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Standard Practices for Force Verification of Testing Machines[1]

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 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 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.

1.4 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:*

D 76 Specification for Tensile Testing Machines for Textiles[2]

E 74 Practice for Calibration of Force Measuring Instruments for Verifying the Force Indication of Testing Machines[3]

E 467 Practice for Verification of Constant Amplitude Dynamic Loads on Displacements in an Axial Load Fatigue Testing System[3]

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.

3.1.2 *tension testing machine, CRT (constant-rate-oftraverse)*—a mechanical device for applying a load (force) to a specimen and in which the force is measured by means of a pendulum.

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

3.1.3.1 *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). The newton is that force which acting on a 1-kg mass will give to it an acceleration of 1 m/s^2.

3.1.4 *accuracy*—the specified permissible variation from the correct value. A testing machine is said to be accurate if the indicated force is within the specified permissible variation from the actual force.

3.1.4.1 *Discussion*—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

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[2] *Annual Book of ASTM Standards*, Vol 07.01.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

general limited by the sensitivity.

3.1.5 *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.

3.1.5.1 *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)."

3.1.6 *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.

3.1.6.1 *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, Ep, 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.

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

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

3.1.8.1 *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.

3.1.9 *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.

3.1.10 *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.

3.1.10.1 *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.

3.1.10.2 *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.

3.1.11 *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.

3.1.12 *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.

3.1.12.1 *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.

(*1*) *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).

3.1.12.2 *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.

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

3.1.13 If the force indication, for either type of force indicator, fluctuates by more than twice the resolution, as described in 3.1.12.1 or 3.1.12.2, 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.

7.2 System verification is invalid if the devices are removed and checked independently of the testing machine.

7.3 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.

7.3.1 If the initial verification run produces values within the Practices E 4 requirements of Section 18, the data may be used "as found" for run one of the two required for the new verification report.

7.3.2 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.

7.3.3 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/s^2,
d = air density (0.0012 Mg/m^3), 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:

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

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:** 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 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 For any force range, verify the testing machine by applying at least five test forces, at least two times, with the difference between any two successive force applications being no larger than one-third the difference between the selected maximum and minimum test forces. Minimum may be one-tenth the maximum force. Applied forces on second run are to be approximately the same as those on the first run. Report all

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

values, including the indicator reading, after removal of forces. Include indicator resolution for the minimum force. (Fewer test force applications are required for testing machines designed to measure only a smaller number of discrete forces, such as certain hardness testers, creep testers, etc.)

10.2 If it is desired to establish the lower limit of a verified force range lower than 10 % of the capacity of the range, verify the lower limit by five successive applications of force, none of which may differ from the lower limit force by more than ±2.5 % of this force (only three successive force applications are required for creep machines with fixed lever ratios of 20:1, nominal, or less). The lower force limit must be at least 100 times the indicator resolution, see 3.1.12. Report all values, including the indicator reading after removal of forces, and the indicator resolution at the lowest force limit.

10.3 For force ranges of testing machines, where the resolution of the force indicator changes automatically and extends or selects ranges without the influence of an operator, verify the force range by applying at least two successive series of forces, arranged in overlapping decade groups, such that the maximum force in one decade is the minimum force in the next higher decade. Starting with the selected minimal force in each decade, there are to be at least five force applications, in an approximate ratio of 1:1, 2:1, 4:1, 7:1, and 10:1, unless the maximum force is reached prior to completing all force application ratios. The resolution of the force indicator in each decade must be a force 200 or more times smaller than the decade's minimum force. Report all force values, their percent errors, and the indicator reading after removal of forces. Include the resolution of the force indicator for each decade. See 3.1.12.2 and Appendix X1, which contains a nonmandatory method for determining resolution.

NOTE 6—Example: If full scale is 5000 lbf and the minimal force resolution is 0.04 lbf, the minimum verified force would be 8 lbf (0.04 × 200). Instead of decades of 8, 80 and 800 lbf, three decades of 10, 100 and 1000 lbf could be selected to cover the force application range. Suitable verification test forces would then be approximately 10, 20, 40, 70, 100, 200, 400, 700, 1000, 2000, 4000, 5000 lbf. Note that the uppermost decade would not be a complete decade and would be terminated with the maximum force in the range. Report the resolution of each decade and the percent error for each test force of the two runs. The largest reported error of the two sets of the test runs is the maximum error for the force range.

10.4 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.

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.

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. 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 connection with the required limit 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 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 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