Designation: E74 – 18$^{\epsilon 1}$

Standard Practices for Calibration and Verification for Force-Measuring Instruments[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 U.S. Department of Defense.

ϵ^1 NOTE—Editorial corrections were made to 3.2.4.1 and 3.2.9.1 in April 2019.

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1. Scope

1.1 The purpose of these practices 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(**1**)[2], Methods of Calibrating Weights for Piston Gages.

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

1.5 *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:*[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 *ASME Standard:*

B46.1 Surface Texture, Surface Roughness, Waviness and Lay[4]

FORCE-MEASURING INSTRUMENTS

3. Terminology

3.1 *Definitions:*

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

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 the International System of Units (SI) (**2**) 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:*

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[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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[2] The boldface numbers in parentheses refer to a list of references at the end of this standard.

[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 Society of Mechanical Engineers (ASME), ASME International Headquarters, Two Park Ave., New York, NY 10016-5990, http://www.asme.org.

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 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 force-measuring instruments, 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 force-measuring instruments, 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 *verified range of forces*—in the case of force-measuring instruments, the range of indicated forces for which the force-measuring instrument gives results within the permissible variations specified.

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-measuring instrument*—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 force-measuring instruments.

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 these practices.

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 verified range of forces, see 8.5. Other factors evaluated in establishing the lower limit of the verified range of forces are the resolution of the instrument and the lowest non-zero force applied in the calibration 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 force-measuring instruments whose force characteristics are known to be traceable to the SI. Practices E74 describes how these force-measuring instruments 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, service organizations that use the force-measuring instruments to verify testing machines, and testing laboratories performing general structural test measurements.

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 (Roughness Average or R_a) of 3.2 µm (125 µin.) or less as specified in ASME B46.1.

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

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

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 International System of Units (SI) (**2**) for 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 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:

$$1\ \text{kgf} = 9.806\,65\ \text{N}\ (\text{exact}) \qquad (2)$$

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

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 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 Force-measuring instruments used as secondary force standards shall be calibrated by primary force standards and used only over the Class AA verified range of forces (see 8.6.3.1). 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 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:

$$LLF_c = \sqrt{LLF_0{}^2 + LLF_1{}^2 + LLF_2{}^2 + \ldots LLF_n{}^2} \qquad (3)$$

where:

LLF_c = lower limit factor of the combination, and
$LLF_{0,\,1,\,2\,...\,n}$ = lower limit factor of the individual instruments.

6.2.2 The multiplying ratio of a 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 system shall be checked annually by elastic force-measuring instruments used within their class AA verified range of forces 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 force-measuring instrument. A polynomial equation is fitted to the calibration data by the least squares method to predict deflection values throughout the verified range of force. 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 approximately 99 %. The LLF is, therefore, an estimate of one source of measurement uncertainty contributed by the force-measuring instrument when forces measured in service are calculated by means of the calibration equation. Actual measurement uncertainty in service is likely to be different if forces are applied under mechanical and environmental conditions differing from those

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

of calibration. Other sources of measurement uncertainty such as those listed in Appendix X1 could increase the measurement uncertainty of measurement of the force-measuring instrument in service. While it is the responsibility of the calibration laboratory to calibrate the force-measuring instrument in accordance with the requirements of these practices, it is the responsibility of the user to determine the measurement 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 force-measuring instruments 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 force-measuring instruments. Equations of greater than 5th degree shall not be used.

NOTE 3—Experimental work by several force calibration laboratories in fitting higher than second degree polynomials to the observed data indicates that, for some force-measuring instruments, use of a higher degree equation can result in a lower 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 can occur if calculations are performed with insufficient precision.

A force-measuring instrument 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 force-measuring instrument 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.

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 shall be made by the calibration laboratory. An exception to this, and to the recommendations of 7.2.1 and 7.2.4, is made for specific force-measuring instruments, 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 force-measuring 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 force limit of the verified range of forces of the force-measuring instrument (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 force limit. In no case should the smallest force applied be below the lower force limit of the force-measuring instrument as defined by the values:

$$400 \times \text{resolution for Class A verified range of forces} \tag{4}$$

$$2000 \times \text{resolution for Class AA verified range of forces}$$

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 force-measuring instruments 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 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-Measuring Instruments (Limited Force-Measuring Instruments)*—Because these force-measuring instruments 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 ensure 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 force-measuring instrument as possible. It is recommended that the test temperature not change more than

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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.

