Designation: ~~E74 – 13~~ E74 – 13a

Standard Practice of
Calibration of Force-Measuring Instruments for Verifying the Force Indication of Testing Machines[1]

This standard is issued under the fixed designation E74; 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 The purpose of this practice is to specify procedures for the calibration of force-measuring instruments. Procedures are included for the following types of instruments:

1.1.1 Elastic force-measuring instruments, and

1.1.2 Force-multiplying systems, such as balances and small platform scales.

NOTE 1—Verification by deadweight loading is also an acceptable method of verifying the force indication of a testing machine. Tolerances for weights for this purpose are given in Practices E4; methods for calibration of the weights are given in NIST Technical Note 577, Methods of Calibrating Weights for Piston Gages.[2]

1.2 The values stated in SI units are to be regarded as the standard. Other metric and inch-pound values are regarded as equivalent when required.

1.3 This practice is intended for the calibration of static force measuring instruments. It is not applicable for dynamic or high speed force calibrations, nor can the results of calibrations performed in accordance with this practice be assumed valid for dynamic or high speed force measurements.

1.4 *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:*[3]

E4 Practices for Force Verification of Testing Machines

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

E1012 Practice for Verification of Testing Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application

2.2 *American National Standard:*

B46.1 Surface Texture[4]

ELASTIC FORCE-MEASURING INSTRUMENTS

3. Terminology

3.1 *Definitions:*

3.1.1 *elastic force-measuring ~~device—~~instrument—*a device or system consisting of an elastic member combined with a device for indicating the magnitude (or a quantity proportional to the magnitude) of deformation of the member under an applied force.

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[1] This practice is under the jurisdiction of ASTM Committee E28 on Mechanical Testing and is the direct responsibility of Subcommittee E28.01 on Calibration of Mechanical Testing Machines and Apparatus.

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[2] Available from National Institute for Standards and Technology, Gaithersburg, MD 20899.

[3] 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.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3.1.2 *primary force standard*—a deadweight force applied directly without intervening mechanisms such as levers, hydraulic multipliers, or the like, whose mass has been determined by comparison with reference standards traceable to national standards of mass.

3.1.3 *secondary force standard*—an instrument or mechanism, the calibration of which has been established by comparison with primary force standards.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *calibration equation*—a mathematical relationship between deflection and force established from the calibration data for use with the instrument in service, sometimes called the calibration curve.

3.2.2 *continuous-reading* ~~*device—*~~*instument—*a class of instruments whose characteristics permit interpolation of forces between calibrated forces.

3.2.2.1 *Discussion—*

Such instruments usually have force-to-deflection relationships that can be fitted to polynominal equations.

3.2.3 *creep*—The change in deflection of the force-measuring instrument under constant applied force.

3.2.3.1 *Discussion—*

Creep is expressed as a percentage of the output change at a constant applied force from an initial time following the achievement of mechanical and electrical stability and the time at which the test is concluded. Valid creep tests may require the use of primary force standards to maintain adequate stability of the applied force during the test time interval. Creep results from a time dependent, elastic deformation of the instrument mechanical element. In the case of strain gage based load cells, creep is adjusted by strain gage design and process modifications to reduce the strain gage response to the inherent time-dependent elastic deflection.

3.2.4 *creep recovery*—The change in deflection of the force-measuring instrument after the removal of force following a creep test.

3.2.4.1 *Discussion—*

Creep Recovery is expressed as a percentage difference of the output change at zero force following a creep test and the initial zero force output at the initiation of the creep test divided by the output during the creep test. The zero force measurement is taken at a time following the achievement of mechanical and electrical stability and a time equal to the creep test time. For many devices, the creep characteristic and the creep recovery characteristic are approximate mirror images.

3.2.5 *deflection*—the difference between the reading of an instrument under applied force and the reading with no applied force.

3.2.5.1 *Discussion—*

This definition applies to instruments that have electrical outputs as well as those with mechanical deflections.

3.2.6 *loading range*—a range of forces within which the lower limit factor is less than the limits of error specified for the instrument application.

3.2.7 *reading*—a numerical value indicated on the scale, dial, or digital display of a force-measuring instrument under a given force.

3.2.8 *resolution*—the smallest reading or indication appropriate to the scale, dial, or display of the force measuring instrument.

3.2.9 *specific force device*—an alternative class of instruments not amenable to the use of a calibration equation.

3.2.9.1 *Discussion—*

Such instruments, usually those in which the reading is taken from a dial indicator, are used only at the calibrated forces. These instruments are also called ~~limited-load~~limited-force devices.

3.2.10 *lower limit factor, LLF*—a statistical estimate of the error in forces computed from the calibration equation of a force–measuring instrument when the instrument is calibrated in accordance with this practice.

3.2.10.1 *Discussion—*

The lower limit factor was termed "Uncertainty" in previous editions of E74. The Lower Limit Factor is used to calculate the lower end of the loading range, see 8.5. Other factors evaluated in establishing the lower limit of the loading range of forces are the resolution of the instrument and the lowest non-zero force applied in the calibration ~~load~~force sequence, The Lower Limit Factor is one component of the measurement uncertainty. Other uncertainty components should be included in a comprehensive measurement uncertainty analysis. See Appendix X1 for an example of measurement uncertainty analysis.

