



Standard Practices for Force Verification of Testing Machines¹

This standard is issued under the fixed designation E 4; 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 reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

This standard has been approved for use by agencies of the 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 D 76.

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 Since conversion factors are not required in this practice, either inch-pound units, SI units, or metric values can be used as the standard.~~

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3.1 Since conversion factors are not required in this practice, either inch-pound units, SI units, or metric values can be used as the standard.

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 E 4.

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

D 76 [Specification for Tensile Testing Machines for Textiles](#)

E 74 [Practice of Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines](#)

E 467 [Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System](#)

3. Terminology

3.1 *Definitions:*

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

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

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 Dec. April 1, 2008-2009. Published January June 2009. Originally approved in 1923. Last previous edition approved in 2007-2008 as E4-07-E 4 – 08.

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.

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

3.1.2.1 *Discussion*—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 ($32.1740 \text{ ft/s}^2 \times \frac{9.80665 \text{ m/s}^2}{32.1740 \text{ ft/s}^2}$)). The newton is that force which acting on a 1-kg mass will give to it an acceleration of 1 m/s^2 .

3.1.3 *accuracy*—the specified permissible variation from the reference value.

3.1.3.1 *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.

3.1.4 *error (or the deviation from the correct value)*—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.

3.1.4.1 *Discussion*—The word “error” shall be used with numerical values, for example, “At a force of 30 000 lbf (133 kN), the error of the testing machine was + 15 lbf (67 N).”

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

3.1.5.1 *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:

$$E = A - B \quad (1)$$

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

where:

A = force indicated by machine being verified, lbf (or N), and

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

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

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

3.1.7.1 *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.

3.1.8 *capacity range*—in the case of testing machines, the range of forces for which it is designed. Some testing machines have more than one capacity range, that is, multiple ranges.

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

3.1.9.1 *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.

3.1.9.2 *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.

3.1.10 *elastic calibration device*—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.

3.1.11 *resolution of the force indicator*—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.

3.1.11.1 *resolution of analog type force indicators (scales, dials, recorders, etc.)*—the resolution is the smallest change in force indicated by a displacement of a pointer, or pen line. 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 0.10 in. (2.5 mm) or greater is recommended for the ratio of 1:10. A ratio less than 1:10 should not be used.

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

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

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

3.1.12 If the force indication, for either type of force indicator, fluctuates by more than twice the resolution, as described in 3.1.11.1 or 3.1.11.2, the resolution, expressed as a force, shall be equal to one-half the range of the fluctuation.

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 the amount of force that is applied and indicated, and that the accuracy of the force is traceable to the National Institute of Standards and Technology (NIST), formerly NBS. Practices E 4 provides a procedure to verify these machines, in order that the indicated forces may be traceable. A key element to this NIST traceability is that the devices used in the verification have known force characteristics, and have been calibrated in accordance with Practice E 74.

4.2 The procedures in Practices E 4 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 E 74.

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 E 4 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 E 4 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 E 4 requirements of Section 17, 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 E 4 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 air buoyancy.

8.2 Calculate the force exerted by a weight in air as follows:

$$\text{Force} = \frac{Mg}{9.80665} \left(1 - \frac{d}{D} \right) \quad (2)$$

where:

- M = mass of the weight,
- g = local acceleration due to gravity, m/s²,
- d = air density (0.0012 Mg/m³), and
- D = density of the weight in the same units as d .

For use in verifying testing machines, corrections for local values of gravity and air buoyancy can be made with sufficient accuracy using the multiplying factors from Table 1.

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

$$1 \text{ lbf} = 4.448222 \text{ N} \quad 1 \text{ kgf} = 9.80665 \text{ N (exact)} \quad (3)$$

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 3—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 E 4. ~~NOTE 4—Caution: Warning—~~ Practices E 4 verification values are not to be assumed valid for high-speed or dynamic testing applications (see Practice E 467).

