.3.10.2 *Discussion*—If a force indicating dial has graduations spaced every 2.0 mm [0.080 in.], the width of the pointer is approximately 1.0 mm (0.040 in.), and one graduation represent 25N [5 lbf]. The ratio used would be 1:2 and the resolution would be equal to 12-½ N [2-½ lbf].

3.3.11 *resolution of digital type force indicators (numeric, displays, printouts, etc.), n*—the resolution is the smallest change in force that can be displayed on the force indicator, at any applied force.

3.3.11.1 *Discussion*—A single digit or a combination of digits may be the smallest change in force that can be indicated.

3.3.11.2 *Discussion*—If the force indication, for either type of force indicator, fluctuates by more than twice the resolution, as described in 3.3.10 or 3.3.11, the resolution, expressed as a force, shall be equal to one-half the range of the fluctuation.

3.3.12 *verification, n— in the case of force testing machines*, the process of comparing the force indication of the machine under test to that of a standard and reporting results, without making adjustments.

3.3.13 *verified range of forces, n*—in the case of testing machines, the range of indicated forces for which the testing machine gives results within the permissible variations specified.

4. Significance and Use

4.1 Testing machines that apply and indicate force 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 that the amount of force applied and indicated is traceable to the International System of Units (SI) through a National Metrology Institute (NMI). The procedures in Practices E4 may be used to verify these machines so that the indicated forces are traceable to the SI. A key element of traceability to the SI is that the devices used in the verification have known force characteristics, and have been calibrated in accordance with Practice E74.

4.2 The procedures in Practices E4 may be used by those using, manufacturing, and providing calibration service for testing machines and related instrumentation.

5. Calibration Devices

5.1 When verifying testing machines, use calibration devices only over their Class A force ranges as determined by Practice E74.

6. Advantages and Limitations of Methods

6.1 *Verification by Standard Weights*—Verification by the direct application of standard weights to the weighing mechanism of the testing machine, where practicable, is the most accurate method. Its limitations are: (*1*) the small range of forces that can be verified, (*2*) the nonportability of any large amount of standards weights, and (*3*) its nonapplicability to horizontal testing machines or vertical testing machines having weighing mechanisms that are not designed to be actuated by a downward force.

6.2 *Verification by Equal-Arm Balance and Standard Weights*—The second method of verification of testing machines involves measurement of the force by means of an equal-arm balance and standard weights. This method is limited to a still smaller range of forces than the foregoing method, and is generally applicable only to certain types of hardness testing machines in which the force is applied through an internal lever system.

6.3 *Verification by Elastic Calibration Devices*—The third method of verification of testing machines involves measurement of the elastic strain or deflection under force of a ring, loop, tension or compression bar, or other elastic device. The elastic calibration device is free from the limitations referred to in 6.1 and 6.2.

7. System Verification

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

7.1.1 If this is not technically possible, refer to Annex A1, Verifying the Force Measuring System out of the Test Machine. Out of the test machine verifications shall be in accordance with the main body of Practices E4 and its Annex A1

7.2 System verification is invalid if the devices are removed and checked independently of the testing machine unless verification is performed according to Annex A1.

7.3 Many testing machines utilize more than one force measuring device in order to obtain more accurate force indication at lower applied forces. These devices are routinely installed and uninstalled in the testing machine. For such devices, interchangeability shall be established during the original verification and shall be reestablished after an adjustment is performed. This is accomplished by performing a normal verification with the device in place as during normal use. It is advisable that orientation be kept consistent, such as by noting the direction of the cable connector so that when reinstalling the device, the orientation will be repeated. Remove and reinstall the device between the two verification runs to demonstrate interchangeability. Repeat the procedure for each interchangeable force measuring device used in the testing machine.

7.3.1 Introduction of the new force measuring devices shall require that interchangeability be established per 7.3.

7.4 A Practices E4 Verification consists of at least two verification runs of the forces contained in the force range(s) selected. See 10.1 and 10.3.

7.4.1 If the initial verification run produces values within the Practices E4 requirements of Section 14, the data may be used "as found" for run one of the two required for the new verification report.

7.4.2 If the initial verification run produces any values which are outside of the Practices E4 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 force indicator system(s), after which the two required verification runs shall be conducted and reported in the new verification report and certificate.