4. Significance and Use

4.1 Testing machines that apply and indicate force are in general use in many industries. Practices E4 has been written to provide a practice for the force verification of these machines. A necessary element in Practices E4 is the use of devices whose force characteristics are known to be traceable to national standards. Practice E74 describes how these devices are to be calibrated. The procedures are useful to users of testing machines, manufacturers and providers of force measuring instruments, calibration laboratories that provide the calibration of the instruments and the documents of traceability, and service organizations that use the devices to verify testing machines.

5. Reference Standards

5.1 Force-measuring instruments used for the verification of the force indication systems of testing machines may be calibrated by either primary or secondary force standards.

5.2 Force-measuring instruments used as secondary force standards for the calibration of other force-measuring instruments shall be calibrated by primary force standards. An exception to this rule is made for instruments having capacities exceeding the range of available primary force standards. Currently the maximum primary force-standard facility in the United States is 1 000 000-lbf (4.4-MN) deadweight calibration machine at the National Institute of Standards and Technology.

6. Requirements for Force Standards

6.1 *Primary Force Standards*—Weights used as primary force standards shall be made of rolled, forged, or cast metal. Adjustment cavities shall be closed by threaded plugs or suitable seals. External surfaces of weights shall have a finish of 125 or less as specified in ANSI B46.1.

6.1.1 The force exerted by a weight in air is calculated as follows:

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

where:

M = mass of the weight,
g = local acceleration due to gravity, m/s^2,
d = air density (approximately 0.0012 Mg/m^3),
D = density of the weight in the same units as d, and
9.80665 = the factor converting SI units of force into the customary units of force. For SI units, this factor is not used.

6.1.2 The masses of the weights shall be determined within 0.005 % of their values by comparison with reference standards traceable to the national standards of mass. The local value of the acceleration due to gravity, calculated within 0.0001 m/s^2 (10 milligals), may be obtained from the National ~~Geodotie~~Geodetic Information Center, National Oceanic and Atmospheric Administration.[5]

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

$$1\ \text{lbf} = 4.448\,22\,N \tag{2}$$

$$1\,\text{kgf} = 9.806\,65\,N\,(\text{exact})$$

The Newton is defined as that force which, applied to a 1-kg mass, would produce an acceleration of 1 m/s/s.
The pound-force (lbf) is defined as that force which, applied to a 1-lb mass, would produce an acceleration of 9.80665 m/s/s.
The kilogram-force (kgf) is defined as that force which, applied to a 1-kg mass, would produce an acceleration of 9.80665 m/s/s.

6.2 *Secondary Force Standards*—Secondary force standards may be either elastic force-measuring instruments used in conjunction with a machine or mechanism for applying force, or some form of mechanical or hydraulic mechanism to multiply a relatively small deadweight force. Examples of the latter form include single- and multiple-lever systems or systems in which a force acting on a small piston transmits hydraulic pressure to a larger piston.

6.2.1 Elastic force-measuring instruments used as secondary force standards shall be calibrated by primary force standards and used only over the Class AA loading range (see 8.6.2.1). Secondary force standards having capacities exceeding 1 000 000 lbf (4.4 MN) are not required to be calibrated by primary force standards. Several secondary force standards of equal compliance may be

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[5] Available from National Oceanic and Atmospheric Administration (NOAA), 14th St. and Constitution Ave., NW, Room 6217, Washington, DC 20230.

combined and loaded in parallel to meet special needs for higher capacities. The Lower Limit Factor (see 8.5) of such a combination shall be calculated by adding in quadrature using the following equation:

$$LLF_c = \sqrt{LLF_o{}^2 + LLF_1{}^2 + LLF_2{}^2 + \ldots LLF_n{}^2} \tag{3}$$

where:

LLF_c = Lower Limit Factor of the combination, and
$LLF_{o,\,1,\,2\,\ldots\,n}$ = Lower Limit Factor of the individual instruments.

6.2.2 The multiplying ratio of a ~~force multiplying~~ force-multiplying system used as a secondary force standard shall be measured at not less than three points over its range with an accuracy of 0.05 % of ratio or better. Some systems may show a systematic change in ratio with increasing force. In such cases the ratio at intermediate points may be obtained by linear interpolation between measured values. Deadweights used with multiplying-type secondary force standards shall meet the requirements of 6.1 and 6.1.2. The force exerted on the system shall be calculated from the relationships given in 6.1.1. The ~~force multiplying~~ force-multiplying system shall be checked annually by elastic force measuring instruments used within their class AA loading ranges to ascertain whether the forces applied by the system are within acceptable ranges as defined by this standard. Changes exceeding 0.05 % of applied force shall be cause for reverification of the force multiplying system.

7. Calibration

7.1 *Basic Principles*—The relationship between the applied force and the deflection of an elastic force-measuring instrument is, in general, not linear. As force is applied, the shape of the elastic element changes, progressively altering its resistance to deformation. The result is that the slope of the force-deflection curve changes gradually and continuously over the entire range of the instrument. This characteristic curve is a stable property of the instrument that is changed only by a severe overload or other similar cause.

