Designation: E 74 – 02

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 E 74; 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.

.

Note-Section 8.3 and Equation 6 were editorially corrected on April 5, 2002

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 E 4; 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:*

E 4 Practices for Force Verification of Testing Machines[3]

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications[4]

2.2 *American National Standard:*

B46.1 Surface Texture[5]

ELASTIC FORCE-MEASURING INSTRUMENTS

3. Terminology

3.1 *Definitions:*

3.1.1 *elastic force-measuring device*—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.

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*—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. Departures from the fitted curve are reflected in the uncertainty (8.4).

---

[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.

Current edition approved April 5, 2002. Published April 2002. Originally published as E 74 – 47 T. Last previous edition E 74 – 01.

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

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

[4] *Annual Book of ASTM Standards*, Vol 14.02.

[5] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

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

3.2.4 *loading range*—a range of forces within which the uncertainty is less than the limits of error specified for the instrument application.

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

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

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

3.2.7.1 *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 devices.

3.2.8 *uncertainty*—a statistical estimate of the limits of error in forces computed from the calibration equation of a force–measuring instrument when the instrument is calibrated in accordance with this practice.

4. Significance and Use

4.1 Testing machines that apply and indicate force are in general use in many industries. Practices E 4 has been written to provide a practice for the force verification of these machines. A necessary element in Practices E 4 is the use of devices whose force characteristics are known to be traceable to national standards. Practice E 74 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 standards.

5.2 Force-measuring instruments used as secondary standards for the calibration of other force-measuring instruments shall be calibrated by primary standards. An exception to this rule is made for instruments having capacities exceeding the range of available primary 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 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 (Note 4), 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 Geodotic Information Center, National Oceanic and Atmospheric Administration.[6]

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 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 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 standards shall be calibrated by primary standards and used only over the Class AA loading range (see 8.5.2.1). Secondary standards having capacities exceeding 1 000 000 lbf (4.4 MN) are not required to be calibrated by primary standards. Several secondary standards of equal compliance may be combined and loaded in parallel to meet special needs for higher capacities. The uncertainty (see 8.4) of such a combination shall be calculated by adding in quadrature using the following equation:

$$U_c = \sqrt{U_o{}^2 + U_1{}^2 + U_2{}^2 + \ldots U_n{}^2} \tag{3}$$

where:

U_c = uncertainty of the combination, and

$U_{o,\,1,\,2\,\ldots\,n}$ = uncertainty of the individual instruments.

6.2.2 The multiplying ratio of a force multiplying system used as a secondary standard shall be measured at not less than

---

[6] Available from the National Oceanic and Atmospheric Administration, Rockville, MD.

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 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 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 uniformly over the entire range of the instrument. This characteristic full-scale nonlinearity is a stable property of the instrument that is changed only by a severe overload or other similar cause.

7.1.1 *Localized Nonlinearities*—Superposed on this curve are localized nonlinearities introduced by the 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 voltage and sensing instabilities in a load cell system. Some of these imperfections are less stable than the full-scale nonlinearity and may change significantly from one calibration to another.

7.1.2 *Curve Fitting*—In the treatment of the calibration data, a second degree polynomial fitted to the observed data using the method of least squares has been found to predict within the limit of the uncertainty (8.4) deflection values for applied force throughout the loading range of the elastic force measuring instrument. Such an equation compensates effectively for the full-scale nonlinearity, allowing the localized nonlinearities to appear as deviations. A statistical estimate, called the uncertainty, is made of the width of the band of these deviations about the basic curve. The uncertainty is, therefore, an estimate of the limits of error 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 greater if forces are applied under loading and environmental conditions differing from those of the calibration.

7.1.3 *Curve Fitting for High Resolution Devices*—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 load. Annex A1 recommends a procedure for obtaining the degree of the best fit calibration curve for these devices.

NOTE 3—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 than that derived from the second degree fit. (ASTM RR: E28-1009) 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.