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

8. Gravity and Air Buoyancy Corrections

8.1 In the verification of testing machines, where standard weights are used for applying forces directly or through lever or balance-arm systems, correct the force for the local value of gravity and for nominal air buoyancy.

8.1.1 The force exerted by a weight in air is determined by:

$$\text{Force} = Mg\left(1 - \frac{d}{D}\right) \quad (2)$$

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.

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

$$g = 9.7803\left[1 + 0.0053\left(\sin \varnothing\right)^2\right] - 0.000001967h \quad (3)$$

where:

where:

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

NOTE 2—Eq 3 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 counter-acting 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.

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

$$F_c = \frac{Mg}{9.80665}\left(1 - \frac{d}{D}\right) \quad (4)$$

where:

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 for standard gravity, 9.80665 m/s^2.

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

$$1\ \text{lbf} = 4.448222\text{N} \quad (5)$$

$$1\ \text{kgf} = 9.80665\ \text{N (exact)} \quad (6)$$

8.2.1 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.

$$MF = \frac{9.7803[1 + 0.0053(\sin \varnothing)^2] - 0.000001967h}{9.80665} \times 0.99985 \quad (7)$$

where:

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

NOTE 3—Eq 7 and Table 1 correct for the shape of the earth, elevation above sea level, and air bouyancy. 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, temperature, and humidity when using steel weights, is approximately 0.01%. If aluminum weigths are used, errors on the order of 0.03% can result.

8.3 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, the weight will exert that force only under those conditions. When used in locations where the acceleration of gravity differs from the one in the calibration location, 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.

9. Application of Force

9.1 In the verification of a testing machine, approach the force by increasing the force from a lower force.

NOTE 4—For any testing machine the errors observed at corresponding forces taken first by increasing the force to any given test force and then by decreasing the force to that test force, may not agree. Testing machines are usually used under increasing forces, but if a testing machine is to be used under decreasing forces, it should be calibrated under decreasing forces as well as under increasing forces.

9.2 Testing machines that contain a single test area and possess a bidirectional loading and weighing system must be verified separately in both modes of weighing.

9.3 High-speed machines used for static testing must be verified in accordance with Practices E4. **Warning—** Practices E4 verification values are not to be assumed valid for high-speed or dynamic testing applications (see Practice E467).

NOTE 5—The error of a testing machine of the hydraulic-ram type, in which the ram hydraulic pressure is measured, may vary significantly with ram position. To the extent possible such machines should be verified at the ram positions used.

TABLE 1 Multiplying Factor, MF, in Air at Various Latitudes, see Eq 7

Latitude, Ø,°	Elevation Above Sea Level, h, m (ft)					
	0 (0)	500 (1640)	1000 (3280)	1500 (4920)	2000 (6560)	2500 (8200)
0	0.9972	0.9971	0.9970	0.9969	0.9968	0.9967
5	0.9972	0.9971	0.9970	0.9969	0.9968	0.9967
10	0.9973	0.9972	0.9971	0.9970	0.9969	0.9968
15	0.9975	0.9974	0.9973	0.9972	0.9971	0.9970
20	0.9978	0.9977	0.9976	0.9975	0.9974	0.9973
25	0.9981	0.9980	0.9979	0.9978	0.9977	0.9976
30	0.9985	0.9984	0.9983	0.9982	0.9981	0.9980
35	0.9989	0.9988	0.9987	0.9986	0.9985	0.9984
40	0.9993	0.9992	0.9991	0.9990	0.9989	0.9988
45	0.9998	0.9997	0.9996	0.9995	0.9994	0.9993
50	1.0003	1.0002	1.0001	1.0000	0.9999	0.9998
55	1.0007	1.0006	1.0005	1.0004	1.0003	1.0002
60	1.0011	1.0010	1.0009	1.0008	1.0007	1.0006
65	1.0015	1.0014	1.0013	1.0012	1.0011	1.0010
70	1.0018	1.0017	1.0016	1.0015	1.0014	1.0013

10. Selection of Verification Forces

10.1 Determine the upper and lower limits of the verified force range of the testing machine to be verified. In no case shall the verified force range include forces below 200 times the resolution of the force indicator.

