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Standard Practices for
Force Calibration and 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 calibration and verification, by means of force measurement standards, of tension or compression, or both, static or quasi-static testing machines (which may, or may not, have ~~force-indicating systems).~~ force-indicators). These practices are not intended to be complete purchase specifications for testing machines.

1.2 Testing machines may be verified by one of the three following methods or combination thereof. Each of the methods require a specific ~~uncertainty of measurement,~~ measurement uncertainty, displaying metrological traceability to The International System of Units (SI).

1.2.1 Use of standard weights,

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

1.2.3 Use of ~~force-measuring instruments.~~elastic force measurement standards.

~~1.3 The term 'metrological traceability' is used as defined in the JCGM 200: International vocabulary of metrology-Basic and general concepts and associated terms (VIM).~~

1.3 The procedures of 1.2.1–1.2.3 apply to the calibration and verification of the ~~force-indicating~~force-measuring systems associated with the testing machine, including the force indicators 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~~force-measuring system(s) to be verified and included in the ~~report.~~certificate and report of calibration and verification.*

1.4 *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 are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

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

[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.

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

1.5 Forces indicated on displays/printouts of testing machine data systems—be they instantaneous, delayed, stored, or retransmitted—which are verified with provisions of 1.2.1, 1.2.2, or 1.2.3, and are within the ±1 % measurement accuracy requirement,specifications stated in Section 15, comply with Practices E4.

1.6 The requirements of these practices limit the major components of measurement uncertainty when verifyingcalibrating testing machines. These Standard Practices do not require the allowable force measurement error to be reduced by the amount of the measurement uncertainty encountered during a verification.calibration. As a result, a testing machine verified using these practices may produce a deviation from the true force greater than ±1.0 % when the force measurement error is combined with the measurement uncertaintyuncertainty.

1.7 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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 Practices for Calibration and Verification for Force-Measuring Instruments
E467 Practice for Verification of Constant Amplitude Dynamic Forces in an Axial Fatigue Testing System

2.2 *BIPM Standard:*[3]

JCGM 100 : Evaluation of measurement data - Guide to the Expression of Uncertainty in Measurement.
JCGM 200 : International vocabulary of metrology — Basic and general concepts and associated terms (VIM).

3. Terminology

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

3.2 *Definitions:*

3.2.1 *calibration, n*—operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.

3.2.1.1 *Discussion—*
A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

3.2.1.2 *Discussion—*
Calibration should not be confused with adjustment of a measuring system, often mistakenly called "self-calibration", nor with verification of calibration.

3.2.1.3 *Discussion—*
Often, the first step alone in the above definition is perceived as being calibration. **JCGM 200:2012** [4]

3.2.2 *elastic force measurement standard, n*—system consisting of an elastic member combined with an appropriate device for indicating the magnitude (or a quantity proportional to the magnitude) of deformation of the member under an applied force.

3.2.3 *exercise, v*—apply the maximum force to be used in the verificationcalibration to either a force-measuring instrument an

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

[3] Available from BIPM - Pavillon de Breteuil F-92312 Sèvres Cedex FRANCE. this document is available free-of-charge at https://www.bipm.org/en/publications/guides/vim.html

[4] This definition is reproduced here from JCGM 200:2012 International vocabulary of metrology – Basic and general concepts and associated terms (VIM) with permission from the Director of BIPM. The text has been put in ASTM International's form and style.

elastic force measurement standard or the force-sensing device of a testing machine, or to both, to reestablish the hysteresis pattern that tends to disappear during periods of disuse, or with the change of mode of force application, as from compression to tension.

3.2.4 *force indicator, n—of a testing machine*, a component of a force-measuring system that presents, in force units, the force measured by the force-measuring system.

3.2.5 *force measurement error, E, n*—in the case of a testing machine, the difference obtained by subtracting the force indicated by the force measurement standard from the indicated force of the testing machine.

3.2.5.1 *Discussion—*

In a certificate and report of calibration and verification, "force measurement error" shall be used with numerical values, for example, "At a force of 300 kN [60 000 lbf], the force measurement error of the testing machine was + 67 N [+ 15 lbf]."

3.2.6 *force measurement standard, n*—a standard weight, an equal-arm balance and a standard weight, or an elastic force measurement standard used as a reference, with associated measurement uncertainty, in compliance with these practices and Practices E74.

3.2.6.1 *Discussion—*

A force measurement standard is a specific type of "measurement standard" as defined in JCGM 200: International vocabulary of metrology — Basic and general concepts and associated terms (VIM).

3.2.7 *force-measuring system, n—of a testing machine*, a component of a testing machine that measures and indicates the force applied by the testing machine.