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 8.5.1) 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 theoretical lower limit of the instrument as defined by the values:

$$\begin{aligned} &400 \times \text{resolution for Class A loading range} \\ &2000 \times \text{resolution for Class AA loading range} \end{aligned} \tag{4}$$

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. Likewise, in a load cell calibration, forces selected to give readings near the step-switch points will fail to sample the slidewire irregularities or mismatching of the slidewire span to the step-switch increments.

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 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 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 4—Overload or proofload 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 5—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 standardizing 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 axis on the center load axis of the machine, or replace the bearing block under the instrument by a block having different deflection characteristics. 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 6—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.

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 the instrument under applied force and the averages of the zero-force readings taken before and after each application of force. If a series of incremental force readings has been taken without return to zero, 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 E 29.

8.2 *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.

8.2.1 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 8.2, and proceed to analyze the data per 8.3-8.5.2.2.

8.3 *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 7—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 nonlinearities 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.

8.4 *Uncertainty*—For the purposes of this practice, uncertainty is defined as 2.4 times the standard deviation. If the calculated uncertainty is less than the instrument resolution, the uncertainty is then defined as that value equal to the resolution. Express the uncertainty in force units, using the average ratio of force to deflection from the calibration data.

NOTE 8—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.

8.5 *Loading Range*—This is the range of forces within which the uncertainty of a force-measuring instrument does not exceed the maximum permissible limits of error specified as a fraction or percentage of force. Since the uncertainty for the instrument is of constant force amplitude 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 uncertainty 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.

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

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

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

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

NOTE 9—For example, an instrument calibrated using primary force standards had a calculated uncertainty 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 uncertainty will be less than 0.05 % of force for forces greater than this lower force limit to the capacity of the instrument. In no case shall the lower limit be less than 2 % (1⁄50) of the capacity of the instrument.

8.5.2.2 *Class A*—For instruments used to verify testing machines in accordance with Practices E 4, the uncertainty of the instrument must not exceed 0.25 % of force. The lower force limit of the instrument is 400 times the uncertainty, in force units, obtained from the calibration data.

NOTE 10—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 uncertainty will be less than 0.25 % of force for forces greater than this lower force limit up the capacity of the instrument.

NOTE 11—The term "loading range" used in this practice is parallel in meaning to the same term in Practices E 4. 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 8.5.2 is desirable, the appropriate limit of error should be specified in the applicable method of test.

8.5.3 *Precision and Bias*—The magnitudes of uncertainty (see 8.4) and lower limit of loading ranges (see 8.5.2) which determine compliance to this standard are derived quantities based on statistical analysis of the calibration data. The calculated uncertainty is 2.4 times the standard deviation. As a function of probability, this limit of uncertainty means that, with 99 % probability, the error will not exceed the value of uncertainty.