10.2 If the lower limit of the verified force range is greater than or equal to one-tenth of the upper limit, five or more different verification forces shall be selected such that the difference between two adjacent verification forces is greater than or equal to one twentieth and less than or equal to one-third the difference between the upper and lower limits of the verified force range. One verified force shall be the lower limit of the verified force range and another verified force shall be the upper limit. (Fewer verification forces are required for testing machines designed to measure only a small number of discrete forces, such as certain hardness testers, creep testers, etc.)

10.3 If the lower limit of the verified force range is less than one-tenth the upper limit, verification forces shall be selected as follows:

10.3.1 Starting with the lower limit of the verified force range, establish overlapping force decades such that the maximum force in each decade is ten times the lowest force in the decade. The lowest force in the next higher decade is the same as the highest force in the previous decade. The highest decade might not be a complete decade.

10.3.2 Five or more different verification forces shall be selected per decade such that the difference between two adjacent verification forces is greater than or equal to one-twentieth and less than or equal to one-third the difference between the maximum and the minimum force in that decade. It is recommended that starting with the lowest force in each decade, the ratio of the verification forces to the lowest force in the decade are 1:1, 2:1, 4:1, 7:1, 10:1 or 1:1, 2.5:1, 5:1, 7.5:1, 10:1.

10.3.3 If the highest decade is not a complete decade, choose verification forces at the possible ratios and include the upper limit of the verified force range. If the difference between two adjacent verification forces is greater than one-third of the upper limit, add an additional verification force.

NOTE 6—Example: A testing machine has a full-scale range of 5000 N and the resolution of the force indicator is 0.0472 N. The lowest possible verified force is 9.44 N (0.0472 × 200). Instead of decades starting at 9.44, 94.4 and 944 N, three decades, starting at 10, 100, and 1000 N are selected to cover the verified range of forces. Suitable verification forces are 10, 20, 40, 70, 100, 200, 400, 700, 1000, 2000, 3000, 4000, 5,000. Note that the uppermost decade is not a complete decade and is terminated with the upper limit of the verified force range. The 3000 N reading was added because the difference between 2000 and 4000 was greater than one-third of 5000. If the alternative distribution of forces is used, the verification forces selected would be 10, 25, 50, 75, 100, 250, 500, 750, 1000, 2500, 3750, 5000.

10.4 All selected verification forces shall be applied twice during the verification procedure. Applied forces on the second run are to be approximately the same as those on the first run.

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

11. Eccentricity of Force

11.1 For the purpose of determining the verified force range of a testing machine, apply all calibration forces so that the resultant force is as nearly along the axis of a testing machine as is possible.

NOTE 7—The effect of eccentric force on the accuracy of a testing machine may be determined by verification readings taken with calibration devices placed so that the resultant force is applied at definite distances from the axis of the machine, and the verified force range determined for a series of eccentricities.

12. Methods of Verification

12.1 *Method A, Verification by Standard Weights:*

12.1.1 *Procedure:*

12.1.1.1 Place standard metal weights of suitable design, finish, and adjustment on the weighing platform of the testing machine or on trays or other supports suspended from the force measuring mechanism in place of the specimen. Use weights certified within five years to be accurate within 0.1%. Apply the weights in ascending increments. If data is to be taken in both ascending and descending directions, remove the weights in reverse order. Record the forces, corrected for gravity and air buoyancy in accordance with Section 8.

NOTE 8—The method of verification by direct application of standard weights can be used only on vertical testing machines in which the force on the weighing table, hydraulic support, or other weighing device is downward. The total force is limited by the size of the platform and the number of weights available. Twenty-five kg or [fifty lb] weights are usually convenient to use. This method of verification is confined to small testing machines and is rarely used above 5000 N [1000 lbf].

12.2 *Method B. Verification Of Hardness Testing Machines by Equal-Arm Balance and Standard Weights:*

12.2.1 *Procedure:*

12.2.1.1 Position the balance so that the indenter of the testing machine being calibrated bears against a block centered on one pan of the equal-arm balance, the balance being in its equilibrium position when the indenter is in that portion of its travel normally occupied when making an impression. Place standard weights complying with the requirements of Section 12 on the opposite pan to balance the load exerted by the indenter.