3.2.8 ~~*force-measuring instrument,*~~*force-sensing device, n*—~~system~~ ~~*consisting of an elastic member*~~*of a testing machine,* ~~combined with an appropriate device for indicating the magnitude (or a quantity proportional to the magnitude) of deformation of the member under an applied force.~~a component of the force-measuring system, that measures through deformation or other means the force applied by the testing machine.

3.2.8.1 *Discussion—*

Examples of a force-sensing device include a strain-gage force transducer (commonly called a load cell) and a pressure transducer.

3.2.9 *measurement accuracy, n*—closeness of agreement between a measured quantity value and a true quantity value of a ~~measurand~~measurand.

3.2.9.1 *Discussion—*

The concept ~~'measurement accuracy'~~"measurement accuracy" is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement error.

3.2.9.2 *Discussion—*

The term "measurement accuracy" should not be used for measurement trueness and the term "measurement precision" should not be used for 'measurement accuracy', which, however, is related to both these concepts.

3.2.9.3 *Discussion—*

~~'Measurement accuracy'~~"Measurement accuracy" is sometimes understood as closeness of agreement between measured quantity values that are being attributed to the measurand.

JCGM 200:2012 [4]

3.2.10 *metrological traceability, n*—property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty.

3.2.10.1 *Discussion—*

For this definition, a ~~'reference'~~"reference" can be a definition of a measurement unit through its practical realization, or a measurement procedure including the measurement unit for a non-ordinal quantity, or a measurement standard.

3.2.10.2 *Discussion—*

Metrological traceability requires an established calibration hierarchy.

3.2.10.3 *Discussion—*

Specification of the reference must include the time at which this reference was used in establishing the calibration hierarchy, along with any other relevant metrological information about the reference, such as when the first calibration in the calibration hierarchy was performed.

3.2.10.4 *Discussion—*

For measurements with more than one input quantity in the measurement model, each of the input quantity values should itself be metrologically traceable and the calibration hierarchy involved may form a branched structure or a network. The effort involved in establishing metrological traceability for each input quantity value should be commensurate with its relative contribution to the measurement result.

3.2.10.5 *Discussion—*
Metrological traceability of a measurement result does not ensure that the measurement uncertainty is adequate for a given purpose or that there is an absence of mistakes.

3.2.10.6 *Discussion—*
A comparison between two measurement standards may be viewed as a calibration if the comparison is used to check and, if necessary, correct the quantity value and measurement uncertainty attributed to one of the measurement standards. **JCGM 200:2012** [4]

3.2.11 ~~*portable testing machine (force-measuring type),*~~ *testing machine, n—force-measuring type,* a ~~device specifically designed to be moved from place to place and for applying a force (load) to a specimen.~~ mechanical device for applying and measuring forces on a specimen being tested.

3.2.11.1 *Discussion—*
A testing machine generally consists of two components, a mechanism for applying forces to a specimen being tested and a force-measuring system for measuring the applied forces.

3.2.11.2 *Discussion—*
Some testing machines do not have a force indicator such as some creep testing machines which apply a force utilizing weights and a lever mechanism.

~~3.2.7 *testing machine (force-measuring type), n*—a mechanical device for applying a force to a specimen.~~

3.2.12 *verification, n*—provision of objective evidence that a given item fulfils specified requirements.

3.2.12.1 *Discussion—*
EXAMPLE 1 Confirmation that a given reference material as claimed is homogeneous for the quantity value and measurement procedure concerned, down to a measurement portion having a mass of 10 mg.

3.2.12.2 *Discussion—*
EXAMPLE 2 Confirmation that performance properties or legal requirements of a measuring system are achieved.

3.2.12.3 *Discussion—*
EXAMPLE 3 Confirmation that a target measurement uncertainty can be met.

3.2.12.4 *Discussion—*
When applicable, measurement uncertainty should be taken into consideration.

3.2.12.5 *Discussion—*
The item may be, for example, a process, measurement procedure, material, compound, or measuring system.

3.2.12.6 *Discussion—*
The specified requirements may be, for example, that a manufacturer's specifications are met.

3.2.12.7 *Discussion—*
Verification in legal metrology, as defined in ~~VIML[53],~~ VIML[5], and in conformity assessment in general, pertains to the examination and marking and/or issuing of a verification certificate for a measuring system.

3.2.12.8 *Discussion—*
Verification should not be confused with calibration. Not every verification is a validation.