8.6 *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

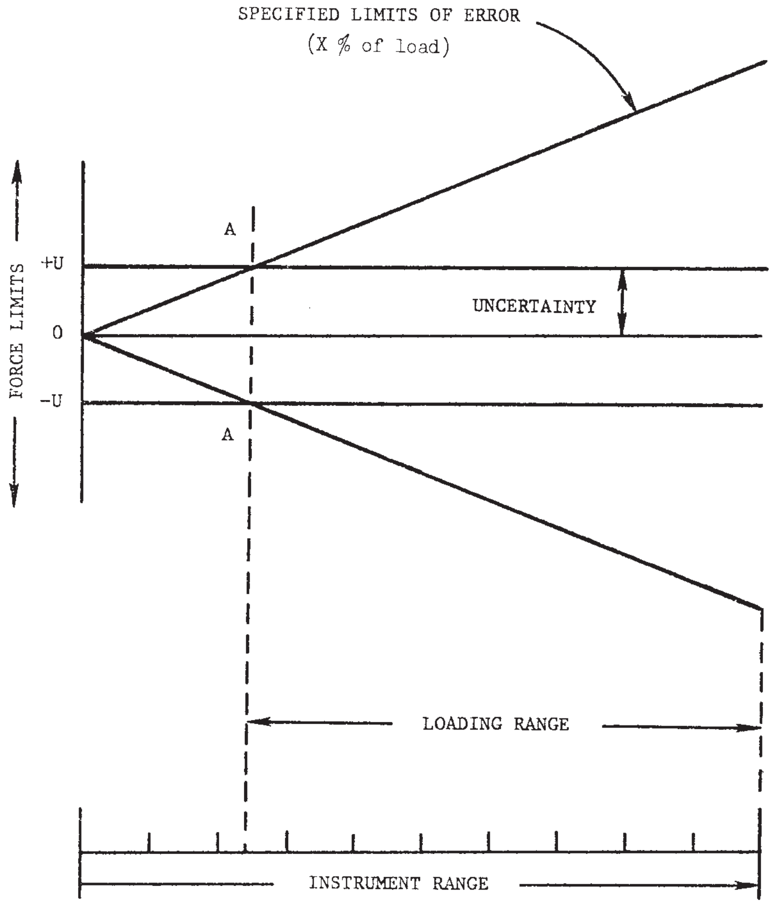

FIG. 1 Relationship of Loading Range to Instrument Uncertainty and Specified Limits of Error

by indicator gearing produce an uncertainty 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 8.2-8.4 are replaced by the following procedures:

8.6.1 *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 standards, adjust the observed deflections to values corresponding to the nominal force by linear interpolation provided that the load differences do not exceed ±1 % of capacity force. The average value of the nominal load deflection is the calibrated value for that force.

8.6.2 *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.

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

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

$$\text{Uncertainty} = (2s + r)f \quad (8)$$

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

8.6.4 *Precision Force*—A specific force device does not have a loading range as specified in 8.5, 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 8.5-8.5.2.2.

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 12).

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 12).

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 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 12—There is a negligible effect on the maximum values for Class AA uncertainty (0.05% of applied force) and Class A uncertainty (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 0.0100% /°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 17) or better. Since the multiplying ratio is a constant factor, it should be determined with an accuracy of 0.1 %.

NOTE 13—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 weighbeam 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 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

11. Time Interval Between Calibration

11.1 All force-measuring instruments and systems used as secondary standards (see 6.2-6.2.2) shall be calibrated or verified annually.

11.2 The calibration intervals for force-measuring instruments and systems used for verification of the force indication of testing machines are:

11.2.1 *Mechanical Force-Measuring Instruments*—Instruments such as proving rings, Amsler boxes, rings or loops with dial indicators, and rings or loops with optical scales and microscopes in which the transfer of the deformation of the elastic element to the scale reading is by purely mechanical or optical means shall be calibrated at intervals not exceeding 2 years.

11.2.2 *Electrical Force-Measuring Instruments*—Instruments such as strain-gaged load cells, rings or loops with differential transformers or variable reluctance sensors, and piezo-electric load cells in which the transfer of the deformation of the elastic element to the scale reading is by electrical means, shall be recalibrated 1 year after the first calibration and thereafter at intervals not exceeding 2 years, provided that the changes between the most recent calibration equation values (average deflections for specific force devices) and those from the previous calibration do not exceed 0.1 % of the capacity-force deflection. If the changes should exceed this tolerance, recalibration shall be on an annual basis until a history of stability is established.

11.2.3 *Balances, Scales, and Other Lever Systems*—Mechanical force-multiplying systems used for the verification of test machines shall be verified at intervals not exceeding 5 years. If a balance or platform scale shows evidence of binding or excessive friction in the lever pivots as demonstrated by a lack of free action in the balance beam before the unit is coupled to the testing machine, the system shall be examined to locate the source of friction and the condition corrected. However, once the system is coupled to the testing machine and force is applied, it is an acceptable condition that the balance beam is no longer free to swing in the normal manner characteristic of deadweight loading.

11.3 *Calibration Following Repairs or Overloads*—A force-measuring instrument or multiplying system shall be recalibrated following any repairs or modifications that might affect its response, or whenever the calibration of the device might be suspect. Any instrument sustaining an overload that produces a permanent shift in the zero-force reading amounting to 1 % or more of the capacity deflection shall be recalibrated before further use.