NOTE 9—This method may be used for the verification of testing machines other than hardness-testing machines by positioning the force-applying member of the testing machine in the same way that the indenter of a hardness-testing machine is positioned. For other methods of verifying hardness testing machines see the applicable ASTM test method.

12.2.1.2 Since the permissible travel of the indenter of a hardness-testing machine is usually very small, do not allow the balance to oscillate or swing. Instead, maintain the balance in its equilibrium position through the use of an indicator such as an electric contact, which shall be arranged to indicate when the reaction of the indenter force is sufficient to lift the pan containing the standard weights.

12.2.1.3 Using combinations of fractional weights, determine both the maximum value of the dead-weight force that can be lifted by the testing machine indenter force during each of ten successive trials, and the minimum value that cannot be lifted during any one of ten successive trials. Take the correct value of the indenting force as the average of these two values. The difference between the two values shall not exceed 0.5 % of the average value.

12.3 *Method C. Verification by Elastic-Calibration Device:*

12.3.1 *Temperature Equalization:*

12.3.1.1 When using an elastic calibration device to verify the readings 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 response of device is stable.

12.3.1.2 During the verification, measure the temperature of the elastic device within ±1°C [±2°F] by placing a calibrated thermometer as close to the device as possible.

12.3.1.3 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. Refer to Practice E74 for further information.

12.3.2 *Procedure:*

12.3.2.1 Place the elastic device in the testing machine so that its center line coincides with the center line of the heads of the testing machine. Record the Practice E74 Class A verification value which establishes the lowest limit, or force level, allowable for the calibration device's loading range (see Practice E74). Each elastic calibration device is to be used only within its Class A force range and identified with the verification readings for which it is used.

12.3.2.2 To ensure a stable zero, flex the elastic device from no force to the maximum force at which the device will be used. Repeat as necessary, allowing sufficient time for stability.

12.3.2.3 There are two methods for using elastic calibration devices:

12.3.2.4 *Follow-the-Force Method*—The force on the elastic calibration device is followed until the force reaches a nominal graduation on the force-readout scale of the testing machine. Record the force on the elastic calibration device.

12.3.2.5 *Set-the-Force Method*—The nominal force is preset on the elastic calibration device, and the testing machine force readout is read when the nominal force on the elastic calibration device is achieved.

12.3.2.6 After selecting suitable test force increments, obtain zero readings for both machine and elastic device, and apply forces slowly and smoothly during all verification measurements.

12.3.2.7 The calibration procedure must ensure that use of the maximum force indicator, recorder, or other accessory force devices does not cause testing machine errors to exceed the acceptable tolerances of 14.1.

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

12.3.2.9 Under certain conditions, multi-device setups may be used in compression loading. All devices to be loaded in parallel should be the same height (shims may be used) and the machine's load axis should be coincidental with the force axis of the device setup. This is necessary so that a net moment is not applied to the testing machine loading member. Multi-device setups are not recommended unless the use of a single calibration device is not practical.

13. Lever-Type Creep-Rupture Testing Machines

13.1 Lever-type creep-rupture machines, which do not have a force-indicating device, may be verified using standard weights or elastic calibration device(s), or both. Weights used for verification should conform to the requirements of Section 12. In using an elastic calibration device, the requirements of 12.3.2 must be met as applicable.

13.2 *Procedure:*

13.2.1 Place the calibration device in the testing machine and adjust the counterbalance (if the machine is so equipped) to compensate for the weight of the calibration device.

13.2.2 Connect the lower crosshead of the machine to the calibration device, and apply forces using standard weights in increments conforming to the provisions of 10.1.

13.2.3 Since many lever-type creep-rupture machines do not have a provision for adjustment of the lever ratio or tare, or both, it may be necessary to determine the "best fit" straight line through the calibration data, using the least squares method. By doing this, the actual lever ratio and tare of each machine can be determined, and thus reduce force errors due to small variations of lever ratios. Maximum errors should not exceed the requirements stated in 14.1.

CALCULATION AND REPORT

14. Basis of Verification

14.1 The percent error for forces within the range of forces of the testing machine shall not exceed ±1.0 %. The algebraic difference between errors of two applications of same force (repeatability) shall not exceed 1.0 % (see 10.1 and 10.3).