3.2.12.9 *Discussion—*
In chemistry, verification of the identity of the entity involved, or of activity, requires a description of the structure or properties of that entity or activity. **JCGM 200:2012** [4]

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *calibration force, n*—A force selected where the indicated force of the testing machine is compared with the applied force as indicated by the force measurement standard.

3.3.1.1 *Discussion—*
Calibration forces shall be selected in accordance with these Practices E4, see Section 11.

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

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

[5] OIML, *International Vocabulary of Terms in Legal Metrology (VIML).*

~~3.3.2 *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.~~

~~3.3.3 *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.~~

~~3.3.3.1 *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]."~~

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

3.3.3.1 *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].

~~3.3.5 *force measurement standard, n*—a standard weight, an equal-arm balance and a standard weight, or a force-measuring instrument used as a reference, with associated measurement uncertainty, in compliance with these practices and Practices E74.~~

~~3.3.5.1 *Discussion*—~~

~~A force measurement standard is a specific type of "measurement standard" as defined in JCGM 200: International vocabulary of metrology — Basic and general concepts and associated terms (VIM).~~

3.3.4 *percent error of ~~force,~~ force E_P, n*—in the case of a testing machine, the ratio, ~~expressed as a percent,~~ of the force measurement error to the ~~correct value of the applied force.~~applied force as measured by the force measurement standard, expressed as a percent.

3.3.4.1 *Discussion*—

The ~~test force, as indicated by~~ indicated force of the testing machine, and the applied force, as ~~computed from the readings of the verification device,~~ measured by the force measurement standard, shall be recorded at each ~~test point. The~~ calibration force. The force measurement error, *E*, and the percent error of forces, E_P,~~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 force measurement standard.~~

A = force indicated by the testing machine being verified, N [or lbf, etc.], and
B = value of the applied force, N [or lbf, etc.], as measured by the force measurement standard, in the same units as *A*.

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

3.3.5.1 *Discussion*—

It is convenient to express permissible variation in terms of ~~percentage~~ percent error of ~~error.~~force. The numerical value of the permissible variation for a testing machine is so stated hereafter in these practices.

3.3.6 *resolution of the ~~force indicator,~~force-measuring system, n*—smallest change of force that can be estimated or ascertained on the force indicating apparatus of the testing machine, at any applied force.

3.3.6.1 *Discussion*—

Appendix X1 describes a method for determining resolution.

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

3.3.7.1 *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~~ 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.

3.3.7.2 *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].

3.3.7.3 *Discussion—*
If the indicated force ~~indication~~ fluctuates by more than twice the resolution, as described in ~~3.3.9~~3.3.7, the resolution, expressed as a force, shall be equal to one-half the range of the fluctuation.

3.3.8 *resolution of digital ~~type~~ force ~~indicators~~ measuring systems (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.

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

3.3.8.2 *Discussion—*
If the indicated force ~~indication~~ fluctuates by more than twice the resolution, as described in ~~3.3.10~~3.3.8, the resolution, expressed as a force, shall be equal to one-half the range of the fluctuation.

3.3.9 *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.

3.3.9.1 *Discussion—*
This term is also defined in Practice E74 and has a different meaning. If the term "verified range of forces" is preceded by "Class A", the Practices E 74 definition shall apply.

4. Summary of Practice

4.1 Practices E4 calibration consists of comparing the indicated force of the testing machine (or the testing machine's applied force in the case of testing machines that do not have force indicators) to a force measurement standard at various calibration forces. These comparisons are used to establish the force measurement error at each calibration force at least two times. The metrological requirements of these Practices E4 intrinsically account for measurement uncertainty by limiting the major contributions to measurement uncertainty such as requirements for the force measurement standard used, resolution, repeatability, and measurement accuracy. As a result, the Practices E4 calibration and verification procedure along with the certificate and report of calibration and verification provide metrological traceability to the SI for the force-measuring system of the testing machine.

4.1.1 Although Practices E4 do not require reporting measurement uncertainty of the calibration, it may be calculated and included in the certificate and report of calibration and verification.

4.2 Practices E4 verification consists of using the force measurement errors determined along with resolution and return-to-zero readings as evidence that the force indicator(s) of a testing machine indicates values, or that the testing machine applies forces, that meet the requirements of these Practices E4 in terms of percent error of force, repeatability, resolution, and return-to-zero at the calibration forces directed by these Practices E4.

4.3 If the force-measuring system of the testing machine fails to meet any of these requirements and is adjusted, a full calibration and verification in accordance with these Practices E4 shall be conducted after the adjustment is made.