12. Substitution of Electronic Force Indicating Devices Used with Elastic Members

12.1 It may be desirable to treat the calibration of the elastic member and the force indicating device separately, thus allowing for the substitution or repair of the force indicating device without the necessity for repeating an end-to-end system calibration. When such substitution or repair is made, the user assumes the responsibility to assure that the accuracy of the force measurement system is maintained. Substitution of the force indication device shall not extend the system calibration/verification date. The following conditions shall be satisfied when substituting a metrologically significant element of the force indicating measurement system.

12.2 The indicating device used in the initial calibration and the device to be substituted shall each have been calibrated and their measurement uncertainties determined. The indicator to be substituted shall be calibrated over the full range of its intended use including both positive and negative values if the system is used in tension and compression. The calibrated range shall include a point less than or equal to the output of the force transducer at the lower load limit and a point equal to or greater than the output of the force transducer at the maximum applied force. A minimum of five points shall be taken within this range. The measurement uncertainty of each device shall be less than or equal to one third of the uncertainty for the force measurement system over the range from the lower load limit to the maximum load.

12.3 The measurement uncertainty of the force indicating device shall be determined by one of the methods outlined in Appendix X1. It is recommended that a transducer simulator capable of providing a series of input mV/V steps over the range of measurement and with impedance characteristics similar to that of the force transducer be employed as a check standard to verify calibration of the force indicating device and in establishing the measurement uncertainty. The measurement uncertainly of the transducer simulator shall be less than or equal to one tenth of the uncertainty for the force measurement system.

12.4 Excitation voltage amplitude, frequency, and waveform shall be maintained in the substitution within limits to assure that the affect on the calibration is negligible. It is a user responsibility to determine limits on these parameters through measurement uncertainty analysis and appropriate tests to assure that this requirement is met. Substitution of an interconnect cable can have a significant affect on calibration. If an interconnect cable is to be substituted, see Note 14.

12.5 A report of calibration for the original and substitute force indicating devices shall be generated. The report shall include the identification of the item calibrated, date of calibration, calibration technician, test readings, the identification of the test equipment used to verify the performance of the force indicating device, and the measurement uncertainty and traceability. The report shall be available for reference as required.

NOTE 14—If an interconnect cable is substituted, care should be taken to assure that the new cable matches the original in all aspects significant to the measurement. (Such factors as the point of excitation voltage sensing and the impedance between the point of excitation voltage sensing and the elastic force transducer may affect the sensitivity of the device to changes in applied force.) It is recommended that the electronic force indicator/cable performance be verified using a transducer simulator or other appropriate laboratory, instruments.

NOTE 15—Metrologically insignificant elements of force measuring devices such as digital displays, printers, and computer monitors may be substituted following verification of proper function.

13. Report

13.1 The report issued by the standardizing laboratory on the calibration of a force-measuring instrument shall be error-free and contain no alteration of dates, data, etc. The report shall contain the following information:

13.1.1 Statement that the calibration has been performed in accordance with Practice E 74. It is recommended that the calibration be performed in accordance with the latest published issue of Practice E 74.

13.1.2 Manufacturer and identifying serial numbers of the instrument calibrated,

13.1.3 Name of the laboratory performing the calibration,

13.1.4 Date of the calibration,

13.1.5 Type of reference standard used in the calibration with a statement of the limiting errors or uncertainty,

13.1.6 Temperature at which the calibration was referenced,

13.1.7 Listing of the calibration forces applied and the corresponding deflections,

13.1.8 List of the coefficients for any fitted calibration equation and the deviations of the experimental data from the fitted curve,

13.1.9 Values for the instrument resolution, the uncertainty associated with the calibration results, and the limits of the Class A loading range,

13.1.10 Tabulation of values from the fitted calibration equation for each force applied during calibration and, if available and suitable for comparison, a tabulation of the change in calibrated values since the last calibration for other than new instruments, and

NOTE 16—The comparison should be made between the unsynthesized calibration data sets, not between data sets derived from the calibration curves, unless the same degree of fit is used in both calibrations under comparison.

13.1.11 Working table of forces, or a correction curve from a nominal factor, or other device to facilitate use of the instrument in service.