7.1.1 Superposed on this curve are local variations of instrument readings introduced by imperfections in the force indicating system of the instrument. Examples of imperfections include: non-uniform scale or dial graduations, irregular wear between the contacting surfaces of the vibrating reed and button in a proving ring, and instabilities in excitation voltage, voltage measurement, or ratio-metric voltage measurement in a load cell system. Some of these imperfections are less stable than the characteristic curve and may change significantly from one calibration to another.

7.1.2 *Curve Fitting*—To determine the force-deflection curve of the force-measuring instrument, known forces are applied and the resulting deflections are measured throughout the range of the instrument. A polynomial equation is fitted to the calibration data by the least squares method to predict deflection values throughout the loading range. Such an equation compensates effectively for the nonlinearity of the calibration curve. The standard deviation determined from the difference of each measured deflection value from the value derived from the polynomial curve at that force provides a measure of the error of the data to the curve fit equation. A statistical estimate, called the Lower Limit Factor, LLF, is derived from the calculated standard deviation and represents the width of the band of these deviations about the basic curve with a probability of 99%. The LLF is, therefore, an estimate of one source of uncertainty contributed by the instrument when forces measured in service are calculated by means of the calibration equation. Actual errors in service are likely to be different if forces are applied under mechanical and environmental conditions differing from those of calibration. Other sources of uncertainty such as those listed in Appendix X1 could increase the uncertainty of measurement of the instrument in service.

NOTE 3—While it is the responsibility of the calibration laboratory to calibrate the instrument in accordance with the requirements of this practice, it is the responsibility of the user to determine the uncertainty of the instrument in service. Errors in service are likely to be different if forces are applied under mechanical and environmental conditions differing from those of calibration. Other sources of uncertainty, such as those listed in Appendix X1, must be considered by the user to determine the uncertainty of the instrument in service.

7.1.3 *Curve Fitting using polynomials of greater than 2nd degree*—The use of calibration equations of the 3rd, 4th, or 5th degree is restricted to devices having a resolution of 1 increment of count per 50000 or greater active counts at the maximum calibration force. Annex A1 specifies the procedure for obtaining the degree of the best fit calibration curve for these devices. Equations of greater than 5th degree shall not be used.

NOTE 4—Experimental work by several force calibration laboratories in fitting higher than second degree polynomials to the observed data indicates that, for some devices, use of a higher degree equation may result in a lower ~~uncertainty~~LLF than that derived from the second degree fit. (ASTM RR:E28-1009)[6] Overfitting should be avoided. Equations of greater than 5th degree cannot be justified due to the limited number of force increments in the calibration protocol. Errors caused by round-off may occur if calculations are performed with insufficient precision.

A force measuring device not subjected to repair, overloading, modifications, or other significant influence factors which alter its elastic properties or its sensing characteristics will likely exhibit the same degree of best fit on each succeeding calibration as was determined during its initial calibration using this procedure. A device not subjected to the influence factors outlined above which exhibits continued change of degree of best fit with several successive calibrations may not have sufficient performance stability to allow application of the curve fitting procedure of Annex A1.

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[6] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E28-1009. Contact ASTM Customer Service at service@astm.org.

7.2 *Selection of Calibration Forces*— A careful selection of the different forces to be applied in a calibration is essential to provide an adequate and unbiased sample of the full range of the deviations discussed in 7.1 and 7.1.1. For this reason, the selection of the calibration forces is made by the standardizing laboratory. An exception to this, and to the recommendations of 7.2.1 and 7.2.4, is made for specific force devices, where the selection of the forces is dictated by the needs of the user.

7.2.1 *Distribution of Calibration Forces*— Distribute the calibration forces over the full range of the instrument, providing, if possible, at least one calibration force for every 10 % interval throughout the range. It is not necessary, however that these forces be equally spaced. Calibration forces at less than one tenth of capacity are permissible and tend to give added assurance to the fitting of the calibration equation. If the lower limit of the loading range of the device (see 8.6.1) is anticipated to be less than one tenth of the maximum force applied during calibration, then forces should be applied at or below this lower limit. In no case should the smallest force applied be below the lower limit of the instrument as defined by the values:

$$400 \times \text{resolution for Class A loading range} \tag{4}$$

$$2000 \times \text{resolution for Class AA loading range}$$

An example of a situation to be avoided is the calibration at ten equally spaced force increments of a proving ring having a capacity deflection of 2000 divisions, where the program will fail to sample the wear pattern at the contacting surfaces of the micrometer screw tip and vibrating reed because the orientation of the two surfaces will be nearly the same at all ten forces as at zero force. In load cell calibration with electrical instruments capable of linearizing the output signal, whenever possible, select calibration forces other than those at which the linearity corrections were made.