5. Significance and Use

5.1 Testing machines that apply and indicate force are used in many industries, in many ways. They ~~may~~might be used in a research laboratory to measure material properties, ~~and~~or in a production line to qualify a product for shipment. No matter what the end use of the testing 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~~calibrate these testing machines so that the ~~indicated~~measured forces are traceable to the SI. A key element of traceability to the SI is that the ~~devices~~ force measurement standards used in the ~~verification~~calibration have known force characteristics, and have been calibrated in accordance with Practice E74.

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

6. ~~Force-Measuring Instruments~~ Elastic Force Measurement Standards

6.1 When ~~verifying~~calibrating testing machines, ~~use force-measuring instruments only over~~ elastic force measurement standards shall be only used within their Class A ~~force ranges~~ verified range of forces as determined by Practice E74.

7. Advantages and Limitations of Methods

7.1 *~~Verification~~Calibration by Standard Weights*—~~Verification~~Calibration 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,~~calibrated, (*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.

7.2 *~~Verification~~Calibration by Equal-Arm Balance and Standard Weights*—The second method of ~~verification~~calibration 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,~~method and is generally applicable only to certain types of hardness testing machines in which the force is applied through an internal lever system.

7.3 *~~Verification by Force-measuring Instruments—~~Calibration by Elastic Force Measurement Standards*—The third method of ~~verification~~calibration of testing machines involves measurement of the elastic strain or deflection under force of a ring, loop, tension or compression bar, or other ~~force-measuring instrument. The force-measuring instrument~~ elastic force measurement standard. The elastic force measurement standard is free from the limitations referred to in ~~6.1~~7.1 and ~~6.2~~7.2.

8. System ~~Verification~~Calibration

8.1 A testing machine shall be calibrated and verified as a system with the ~~force sensing and indicating devices~~force-sensing device and force indicator (see ~~1.4~~1.3 and ~~1.6~~1.5) in place and operating as in actual use.

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

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

8.3 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~~ are designed to be able to interchange force-sensing devices (usually these are force transducers commonly called load cells). Usually these force-sensing devices vary in capacity range. Lower capacity range force-sensing devices are used for better resolution and accuracy at lower test forces and higher capacity range force-sensing devices are used to apply and measure higher forces. During use of a testing machine of this type, the force-sensing devices may be routinely installed and ~~uninstalled in the testing machine. For such~~ uninstalled, which effectively creates multiple force-measuring systems. For such force-sensing devices, interchangeability shall be established during the original ~~verification~~calibration and shall be reestablished after an adjustment is performed. This is accomplished by performing a ~~normal verification~~Practices E4 calibration with the force-sensing 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 force-sensing device, the orientation will be repeated. Remove and reinstall the force-sensing device between the two ~~verification~~calibration runs to demonstrate interchangeability. Repeat the procedure for each interchangeable ~~force measuring~~ force-sensing device used in the testing machine.

8.3.1 Some testing machines are designed with multiple force-sensing devices permanently mounted usually with different test areas for each force sensing device. Section 8.3 does not apply to such testing machines unless the force-sensing devices are interchanged as described in 8.3.

8.3.2 Introduction of ~~the~~a new interchangeable force ~~measuring devices~~sensing device(s) shall require that interchangeability be established per ~~7.3~~8.3.

8.4 A Practices E4 ~~Verification~~calibration consists of at least two ~~verification~~calibration runs of the calibration forces ~~contained~~selected in the ~~force~~verified range(s) ~~selected.~~ of forces. See ~~10.1~~11.1 ~~and~~to ~~10.3~~11.3.

8.4.1 If the initial ~~verification~~calibration run produces values within the Practices E4 requirements of Section ~~14~~15, the data may be used "as found" for calibration run one of the two required for the new ~~verification report.~~certificate and report of calibration and verification.

8.4.2 If the initial ~~verification~~calibration 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~~ force-measuring system(s), after which the two required ~~verification~~calibration runs shall be conducted and reported in the new ~~verification report and certificate.~~certificate and report of calibration and verification.

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

9. Gravity and Air Buoyancy Corrections

9.1 In the ~~verification~~calibration 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.

9.1.1 The force exerted by a weight in air is ~~determined~~obtained by:

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

$$F = M \times g\left(1 - \frac{d}{D}\right) \tag{2}$$

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.

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

$$g = 9.7803[1 + 0.0053\,(\sin\,\varnothing)^2] - 0.000001967h \tag{3}$$

~~where:~~

where:

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

NOTE 1—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.