NOTE 17—It is advised that a working table of forces versus deflections be supplied, as many users may not have access to data processing at the point of use. The minimum tabular increment of force should not be less than the resolution, nor greater than 10 % of the maximum force applied during calibration.

14. Keywords

14.1 force standard; load cell; proving ring; testing machine

ANNEX

(Mandatory Information)

A1. PROCEDURE FOR DETERMINING DEGREE OF BEST FITTING POLYNOMIAL

A1.1 This procedure may be used to determine the degree of best fitting polynomial for high resolution force-measuring instruments (see 7.1.3).

A1.2 The procedure assumes that a force-measuring instrument has been measured at *n* distinct, non-zero forces, and that the series of *n* measurements has been replicated *k* times at the same forces. At each force, the mean of *k* measurements is computed. (The value *k* is not otherwise used here.) These *n* values are referred to as the mean data. The following analysis is to be applied only to the mean data, and is used only to determine the degree of best fitting polynomial.

A1.3 Fit separate polynomials of degree 1, 2, 3, 4, and 5 to the mean data. Denote the computed residual standard deviations by s_1, s_2, s_3, s_4, and s_5 respectively. The residual standard deviation from an m_1-degree fit is:

$$s_{m_1} = \sqrt{\frac{d_1{}^2 + d_2{}^2 + \ldots + d_n{}^2}{n_1 - m_1 - 1}} \tag{A1.1}$$

where:

d_1, d_2, etc. = differences between the fitted curve and the *n* observed mean values from the calibration data,

n_1 = number of distinct non-zero force increments, and

m_1 = the degree of polynomial fit.

A1.4 These values for residual standard deviation are used in a sequential procedure to test whether the coefficient of the highest order term in the current fit is significant. Use will be made of the constants $C(n_1, m_1)$ in Table A1.1. Quantities of the F distribution were used in computing these constants.

A1.5 Compute s_4/s_5 and compare it to $C(n_1, 5)$. If $s_4/s_5 > C(n_1, 5)$ then the coefficient of the 5th-degree term is significant and the 5th-degree fit is determined to be best. Otherwise, compute s_3/s_4 and compare it to $C(n_1, 4)$. Continue the procedure in the same manner until the coefficient of the highest-degree term in the current fit is determined to be significant. To state the rule generally, if $s_{m_1-1}/s_{m_1} > C(n_1, m_1)$ then the coefficient of the m_1 th degree term is significant and the m_1 degree fit is determined to be best. Otherwise, reduce m_1 by one and repeat the test ($m_1 = 5, 4, 3, 2$).

TABLE A1.1 Factors $C(n_1, m_1) = (1 + [F.975\ (1, n_1 - m_1 - 1) - 1]/(n_1 - m_1))^{1/2}$ for Determining the Best Degree of Polynomial Fit

n_1	$m_1 = 2$	$m_1 = 3$	$m_1 = 4$	$m_1 = 5$
10	1.373	1.455	1.582	1.801
11	1.315	1.373	1.455	1.582
12	1.273	1.315	1.373	1.455
15	1.195	1.215	1.241	1.273
20	1.131	1.141	1.151	1.163

A1.5.1 To illustrate the procedure, let $n_1 = 11$, $s_1 = 1.484$, $s_2 = 0.7544$, $s_3 = 0.2044$, $s_4 = 0.1460$, and $s_5 = 0.1020$ (see NIST Technical Note 1246, A New Statistical Model for Force Sensors[2]). Compute $s_4/s_5 = 1.431 < 1.582 = C(11, 5)$. This indicates the 5th degree term is not significant, therefore compute $s_3/s_4 = 1.400 < 1.455 = C(11, 4)$. This indicates the 4th degree term is not significant, therefore compute $s_2/s_3 = 3.691 > 1.373 = C(11, 3)$. This indicates the 3rd degree term is significant, and the 3rd degree fit is determined to be the best degree of polynomial fit.

A1.6 After determination of the degree of best fit, return to 8.2.1 of this practice to continue calculation and analysis of the calibration data.