7.2.2 The resolution of an analog type force-measuring instrument is determined by the ratio between the width of the pointer or index and the center to center distance between two adjacent scale graduation marks. Recommended ratios are ½, ⅕, or ⅒ . A center to center graduation spacing of at least 1.25 mm is required for the estimation of ⅒ of a scale division. To express the resolution in force units, multiply the ratio by the number of force units per scale graduation. A vernier scale of dimensions appropriate to the analog scale may be used to allow direct fractional reading of the least main instrument scale division. The vernier scale may allow a main scale division to be read to a ratio smaller than that obtained without its use.

7.2.3 The resolution of a digital instrument is considered to be one increment of the last active number on the numerical indicator, provided that the reading does not fluctuate by more than plus or minus one increment when no force is applied to the instrument. If the readings fluctuate by more than plus or minus one increment, the resolution will be equal to half the range of fluctuation.

7.2.4 *Number of Calibration Forces*—A total of at least 30 force applications is ~~requiared~~required for a calibration and, of these, at least 10 must be at different forces. Apply each force at least twice during the calibration.

7.2.5 *Specific Force Devices (Limited ~~Load~~Force Devices)*—Because these devices are used only at the calibrated forces, select those forces which would be most useful in the service function of the instrument. Coordinate the selection of the calibration forces with the submitting organization. Apply each calibration force at least three times in order to provide sufficient data for the calculation of the standard deviation of the observed deflections about their average values.

7.3 *Temperature Equalization During Calibration:*

7.3.1 Allow the force-measuring instrument sufficient time to adjust to the ambient temperature in the calibration machine prior to calibration in order to assure stable instrument response.

7.3.2 The recommended value for room temperature calibrations is 23°C (73.4°F) but other temperatures may be used.

7.3.3 During calibration, monitor and record the temperature as close to the elastic device as possible. It is recommended that the test temperature not change more than ±0.5°C (1°F) during calibration. In no case shall the ambient temperature change by more than ± 1.0°C during calibration.

7.3.4 Deflections of non-temperature compensated devices may be normalized in accordance with Section 9 to a temperature other than that existing during calibration.

7.3.5 Deflections of non-temperature compensated devices must be corrected in accordance with Section 9 to a nominal calibration temperature if the temperature changes more than ±0.2°C during calibration.

7.4 *Procedural Order in Calibration*— Immediately before starting the calibration, preload the force-measuring instrument to the maximum force to be applied at least two times. Preloading is necessary to reestablish the hysteresis pattern that tends to disappear during periods of disuse, and is particularly necessary following a change in the mode of loading, as from compression to tension. Some instruments may require more than two preloads to achieve stability in zero-force indication.

NOTE 5—Overload or ~~proofload~~ proof load tests are not required by this practice. It must be emphasized that an essential part of the manufacturing process for a force-measuring instrument is the application of a series of overloads to at least 10 % in excess of rated capacity. This must be done by the manufacturer before the instrument is released for calibration or service.

7.4.1 After preloading, apply the calibration forces, approaching each force from a lesser force. Forces shall be applied and removed slowly and smoothly, without inducing shock or vibration to the force-measuring instrument. The time interval between successive applications or removals of forces, and in obtaining readings from the force-measuring instrument, shall be as uniform as possible. If a calibration force is to be followed by another calibration force of lesser magnitude, reduce the applied force on the instrument to zero before applying the second calibration force. Whenever possible, plan the loading schedule so that repetitions of the same calibration force do not follow in immediate succession.

NOTE 6—For any force-measuring instrument, 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. Force-measuring instruments are usually used under increasing forces, but if a force-measuring instrument is to be used under decreasing force, it should be calibrated under decreasing forces as well as under increasing force. Use the procedures for calibration and analysis of data given in Sections 7 and 8 except where otherwise noted. When a force measuring device is calibrated with both increasing and decreasing forces, it is recommended that the same force increments be applied, but that separate calibration equations be developed.

7.4.2 The calibration laboratory shall decide whether or not a zero-force reading is to be taken after each calibration force. Factors such as the stability of the zero-force reading and the presence of noticeable creep under applied force are to be considered in making this decision. It is pointed out, however, that a lengthy series of incremental forces applied without return to zero reduces the amount of sampling of instrument performance. The operation of removing all force from the instrument permits small readjustments at the load contacting surfaces, increasing the amount of random sampling and thus producing a better appraisal of the performance of the instrument. It is recommended that not more than five incremental forces be applied without return to zero. This is not necessary when the instrument is calibrated with decreasing forces; however, any return to zero prior to application of all the individual force increments must be followed by application of the maximum force before continuing the sequence.

7.5 *Randomization of Loading Conditions*—Shift the position of the instrument in the calibration machine before repeating any series of forces. In a compression calibration, rotate the instrument by an amount such as one-third, one-quarter, or one-half turn, keeping its ~~load~~force axis on the center ~~load~~force axis of the machine. In a tension calibration, rotate coupling rods by amounts such as one-third, one quarter, or one-half turn, and shift and realign any flexible connectors. In a calibration in both tension and compression, perform a part of the compression calibration, do the tension calibration, then finish the compression calibration afterward. Introduce variations in any other factors that normally are encountered in service, as for example, disconnecting and reconnecting electrical cables. Allow sufficient warmup time if electrical disconnections are made.