9.2 ~~The force in customary units~~ In some cases, a mass might not be designated in kilograms, for instance it might be denoted in pounds and it might be desired to know the force exerted in pound-force units. In other cases, it might be desired to know the force exerted in kilogramforce units where the mass is designated in kilograms. In these cases, the force in non–SI units exerted by a weight in air is calculated as follows:

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

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

where:

where:

~~F_c~~	=	~~force expressed in customary units, that is, pound force or kilogram-force,~~
F_c	=	force expressed in non-SI units, such as, pound force or kilogram-force,
M	=	true mass of the weight, in the corresponding mass units of the, F_c is being expressed, such as, pound or kilogram,
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.~~
9.80665	=	the factor converting SI units of force into non-SI 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~~non-SI force units are related to the newton (N), the SI unit of force, by the following relationships:

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

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

9.2.1 For use in ~~verifying~~calibrating testing machines, corrections for local values of gravity and air buoyancy to standard weights calibrated in pounds can be made with sufficient precision 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 2—Eq 7 and Table 1 correct for the shape of the earth, elevation above sea level, and air ~~bouyancy.~~buoyancy. The correction for the shape of the earth is a simplification of the World Geodetic System 84 Ellipsoidal Gravity Formula. The results obtained with the simplified formula differ by less than ~~0.0005%.~~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%.~~0.01 %. If aluminum ~~weigths~~weights are used, errors on the order of ~~0.03%~~0.03 % can result.

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

9.3 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.

10. Application of Force

10.1 In the ~~verification~~calibration of a testing machine, approach the calibration force by increasing the force from a lower force.

NOTE 3—For any testing machine the force measurement errors observed at corresponding calibration forces taken first by increasing the force to any given ~~test~~calibration force and then by decreasing the force to that ~~test~~calibration force, ~~may~~might 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.

10.2 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.

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

NOTE 4—The force measurement error of a testing machine of the hydraulic-ram type, in which the ram hydraulic pressure is measured, ~~may~~might vary significantly with ram position. To the extent possible such testing machines should be verified at the ram positions used.

11. Selection of ~~Verification~~Calibration Forces

11.1 Determine the upper and lower limits of the verified ~~force~~ range of forces of the testing machine to be verified. ~~In no case shall~~All calibration forces in the verified ~~force~~ range ~~include forces below 200 times~~ of forces shall be at least 200 times larger than the resolution of the ~~force indicator.~~force-measuring system at that calibration force.

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

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

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

11.3.2 Five or more different ~~verification~~calibration forces shall be selected per decade such that the difference between two adjacent ~~verification~~calibration 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 calibration force in that decade. It is recommended that starting with the lowest calibration force in each decade, the ~~ratio~~ratios of the ~~verification~~calibration forces to the lowest calibration 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.

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

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

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

11.5 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~~ return-to-zero reading of the force-measuring system. The absolute value of the return-to-zero reading shall be less than or equal to the greater of the absolute value of 0.1 % of the maximum force just ~~applied, or 1 % of the lowest verified~~applied or the absolute value of 1 % of the lowest calibration force in the ~~range, whichever is greater.~~verified range of forces.

12. Eccentricity of Force

12.1 For the purpose of determining the verified ~~force~~ range of ~~a~~ forces of the 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 6—The effect of eccentric force on the measurement accuracy of a testing machine ~~may~~can be determined by ~~verification~~calibration readings taken with force measurement standards placed so that the resultant force is applied at definite distances from the axis of the testing machine, and the verified ~~force~~ range of forces determined for a series of eccentricities.

13. Methods of ~~Verification~~Calibration

13.1 *Method A, ~~Verification~~Calibration by Standard Weights:*

13.1.1 *Procedure:*

13.1.1.1 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~~ force-sensing device in place of the specimen. Use standard weights certified within five years to be accurate within ~~0.1%.~~0.1 %. Apply the standard weights in ascending increments. If data is to be taken in both ascending and descending directions, remove the standard weights in reverse order. Record the forces, corrected for gravity and air buoyancy in accordance with Section ~~8~~9.

NOTE 7—The method of ~~verification~~calibration 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 standard weights available. Twenty-five kg or [fifty lb] standard weights are usually convenient to use. This method of ~~verification~~calibration is confined to small testing machines and is rarely used above 5000 N [1000 lbf].

13.2 *Method ~~B. Verification Of~~B. Calibration of Hardness Testing Machines by Equal-Arm Balance and Standard Weights:*

13.2.1 *Procedure:*

13.2.1.1 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~~13 on the opposite pan to balance the ~~load~~force exerted by the indenter.

NOTE 8—This method ~~may~~can be used for the ~~verification~~calibration 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~~calibrating hardness testing machines see the applicable ASTM test method.

13.2.1.2 Since the permissible travel of the indenter of a hardness-testing machine is usually very small, do not allow the balance