NOTE 10—This means that the report of the verification of a testing machine will state within what verified range of forces it may be used, rather than reporting a blanket acceptance or rejection of the machine. In machines that possess multiple-capacity ranges, the verified range of forces of each must be stated.

14.2 In no case shall the verified range of forces be stated as including forces outside the range of forces applied during the verification test.

14.3 Testing machines may be more or less accurate than the allowable ±1.0 % error, or more or less repeatable than 1.0 %, which are the Practices E4 verification 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 % or repeatability errors larger than 1.0 % do not comply with Practices E4.

15. Corrections

15.1 The indicated force of a testing machine that exceeds the permissible variation shall not be corrected either by calculation or by the use of a calibration diagram in order to obtain values within the required permissible variation.

16. Time Interval Between Verifications

16.1 It is recommended that testing machines be verified annually or more frequently if required. In no case shall the time interval between verifications 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 verified after completion of the test.

16.2 Testing machines shall be verified immediately after repairs (this includes new or replacement parts, or mechanical or electrical adjustments) that may in any way affect the operation of the weighing system or the values displayed.

16.2.1 Examples of new or replacement parts which may not effect the operation of the weighing system are: printers, computer monitors, keyboards, and modems.

16.3 Verification is required immediately after a testing machine is relocated (except for machines designed to be moved from place to place in normal use), and whenever there is a reason to doubt the accuracy of the force indicating system, regardless of the time interval since the last verification.

17. Accuracy Assurance Between Verifications

17.1 Some product-testing procedures may require daily, weekly, or monthly spot checks to ascertain that a testing machine is capable of producing accurate force values between the testing machine verifications specified in Section 16.

17.2 Spot checks may be performed on ranges of interest or at force levels of interest utilizing a calibration device that complies with Methods A, B, and C as applicable. Elastic calibration devices must meet Class A requirements of Practice E74 for the force level(s) at which the spot checks are made.

17.3 Make spot checks at approximately 20 % and 80 % of a range unless otherwise agreed upon or stipulated by the material supplier/user.

17.4 Testing machine error shall not exceed ±1.0 % of the spot check applied forces. Should errors be greater than ±1.0 % at any of the spot check force levels, verify the testing machine immediately (see 16.3).

17.5 Maintain a record of the spot check tests which shall include the name, serial number, verification date, verification agency, and the minimum Class A, Practice E74 value of the calibrating device(s) used to make spot checks; also include the name of person making the spot checks.

17.6 The testing machine shall be considered verified up to the date of the last successful spot check verification (see 17.4), provided that the testing machine is verified in accordance with Section 16 on a regular schedule. Otherwise spot checks are not permitted.

17.7 When spot checks are made, a clear, concise record must be maintained as agreed upon between the supplier and the user. The record must also contain documentation of the regular verification data and schedule.

18. Report and Certificate

18.1 Prepare clear, complete, and error-free documentation (no alteration of data, dates, etc.) for each verification of a testing machine which shall include the following:

18.1.1 Name of the verification agency,

18.1.2 Date of verification,

18.1.3 Testing machine description, serial number, and location,

18.1.4 Statement identifying the force-indicating system(s) that were verified,

18.1.5 Text identifying the mode of verification, for example, tension, compression, or universal,

18.1.6 Verified range(s) of forces of each force-indicating system of the testing machine and the associated resolution(s),

18.1.7 Indicated force of the testing machine and the force applied to the verification device for each run at each verification force,

18.1.8 Return to zero reading after each run, for each force range,

18.1.9 Testing machine error, percent error, and the percent difference between the runs(repeatability) at each verification force,

18.1.10 Maximum error in percent for each force range verified,

18.1.11 The method of verification used,

18.1.12 Statement that the verification has been performed in accordance with Practice E4-XX. It is recommended that the verification be performed in accordance with the latest published issue of Practice E4,

18.1.13 Manufacturer, serial number, verification agency, verification date, verification recall date, and the limits of the Class A loading range in accordance with Practice E74 of all elastic force-measuring instruments used for the verification,

18.1.14 Temperature of the elastic force-measuring instruments used for the verification and a statement that computed forces have been temperature corrected as necessary,

18.1.15 Manufacturer, serial number, verification agency, verification date, and the verification recall date of all standard weights or weight sets used for the verification,

18.1.16 The identification of the individual who performed the verification,

18.1.17 The name and signature of the person responsible, in charge of the verification, and

18.1.18 Optionally or if required, a statement of the measurement uncertainty of the verification, see Appendix X2.

18.2 Each Report and Certificate document generated by the verification agency shall be uniquely identified. Include page numbers, the total number of pages or a mark to signify the end of the document in order to ensure that the pages are recognized as part of the report and certificate.