NOTE 7—A situation to be avoided is rotating the force-measuring instrument from 0° to 180° to 0° during calibration, since the final position duplicates the first, and reduces the randomization of loading conditions.

NOTE 8—Force measuring devices have sensitivity in varying degrees depending on design to mounting conditions and parasitic forces and moments due to misalignment. A measure of this sensitivity may be made by imposing conditions to simulate these factors such as using fixtures with contact surfaces that are slightly convex or concave, or of varying stiffness or hardness, or with angular or eccentric misalignment, and so forth. Such factors can sometimes be significant contributors to measurement uncertainty and should be reflected in comprehensive measurment uncertainty analyses.

8. Calculation and Analysis of Data

8.1 *Deflection*—Calculate the deflection values for the force-measuring instrument as the differences between the readings of an instrument under applied force and the reading with no applied force. The method selected for treatment of zero should reflect anticipated usage of the force measurement system. The deflection calculation shall *(a)* utilize the initial zero value only or *(b)* a value derived from readings taken before and after the application of a force or series of forces. For method *(a)*, the deflection is calculated as the difference between the deflection at the applied force and the initial deflection at zero force. For method *(b)*, when it is elected to return to zero after each applied force, the average of the two zero values shall be used to determine the deflection. For method *(b)* when a series of applied forces are applied before return to zero force, a series of interpolated zero-force readings may be used for the calculations. In calculating the average zero-force readings and deflections, express the values to the nearest unit in the same number of places as estimated in reading the instrument scale. Follow the instructions for the rounding method given in Practice E29. If method *(a)* is elected, a creep recovery test is required per the criteria of 8.2 to insure that the zero return characteristic of the load cell does not result in excessive error.

8.2 *Determination of Creep Recovery*—Creep affects the deflection calculation. Excessive creep is indicated if large non-return to zero is observed following ~~load~~force application during calibration. A creep recovery test is required to insure that the creep characteristic of the device does not have a significant effect on calculated deflections when method *(a)* is used to determine deflections. The creep test is to be performed for new devices, and for devices that have had major repairs, devices suspected of having been overloaded, or devices that show excessive non-return to zero following calibration. Creep and creep recovery are generally stable properties of a load cell unless the load cell is overloaded, has experienced moisture or other contaminant incursion, or is experiencing fatigue failure. If method *(b)* is used to determine deflections on a device both during calibration and subsequent use, the creep recovery test is not required. The creep recovery test is performed as follows:

8.2.1 Exercise the device to the maximum applied force in calibration at least two times. Allow the zero reading to stabilize and record the value. Apply the maximum applied force used in calibration of the device and hold as constant as possible for 5 minutes. Remove the applied force as quickly as possible and record device output at 30 seconds and 5 minutes. Creep recovery error is calculated as follows:

8.2.1.1 Creep Recovery Error, % of Output at Maximum Applied Force = 100 × (Output 30 seconds after zero ~~load~~force is achieved – Initial zero reading) /Output at Maximum Applied Force

8.2.2 A zero return error shall be calculated as follows:

8.2.2.1 Zero Return Error, % of output at applied force = 100 x (Initial zero reading – final zero reading 5 minutes after the applied force is removed) /Output at Applied force. The creep test shall be repeated if the zero return error exceeds 50% of the creep recovery error limits.

8.2.3 *Creep Recovery Error Limits:—*
Class AA Devices ± 0.02%
Class A Devices ± 0.05%.

8.3 *Calibration Equation*—Fit a polynomial equation of the following form to the force and deflection values obtained in the calibration using the method of least squares:

$$\text{Deflection} = A_0 + A_1 F + A_2 F^2 + \ldots A_5 F^5 \tag{5}$$

where:

F = force, and
A_0 through A_5 = coefficients.

A 2nd degree equation is recommended with coefficients A_3, A_4, and A_5 equal to zero. Other degree equations may be used. For example the coefficients A_2 through A_5 would be set equal to zero for a linearized load cell.

8.3.1 For high resolution devices (see 7.1.3), the procedure of Annex A1 may be used to obtain the best fit calibration curve. After determination of the best fit polynomial equation, fit the pooled calibration data to a polynomial equation of that degree per 8.3, and proceed to analyze the data per 8.4-8.6.2.2.

8.4 *Standard Deviation*—Calculate a standard deviation from the differences between the individual values observed in the calibration and the corresponding values taken from the calibration equation. Calculate a standard deviation as follows:

$$s_m = \sqrt{\frac{d_1^{\,2} + d_2^{\,2} + \ldots + d_n^{\,2}}{n - m - 1}} \tag{6}$$

where:

d_1, d_2, etc. = differences between the fitted curve and the n observed values from the calibration data,
n = number of deflection values, and
m = the degree of polynomial fit.

NOTE 9—It is recognized that the departures of the observed deflections from the calibration equation values are not purely random, as they arise partly from the localized variation in instrument readings discussed in 7.1.1. As a consequence, the distributions of the residuals from the least squares fit may not follow the normal curve of error and the customary estimates based on the statistics of random variables may not be strictly applicable.