~~NOTE 5—The 4—~~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.

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.

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

Latitude, °	Elevation Above Sea Level, ft(m)					
	–100 to 500 (–30.5 to 152)	500 to 1500 (152 to 457)	1500 to 2500 (457 to 762)	2500 to 3500 (762 to 1067)	3500 to 4500 (1067 to 1372)	4500 to 5500 (1372 to 1676)
20	0.9978	0.9977	0.9976	0.9975	0.9975	0.9974
25	0.9981	0.9980	0.9979	0.9979	0.9978	0.9977
30	0.9985	0.9984	0.9983	0.9982	0.9982	0.9981
35	0.9989	0.9988	0.9987	0.9987	0.9986	0.9985
40	0.9993	0.9993	0.9992	0.9991	0.9990	0.9989
45	0.9998	0.9997	0.9996	0.9996	0.9995	0.9994
50	1.0003	1.0002	1.0001	1.0000	0.9999	0.9999
55	1.0007	1.0006	1.0005	1.0005	1.0004	1.0003

NOTE 65—Example: A testing machine has a full-scale range of 5000 lbf and the resolution of the force indicator is 0.0472 lbf. The lowest possible verified force is 9.44 lbf (0.0472×200). Instead of decades starting at 9.44, 94.4 and 944 lbf, three decades, starting at 10, 100, and 1000 lbf 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, 5000 lbf. Note that the uppermost decade is not a complete decade and is terminated with the upper limit of the verified force range. The 3000 lbf 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~~ 10.5 Approximately 30 s after removing the maximum force in a range, record the return to zero indicator reading. This reading shall be $0.0 \pm$ 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 6—~~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.

A. VERIFICATION BY STANDARD WEIGHTS

12. Procedure

~~12.1 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 correct within a limit of error of 0.1%. Apply the weights in increments and remove in the reverse order. Arrange the weights symmetrically with respect to the weighing platform, so that the center of gravity of the force lies in the vertical line through the center of the platform. Record the applied force and the indicated force for each test load applied, and the error and the percent error calculated from these data. 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 7—~~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. Fifty-pound (22.7-kg) weights are usually convenient to use. This method of verification is confined to small testing machines and is rarely used above 1000 or 2000 lb.

NOTE 9—~~In 8—~~In connection with the required limit accuracy of error of 0.1 % it may be noted that, in addition to the National Institute for Standards and Technology, many of the states, some counties, and some universities have departments or offices of weights and measures equipped and staffed to certify weights to tolerances closer than the requirement of a limit of error or an accuracy of 0.1 %.

B. VERIFICATION OF HARDNESS TESTING MACHINES BY EQUAL-ARM BALANCE AND STANDARD WEIGHTS

13. Procedure

13.1 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 10—~~This 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.

13.2 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.

13.3 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.

C. VERIFICATION BY ELASTIC-CALIBRATION DEVICE

14. Temperature Equalization

14.1 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.

14.2 During the verification, measure the temperature of the elastic device within $\pm 2^{\circ}\text{F}$ (or $\pm 1^{\circ}\text{C}$) by placing a calibrated thermometer as close to the device as possible.

14.3 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 E 74 for further information.

15. Procedure

15.1 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 E 74 Class A verification value which establishes the lowest limit, or force level, allowable for the calibration device's loading range (see Practice E 74). 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.

15.2 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.

15.3 There are two methods for using elastic calibration devices:

15.3.1 *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.

15.3.2 *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.

15.4 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.

15.5 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 17.1.

15.6 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.

15.7 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.

16. Lever-Type Creep-Rupture Testing Machines

16.1 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 12.1. In using an elastic calibration device, the requirements of Sections 14 and 15 must be met as applicable.

16.2 *Procedure:*

16.2.1 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.

16.2.2 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.

16.2.3 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 17.1.

CALCULATION AND REPORT

17. Basis of Verification

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

NOTE H—This 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.

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