19. Keywords

19.1 calibration; force range; resolution; verification

ANNEX

(Mandatory Information)

A1. VERIFYING THE FORCE MEASURING SYSTEM OUT OF THE TEST MACHINE

A1.1 Significance and Use

A1.1.1 The following are the recognized reasons to perform a force measuring system verification out of the test machine:

A1.1.1.1 Inadequate spacing within the testing application load train to allow placement of a force standard.

A1.1.1.2 Physically impossible to apply a primary deadweight force in the compression mode without removal of the force measuring system.

A1.1.1.3 Test rigs have no reaction frame.

A1.1.2 Verifying the force measuring system out of the testing machine represents an independent and singular uncertainty component of the total test machine system uncertainty. Other uncertainty components within the test machine system exist and need to be identified and quantified to determine, or verify, the test machine total performance and level of measurement uncertainty. For example, mounting considerations, fixtures, hardness, stiffness, alignment, flatness, and bending may contribute to the measurement uncertainty of the test machine.

A1.1.3 Fixture and environment considerations should be made, to the best degree possible, to simulate the environment within the testing application (for example, duplicating a preload).

A1.1.4 Verifying the force measuring system out of the test machine can be performed:

A1.1.4.1 On-site, removed from the test system, consisting of a complete force measuring system (force transducer, conditioning electronics, read-out devices, and cables).

A1.1.4.2 Off-site, removed from the test system, consisting of a complete for measuring system (force transducer, conditioning electronics, read-out devices, and cables).

A1.2 Calibration Devices

A1.2.1 The force measuring system shall be calibrated by primary standards or secondary standards used over their Class A loading range in conjunction with a machine or mechanism for applying force (see Practice E74). Several working standards of equal compliance maybe combined and loaded in parallel to meet special needs for higher capacities.

A1.3 Verification

A1.3.1 Out of test machine verifications shall include the force transducer, conditioning electronics, read-out devices, and cables.

A1.3.2 A minimum of two runs is required per mode (compression or tension). Rotate the position of the force transducer by approximately 120 degrees before repeating any series of forces. During the verification, ensure that the loading axis is on the center load axis of the force applying apparatus. Introduce variations or any other factors that are normally encountered in service.

A1.3.3 Repeatability between the two verification runs shall be less than or equal to 0.5%. If greater than 0.5%, an additional third verification run is required. The force transducer shall be rotated by approximately 240 degrees from the starting position prior to performing the third verification run. The repeatability between the three verification runs shall be less than 1.0%. Refer to A1.1.2 to consider all the uncertainty issues in determining the total test machine system uncertainty.

A1.3.4 The percent error for forces within the verified range of forces of the testing machine system shall not exceed ± 1.0%.

A1.4 Calculation and Report

A1.4.1 Verification of the force measuring system out of a test machine shall be clearly noted on the calibration certificate or report.

APPENDIXES

(Nonmandatory Information)

X1. DETERMINING RESOLUTION OF THE FORCE INDICATOR

X1.1 The resolution of a testing machine in general is a complex function of many variables including applied force, force range, electrical and mechanical components, electrical and mechanical noise, and software employed, to name a few.

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 Force Indicators:*

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

X1.3.2 Divide the pointer width by the distance between two adjacent graduation marks at the force 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 2.5 mm [0.10 in.] 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 2.5 mm [0.10 in.] 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 force represented by one graduation to determine the resolution.

X1.3.4 Apply as constant a force as possible where the resolution is to be ascertained to minimize the fluctuation of the force 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 Force Indicators:*

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

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

X1.4.3 Next apply as constant a force as possible at the force where the resolution is to be ascertained to ensure that the force 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 Force Indicators:*

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

X1.5.1.1 A 150 000 N capacity machine is to be verified from 300 N up to 150 000 N. The resolution should be determined at 300, 3000, and 30 000 N.