8.5 *Determination of Lower Limit Factor, LLF*—LLF is calculated as 2.4 times the standard deviation. If the calculated LLF is less than the instrument resolution, the LLF is then defined as that value equal to the resolution. Express the LLF in force units, using the average ratio of force to deflection from the calibration data.

NOTE 10—Of historical interest, the limit of 2.4 standard deviations was originally determined empirically from an analysis of a large number of force-measuring instrument calibrations and contains approximately 99 % of the residuals from least-squares fits of that sample of data.

8.6 *Loading Range*—This is the range of forces within which the LLF of a force-measuring instrument does not exceed the maximum permissible limits of error specified as a fraction or percentage of force. Since the LLF for the instrument is of constant force value throughout the entire range of the instrument, it will characteristically be less than the specified percentage of force at instrument capacity but will begin to exceed the specified percentage at some point in the lower range of the instrument, as illustrated in Fig. 1. The loading range shown in the figure thus extends from the point, *A*, where the LLF and error limit lines intersect, up to the instrument capacity. The loading range shall not include forces outside the range of forces applied during the calibration.

8.6.1 *Lower Limit of Loading Range*—Calculate the lower end of the loading range for a specified percentage limit of error, *P*, as follows:

$$\text{Lower limit} = \frac{100 \times LLF}{P} \tag{7}$$

8.6.2 *Standard Loading Ranges*—Two standard loading ranges are listed as follows, but others may be used where special needs exist:

8.6.2.1 *Class AA*—For instruments used as secondary ~~reference~~force standards, the LLF of the instrument ~~must~~shall not exceed 0.05 % of force. The lower force limit of the instrument is 2000 times the LLF, in force units, obtained from the calibration data.

NOTE 11—For example, an instrument calibrated using primary force standards had a calculated LLF of 16 N (3.7 lbf). The lower force limit for use as a Class AA device is therefore 16 × 2000 = 32 000 N (3.7 × 2000 = 7400 lbf). The LLF will be less than 0.05 % of force for forces greater than this lower force limit to the capacity of the instrument. It is recommended that the lower force limit be not less than 2 % (1⁄50) of the capacity of the instrument.

8.6.2.2 *Class A*—For instruments used to verify testing machines in accordance with Practices E4, the LLF of the instrument ~~must~~shall not exceed 0.25 % of force. The lower force limit of the instrument is 400 times the LLF, in force units, obtained from the calibration data.