APPENDIXES

(Nonmandatory Information)

Sample Procedures for Determining Force Indicating Instrument Uncertainty

X1. Uncertainty Analysis for an Electronic Force Indicating Instrument for Class A Load Range using a Transducer Simulator and the Method of Measurement Uncertainty Determination in Accordance with the Procedures of ASTM E 74

X1.1 The force transducer in the system for which it is desired to substitute the electronic force indicator has a 2 mV/V output at full capacity. The force measurement system is a Class A system with a lower limit equal to 10% of the force transducer's capacity. The expanded uncertainty of the system is 0.25%. The standard uncertainty is 0.1 %.

X1.2 A transducer simulator with a measurement uncertainty equal to or less than one tenth of the allowable standard uncertainty for the force measurement system is used to provide a series of discrete mV/V steps over the range of measurement (see 8.5.2.1 and 8.5.2.2 for allowable uncertainty). The instrument and transducer simulator shall be connected and allowed to warm up according to manufacturer's recommendations. At least five readings taken three times for each polarity shall be acquired over the calibrated range for the original force indicating instrument and the device to be substituted. The readings shall include a point less than or equal to the lower load limit for the system, and another point equal to or greater than the maximum load for the system. The transducer simulator settings shall provide at least one point for every 20% interval throughout this range. Care shall be taken that environmental conditions do not significantly affect the accuracy of measurements taken.

NOTE X1.1—It is desirable to use the same transducer simulator for determining the readings of both indicators; however, different simulators may be used provided their outputs for a given input are identical within one tenth of the allowable standard uncertainty for the force measurement system.

X1.3 The electronic force indicator to be used as a substitute is evaluated to ensure that the electrical characteristics are the same, and that the interconnect cable is the same with respect to wiring, and wire types, sizes, and lengths.

X1.4 A transducer simulator capable of providing 0.2 mV/V steps is selected.

X1.5 The transducer simulator is connected to the original force indicator and the reading at 0.2 mV/V and each 0.4 mV/V step between 0.4 and 2.0 mV/V are recorded. After the first run of readings, a second and third run are taken. This process is repeated for the opposite polarity. This process is repeated on the indicator to be used as a substitute. It is not required that the verification of the two indicators occur at the same time, provided the transducer simulator stability is evaluated over the relevant time period in the determination of its measurement uncertainty.

X1.6 A linear least squares curve fit is performed on the data set according to the procedure set forth in 8.1-8.4. The standard deviation is determined to be .00005 mV/V, and the uncertainty is 0.00012 mV/V (2.4 times the standard deviation). This value must be less than or equal to one third of the system uncertainty at the lower force limit in electrical units, or less than

$$(0.25\% \times 0.2\ mV/V)\ /\ 3 = 0.000167\ mV/V$$

X2. Uncertainty Analysis for an Electronic Force Indicating Instrument for Class A Load Range using a Measurement Uncertainty Determination in Accordance with the Method of NIST Tech Note 1297

X2.1 Using the same example from Appendix X1, the method of NIST TN 1297 is employed.

X2.2 The first step in a measurement uncertainty analysis of an electronic force indicator is to identify the sources of error. The following are potential sources of measurement error in strain gage based force transducer indicators:

Calibration Uncertainty (Gain Error)
Zero Offset
Temperature Effect on Sensitivity
Quantization Error
Normal Mode Voltage
Excitation Voltage Error
Power Line Voltage Variation
Non-linearity
Temperature Effect on Zero
Gain and Zero Stability
Common Mode Voltage
Noise
Electrical Loading
Error signals due to thermal EMF

X2.3 Each of these potential error sources, and any others of significance, should be evaluated for the conditions in which the indicator will operate. It is recommended that a transducer simulator or equivalent laboratory test instrumentation be used to verify indicator performance and assess errors. The same requirements for number and distribution of test points as given in the previous example apply.