X1.5.1.2 A [60 000 lbf] capacity machine is to be verified from [240 lbf] up to [60 000 lbf]. The resolution should be determined at [240, 2400, and 24 000 lbf].

X1.5.1.3 A 1000 N capacity machine is to be verified from 5 N up to 1000 N. The resolution should be determined at 5, 50, and 500 N.

X1.6 *Procedure for Machines with Discrete Forces Such as Certain Hardness Testers and Creep Testers:*

X1.6.1 These machines generally incorporate fixed lever ratios to apply force. The force applied is determined by the poise applied on the lever multiplied by the lever ratio. They do not have a resolution as described in the standard. This procedure ensures that the sensitivity of the machine is sufficient to apply accurate forces at the lowest verified force and may be substituted for reporting resolution.

X1.6.2 With an elastic calibration device mounted in the machine, apply the appropriate poise for the lowest verified force.

X1.6.3 Gently add weight to the poise approximately equal to 1/200 of the weight of the poise.

X1.6.4 Ensure that at least one-half of the appropriate change in force is detected by the elastic calibration device when the weight is added and when it is gently removed.

X2. IDENTIFYING AND DETERMINING MEASUREMENT UNCERTAINTY COMPONENTS DURING AN ASTM E4 VERIFICATION

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

X2.2 Under normal conditions, the measurement uncertainty of the reported errors of a testing machine determined during a verification using Practice E4 is a combination of three major components: the measurement uncertainty associated with the calibration laboratory performing the verification, the uncertainty due to the repeatability of the testing machine during calibration, and possibly the uncertainty component of the resolution of the force indicator of the testing machine at the force the error is being determined and at zero force.

X2.2.1 The measurement uncertainty associated with the calibration laboratory performing the verification is a combination of factors such as, but not limited to:

X2.2.1.1 The measurement uncertainty of the laboratory's force standards per Practice E74,

X2.2.1.2 Environmental effects such as temperature variations,

X2.2.1.3 Uncertainty in the value used for the local acceleration of gravity at the site where the verification is performed when using standard weights,

X2.2.1.4 Drift in the force standard,

X2.2.1.5 Measurement uncertainty of the verification of the force standard, and

X2.2.1.6 Reproducibility of the force standard due to handling and fixturing.

NOTE X2.1—A laboratory's measurement uncertainty should be based on the maximum uncertainty of the force standards used and the worst environmental conditions allowed. It may be advantageous to evaluate the measurement uncertainty of the actual force standard used at the actual force for which the measurement uncertainty of the error of the testing machine is being determined.

NOTE X2.2—If there are circumstances in which verification is performed under conditions outside of the laboratory's normal operating parameters, additional components may need to be considered. For example, a laboratory may permit a 5°C temperature variation to occur during verification and has factored this into their measurement uncertainty. When greater temperature variations occur, the uncertainty due to this increased temperature variation should be included in the determination of measurement uncertainty.

NOTE X2.3—A calibration laboratory's measurement uncertainty is usually expressed as an expanded uncertainty using a coverage factor of two. If this is the case, prior to combining it with the other uncertainty components, divide it by two to determine the standard uncertainty.

X2.2.2 A way of assessing the uncertainty due to repeatability during the verification process is to evaluate the differences between the two runs of data (the repeatability).

X2.2.2.1 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 X2.4—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.

X2.2.2.2 Usually this type of assessment of uncertainty due to repeatability will include the uncertainty due to the resolution of the testing machine; however, it is possible to repeat runs without seeing the effects of the resolution. At each force, test to see that the uncertainty due to repeatability is greater than the uncertainty due to the resolution of the testing machine. If, at a given verification force, the uncertainty due to repeatability is not greater than or nominally equal to the uncertainty due to the resolution of the testing machine, for that verification force, include the components of uncertainty due to the resolution of the testing machine at that force and at zero force.

X2.2.2.3 The uncertainty due to the resolution of the testing machine at each verification force is the square root of the sum-of-the-squares of the following two components.

(1) The uncertainty component due to the *resolution of the force indicator* of the testing machine being verified can be determined by dividing the *resolution of the force indicator* at the force where uncertainty is being evaluated by the quantity of two times the square root of three.