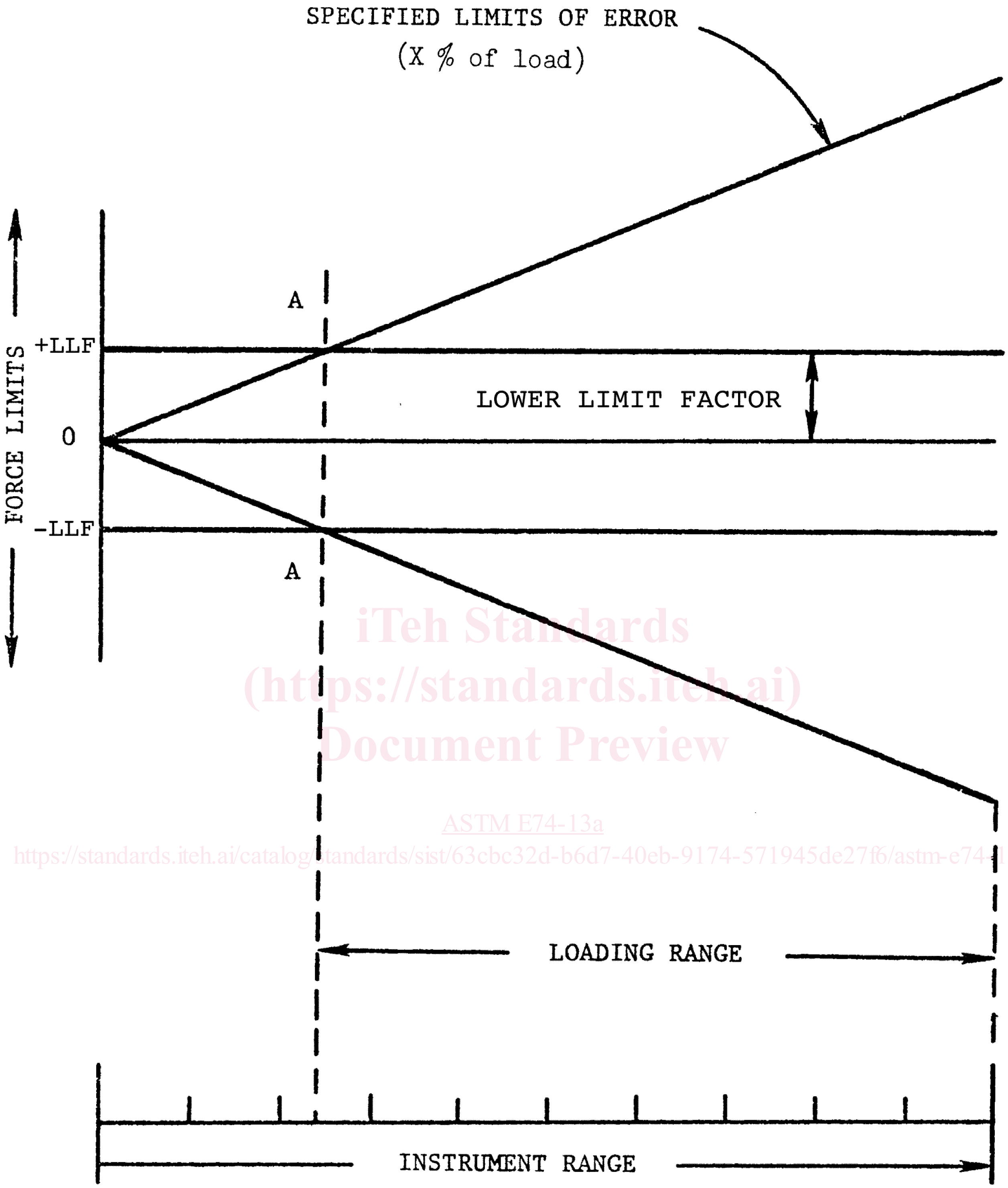

FIG. 1 Relationship of Loading Range to Instrument Lower ~~Load~~Force Limit and Specified Limits of Error

NOTE 12—In the example of Note 11 the lower force limit for use as a Class A device is 16 × 400 = 6400 N (3.7 × 400 = 1480 lbf). The LLF will be less than 0.25 % of force for forces greater than this lower force limit up the capacity of the instrument.

NOTE 13—The term "loading range" used in this practice is parallel in meaning to the same term in Practice E4. It is the range of forces over which it is permissible to use the instrument in verifying a testing machine or other similar device. When a loading range other than the two standard ranges given in 8.6.2 is desirable, the appropriate limit of error should be specified in the applicable method of test.

8.7 *Specific Force Devices*—Any force-measuring device may be calibrated as a specific force device. Elastic rings, loops, and columns with dial indicators as a means of sensing deformation are generally classed as specific force devices because the relatively large localized nonlinearities introduced by indicator gearing produce an LLF too great for an adequate loading range. These instruments are, therefore, used only at the calibrated forces and the curve-fitting and analytical procedures of 8.3-8.5 are replaced by the following procedures:

8.7.1 *Calculation of Nominal Force Deflection*—From the calibration data, calculate the average value of the deflections corresponding to the nominal force. If the calibration forces applied differ from the nominal value of the force, as may occur in the case of a calibration by secondary force standards, adjust the observed deflections to values corresponding to the nominal force by linear interpolation provided that the ~~load~~force differences do not exceed ±1 % of capacity force. The average value of the nominal ~~load~~force deflection is the calibrated value for that force.

8.7.2 *Standard Deviation for a Specific Force Device*—Calculate the range of the nominal force deflections for each calibration force as the difference between the largest and smallest deflections for the force. Multiply the average value of the ranges for all the calibration forces by the appropriate factor from Table 1 to obtain the estimated standard deviation of an individual deflection about the mean value.

8.7.3 *Lower Limit Factor for Specific Force Devices*—The LLF for a specific force device is defined as 2.0 times the standard deviation, plus the resolution. Convert the LLF into force units by means of a suitable factor and round to the number of significant figures appropriate to the resolution. The LLF is expressed as follows:

$$LLF = (2s + r)f \tag{8}$$

where:

s = standard deviation,
r = resolution
f = average ratio of force to deflection from the calibration data.

8.7.4 *Precision Force*—A specific force device does not have a loading range as specified in 8.6, since it can be used only at the forces for which it was calibrated. The use is restricted, however, to those calibrated forces that would be included in a loading range calculated in 8.6-8.6.2.2.

9. Temperature Corrections for Force-Measuring Instruments During Use

9.1 *Referenced Temperature of Calibration*—It is recommended that the temperature to which the calibration is referenced be 23°C (73°F), although other temperatures may be referenced (see 7.3.2).

9.2 *Temperature Corrections*—Nearly all mechanical elastic force-measuring instruments require correction when used at a temperature other than the temperature to which the calibration is referenced. This category includes proving rings, Amsler boxes, and rings, loops, and columns equipped with dial indicators. Uncompensated instruments in which the elastic element is made of steel with not more than 5 % of alloying elements may be corrected on the basis that the deflection increases by 0.027 % for each 1°C increase in temperature.

9.3 *Method of Applying Corrections:*

9.3.1 In using an uncompensated force-measuring instrument at a temperature other than the temperature of calibration, the correction may be made in the following manner:

9.3.1.1 Calculate a force value from the uncorrected observed deflection of the instrument using the working table or other media derived from the calibration equation.

9.3.1.2 Correct this force value for temperature by reducing it by 0.027 % for every 1°C by which the ambient temperature exceeds the temperature of calibration. If the ambient temperature is less than the temperature of calibration, the force value would be increased by the appropriate amount.