±0.5 °C (1 °F) during calibration. In no case shall the ambient temperature change by more than ±1.0 °C (2 °F) during calibration.

7.3.4 Deflections of non-temperature compensated force-measuring instruments 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 force-measuring instruments shall 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, slowly and smoothly apply the maximum force in the calibration sequence to the force-measuring instrument at least two times. This procedure is referred to as exercising the force-measuring instrument. Exercising 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 force application, as from compression to tension. Some force-measuring instruments may require more than two exercise cycles to achieve stability in zero-force indication.

NOTE 4—Overload or proof load tests are not required by these practices. 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 exercising, 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 force-measuring instrument to zero before applying the second calibration force. Whenever possible, plan the force application schedule so that repetitions of the same calibration force do not follow in immediate succession. 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 shall 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 instrument is calibrated with both increasing and decreasing forces, the same force values should be applied for the increasing and decreasing directions of force application, but separate calibration equations should 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 Force Application Conditions*—During the calibration sequence, maintain the force measurement axis of the force-measuring instrument coincident with the force axis of the machine. Shift the position of the force-measuring instrument in the calibration machine before repeating any series of forces. Introduce variations in any other factors that normally are encountered in service, as for example, disconnecting and reconnecting electrical cables. Allow sufficient warm up time if electrical disconnections are made.

7.5.1 In a compression calibration, position the force-measuring instrument to a 0 degree reference position, and then rotate to positions of approximately 120 degrees and 240 degrees. An exception is made for force-measuring instruments that cannot be rotated by 120 degrees such as some proving rings, force dynamometers, and Brinell Hardness Test Calibrators. For these types of force-measuring instruments, position the force-measuring instrument at 0 degrees, and then rotate to positions of approximately 60 degrees and 300 degrees, keeping its force axis on the center force axis of the machine. This exception is made to minimize parallax error.

7.5.2 In a tension calibration, position the force-measuring instrument to a 0 degree reference position, and then rotate to positions of approximately 120 degrees and 240 degrees. An exception is made for force-measuring instruments that cannot be rotated by 120 degrees such as some proving rings and force dynamometers. For these types of force-measuring instruments, position the force-measuring instrument at 0 degrees, and then rotate to positions of approximately 60 degrees and 300 degrees, keeping its force axis on the center force axis of the machine. Shift and realign any flexible connectors between positions. This exception is made to minimize parallax error.

7.5.3 In a two-mode calibration (compression and tension), perform a part of the calibration in one mode, switch modes and continue the calibration, then finish the calibration in the initial calibration mode. It is acceptable practice to change modes at each rotational position

NOTE 5—Force-measuring instruments 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-measuring instrument. 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 ensure that the zero return characteristic of the force-measuring instrument 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 force application during calibration. A creep recovery test is required to ensure 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 force-measuring instruments, and for force-measuring instruments that have had major repairs, force-measuring instruments suspected of having been overloaded, or force-measuring instruments that show excessive non-return to zero following calibration. Creep and creep recovery are generally stable properties of a force-measuring instrument unless the force-measuring instrument is overloaded, has experienced moisture or other contaminant incursion, or is experiencing fatigue failure. If method *(b)* is used to determine deflections on a force-measuring instrument 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 force-measuring instrument 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 force-measuring instrument and hold as constant as possible for 5 minutes. Remove the applied force smoothly, but as quickly as possible and record 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 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 × (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 For force-measuring instruments calibrated for use over the following verified ranges of forces, the creep recovery error limits of the output at the applied force are:

Class AA: ± 0.020 %
Class A: ± 0.050 %.

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 force-measuring instrument.

8.3.1 For high resolution force-measuring instruments (see 7.1.3), the procedure of Annex A1 shall be used to obtain the maximum degree of the best fit polynomial equation statistically supported by the calibration data set. This calculation is performed with a polynomial equation fitted to the average data at each applied force following the method of Annex A1. After determination of the degree of the best fit polynomial equation, fit a polynomial equation of that degree, or a lower degree, to the entire data set (not the averaged data set) in accordance with 8.3, and proceed to analyze the data in accordance with 8.4 – 8.6.3.2.