X2.4 A Typical Analysis of the Major Error Sources as Determined for an Indicator is given below:

Simulator uncertainty	u_c= 20 ppm	Includes the ratio uncertainty
Indicator Non-linearity	u_{nl}= 116 ppm	For 0.01% non-linearity and an assumed rectangular probability distribution, 0.01/(3)^0.5 × 2.0. Where a factor of 2 is specific to a particular indicator and shall be determined by test to reflect the error over the full range of indicator use. Non-linearity is evaluated by test using a transducer simulator or other suitable instrument.
Temperature Effect on Gain	u_t= 57 ppm	For temperature coef. of 20 ppm/°C, ± 5 °C, Assumed rectangular probability distribution.
Gain Stability	Negligible	Gain stability is not a factor if calibrated on a simulator at the time of substitution as the gain error is incorporated in the transducer simulator uncertainty.
Noise	Evaluated	Noise is already incorporated in the uncertainty that determines the lower load limit. It is only necessary to adjust for noise if the noise exhibited by the substitute indicator exceeds that for the original indicator. The quantization error is often smaller than the noise and is included in the experimental determination of the noise. Noise for each indicator shall be determined by test.

X2.5 Errors from the other potential sources are found to be negligible for this indicator (less than ⅕ of the largest error source). For DC indicators, the thermal emf error source can be significant and should be evaluated experimentally.

X2.6 The Combined Uncertainty based on the error sources evaluated is,

$$\text{Combined Uncertainty } u = (u_c\,{}^\wedge 2 + u_{nl}\,{}^\wedge 2 + u_t\,{}^\wedge 2\,)\,{}^\wedge.5 = 131 \text{ ppm of Rdg.}$$

and the Expanded Uncertainty is,

$$\text{Expanded Uncertainty } U = \pm\, 0.026\% \text{ of Reading in the range of } 0.2 - 2.0\ mV/V$$

Expressed in mV/V units, the uncertainty is 0.000052 mV/V at the 0.2 mV/V level.

The expanded uncertainty defines an interval within which the true value is expected to be contained with 95% probability based on a coverage factor of 2.

The allowable uncertainty for this Class A device, is 0.25% of 0.2 mV/V, or expressed in electrical units, 0.0005 mV/V. Allowable uncertainty for the force indicating instrument is equal to or less than one third of this limit, or 0.000167 mV/V. If the uncertainty is less than 0.000167 mV/V as in this example, the substitution is permitted.

X3. Uncertainty Analysis for an Electronic Force Indicating Instrument for Class AA Load Range using a Measurement Uncertainty Determination in Accordance with NIST Tech Note 1297

X3.1 Following the method in Appendix X2, an analysis is performed for a Class AA electronic force indicator for a system with a 10% lower load limit and a 2mV/V sensitivity at maximum force.

Simulator uncertainty	u_c= 10 ppm	Includes the ratio uncertainty
Indicator Non-linearity	u_{nl}= 58 ppm	For 0.005% non-linearity and an assumed rectangular probability distribution, 0.005/(3)^0.5 × 2.0. Where a factor of 2 is specific to a particular indicator and shall be determined by test to reflect the error over the full range of indicator use.
Temperature Effect on Gain	u_t= 12 ppm	For temperature coef. of 5 ppm/°C, ± 2°C, Assumed rectangular probability distribution.

X3.2 Errors from the other potential sources are found to be negligible for this indicator (less than ⅕ of the largest error source).

X3.3 The Combined Uncertainty based on the error sources evaluated is,

$$\text{Combined Uncertainty } u = (u_c\,{}^\wedge 2 + u_{nl}\,{}^\wedge 2 + u_t\,{}^\wedge 2)\,{}^\wedge.5 = 60 \text{ ppm of Rdg.}$$

and the Expanded Uncertainty is,

$$\text{Expanded Uncertainty } U = \pm\, 0.012\% \text{ of Reading in the range of } 0.2 - 2.0\ mV/V$$

Expressed in mV/V units the uncertainty is 0.000024 mV/V at the 0.2 mV/V level.

The expanded uncertainty defines an interval within which the true value is expected to be contained with 95% probability based on a coverage factor of 2.

The allowable uncertainty for this Class AA device is 0.05% of 0.2 mV/V expressed in electrical units, or 0.0001 mV/V. Allowable uncertainty for the force indicating instrument is one third of this limit, or 0.000033 mV/V. If the uncertainty is less than 0.000033 mV/V, as in this example, the substitution is permitted.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org).