(2) The uncertainty component due to the *resolution of the force indicator* of the testing machine at zero force can be determined by dividing the *resolution of the force indicator* at zero force by the quantity of two times the square root of three.

X2.3 The two major components (or three if necessary) can be combined by squaring each component, adding them together, and then taking the square root of the sum to determine the combined measurement uncertainty of the error determined for the testing machine.

X2.4 The expanded measurement uncertainty may then be determined by multiplying the combined uncertainty by two, for a confidence level of approximately 95%.

NOTE X2.5—Example: The measurement uncertainty of the reported error of a 10,000 N capacity testing machine is to be determined at 2000 N. The calibration laboratory's measurement uncertainty expanded using a factor of 2 is 0.3% of applied force. The testing machine's resolution at 2000 N is 5 N. The resolution of the testing machine at 0 force is 5 N. The following are the results of two calibration runs:

Run 1			Run 2			
Machine Reading 1	Verification Device Reading	Error (%)	Machine Reading 2	Verification Device Reading	Error (%)	% Repeat-ability
100	100.24	-0.24	100	100.02	-0.02	0.22
200	200.21	-0.11	200	200.23	-0.11	0.00
400	400.19	-0.05	400	400.37	-0.09	0.04
700	699.98	0.00	700	700.12	-0.02	0.02
1000	1000.15	-0.01	1000	1001.15	-0.11	0.10
2000	1998.84	0.06	2000	1995.33	0.23	0.17
4000	3994.31	0.14	4000	3988.20	0.30	0.16
7000	6981.97	0.26	7000	6979.86	0.29	0.03
10000	9989.00	0.11	10000	9967.54	0.32	0.21

The uncertainty component due to the calibration laboratory's measurement uncertainty, u_{CL} is:

$$u_{CL} = \frac{0.003 \times 2000}{2} = 3 \text{ N} \quad \text{(X2.1)}$$

The uncertainty component due to reprepeatability at 2000 N, u_r is calculated as follows:
The repeatability at 2000 N and the four closest forces to 2000 N are 0.02% of 700 N, 0.10% of 1000 N, 0.17% of 2000 N, 0.16% of 4000 N, and 0.03% of 7000 N which respectively are 0.14, 1.00, 3.40, 6.40, and 2.10 N. Therefore:

$$u_r = \sqrt{\frac{0.14^2 + 1.00^2 + 3.40^2 + 6.40^2 + 2.10^2}{10}} = 2.4\text{N} \quad \text{(X2.2)}$$

The uncertainty component due to the testing machine's resolution at 2000 N, u_{R2000} is:

$$u_{R2000} = \frac{5}{2\sqrt{3}} = 1.4 \text{ N} \quad \text{(X2.3)}$$

The uncertainty component due to the testing machine's resolution at zero force, u_{RZ} is:

$$u_{RZ} = \frac{5}{2\sqrt{3}} = 1.4 \text{ N} \quad \text{(X2.4)}$$

The total uncertainty component due to resolution at 2000 N is

$$\sqrt{1.4^2 + 1.4^2} = 2.0 \text{ N} \quad \text{(X2.5)}$$

Since the uncertainty due to the repeatability is greater than that due to resolution, the component due to the resolution is not included.

The combined measurement uncertainty of the error determined at 2000 N, u is:

$$u = \sqrt{3^2 + 2.4^2} = 3.8 \text{ N} \quad \text{(X2.6)}$$

The expanded measurement uncertainty of the error determined at 2000 N, U using a coverage factor of two is:

$$U = 2 \times 3.8 = 7.6 \text{ N} \quad \text{(X2.7)}$$

7.6 N is 0.38% of 2000 N.

NOTE X2.6—For additional resources relating to measurement uncertainty, refer to the JCGM 100:2008, Evaluation of measurement data-Guide to the Expression of Uncertainty in Measurement.

SUMMARY OF CHANGES

Committee E28 has identified the location of selected changes to this standard since the last issue (E4–15) that may impact the use of this standard.

(1) Section 3 was revised
(2) Section 12 was renumbered to incorporate old Sections 13 and 14.
(3) Note X2.5 was revised.

Committee E28 has identified the location of selected changes to this standard since the last issue (E4–14) that may impact the use of this standard. (Approved December 1, 2015.)

(1) Revised X2.4.
(2) Revised Section 8.