9.4 *Temperature Effect on the Sensitivity of Temperature-Compensated Devices*—Force measuring devices such as load cells may have temperature compensation built in by the manufacturer. For devices with such compensation, the effect of temperature on the sensitivity of the device shall not exceed the following values:

9.4.1 *Class AA*—For devices used as Class AA standards, the error due to temperature on the sensitivity of the device shall not exceed 0.01%. (See Note 14).

9.4.2 *Class A*—For devices used as Class A standards, the error due to temperature on the sensitivity of the device shall not exceed 0.05%. (See Note 14).

TABLE 1 Estimates of Standard Deviation from the Range of Small Samples

Number of Observations at Each Force	Multiplying Factor for Range
3	0.591
4	0.486
5	0.430
6	0.395

9.4.3 If a force measurement device is used at temperatures other than the temperature at which it was calibrated, it is the ~~users~~user's responsibility to insure that the performance of the device does not exceed the limits of paragraphs 9.4.1 or 9.4.2, or if such limits would be exceeded, that the device is calibrated at the expected temperature of use, or over a range of the expected temperatures of use and corrected accordingly.

NOTE 14—There is a negligible effect on the maximum values for Class AA, LLF (0.05% of applied force) and Class A, LLF (0.25% of applied force) when these values are added as root-sum-squares with the values for temperature error given in 9.4.1 and 9.4.2. Such a combination of error sources is valid in the case of independent error sources. It should be noted the temperature differences between conditions of calibration and use may result in significant errors. This error source should be evaluated by users to assure compliance with these requirements, when such usage occurs. Adequate stabilization times are required to insure that thermal gradients or transients in the force measurement device have equilibrated with the environment in which testing is to be performed. Otherwise, thermal gradients may cause significant errors in both temperature compensated devices and uncompensated devices.

It is recommended that the effect of temperature on the sensitivity of Class AA devices not exceed 0.0030% /C° (0.0017% /°F) and for Class A devices, that the effect of temperature on the sensitivity not exceed 0.010% /°C (0.0056% /°F).

As an example, for the case of force transducers that have temperature coefficients equal to the maximum recommended values, the error due to the temperature is negligible within ± 3°C for class AA devices and ± 5°C for class A devices referenced to the temperature at which those devices were calibrated.

FORCE-MULTIPLYING SYSTEMS

10. Balances and Small Platform Scales

10.1 *General Principles*—Balances and small bench-type platform scales are sometimes useful for the verification at low forces of testing machines that respond to forces acting vertically upwards. The calibration of a balance or platform scale consists of a verification of the multiplying ratio of its lever system, using laboratory mass standards of National Institute of Standards and Technology (NIST) Class F (Note 15) or better. Since the multiplying ratio is a constant factor, it should be determined with an accuracy of 0.1 %.

NOTE 15—Class F weights of 0.91 kg (2 lb) or greater have a tolerance of 0.01 %.

10.2 *Equal-Arm Balances*—With both pans empty, adjust the balance to bring the rest point to approximately the center of the scale and note the value of the rest point. Place equal masses in each pan to an amount between three-quarters and full balance capacity, then add to the appropriate pan to restore the rest point to the original value. Divide the mass in the pan that will eventually bear against the testing machine by the mass in the other pan and round the resulting quotient to the nearest 0.1 %. This value is the multiplying ratio and will generally be nearly 1.000 for a well constructed balance. The test method with necessary modifications, may be employed for single-lever systems in general.

10.3 *Verification of a Platform Scale*—The counterpoise weights of a platform scale are usually marked with mass values that include the nominal multiplication ratio of the scale. The following procedure is a verification for the purpose of calibrating a testing machine, and does not replace or supplement established procedures, such as those set forth in NIST Handbook 44, Specifications, Tolerances and Other Technical Requirements for Commercial Weighing and Measuring Devices,2 for the testing of commercial weighing equipment:

10.3.1 Set the weigh beam poise to zero and carefully balance the scale to bring the beam pointer to the center of the trig loop.

10.3.2 Place standard weights (NIST Class F or the equivalent) on the center of the scale platform and balance the scale using the counterpoise weights and weighbeam poise.

10.3.3 Divide the total mass on the platform by the sum of the counterpoise weight values and the weighbeam poise reading, rounding the quotient to the nearest 0.1 %. This value is the multiplication ratio correction factor and will be nearly 1.000 for a scale in good condition.

10.4 *Calculation of Forces*—The verification of a testing machine force by means of balances, levers, or platform scales is similar to verification by deadweight loading in that gravity and air buoyancy corrections must be applied to the values indicated by these devices. For the verification of a testing machine, the multiplying factors given in Table 2 are sufficiently accurate. Always make corrections to primary force standards in accordance with the formula given in 6.1.1.

TABLE 2 Unit Force Exerted by a Unit Mass in Air at Various Latitudes

Latitude, deg	Elevation Above Sea Level, m (ft)					
	−30.5 to 152 (-100 to 500)	152 to 457 (500 to 1500)	457 to 762 (1500 to 2500)	762 to 1067 (2500 to 3500)	1067 to 1372 (3500 to 4500)	1372 to 1676 (4500 to 5500)
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