Designation: E251 – 20a

Standard Test Methods for Performance Characteristics of Metallic Bonded Resistance Strain Gages[1]

This standard is issued under the fixed designation E251; 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.

INTRODUCTION

The Organization of International Legal Metrology is a treaty organization with approximately 75 member nations. In 1984, OIML issued International Recommendation No. 62, "Performance Characteristics of Metallic Resistance Strain Gages." Test Methods E251 has been modified and expanded to be the United States of America's compliant test specification. Throughout this standard the term "strain gage" represents the longer, but more accurate, "metallic bonded resistance strain gage."

1. Scope

1.1 The purpose of these test methods are to provide uniform test methods for the determination of strain gage performance characteristics. Suggested testing equipment designs are included.

1.2 Test Methods E251 describes methods and procedures for determining five strain gage performance characteristics:

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1.3 Strain gages are very sensitive devices with essentially infinite resolution. Their response to strain, however, is low and great care must be exercised in their use. The performance characteristics identified by these test methods must be known to an acceptable accuracy to obtain meaningful results in field applications.

1.3.1 Strain gage resistance is used to balance instrumentation circuits and to provide a reference value for measurements since all data are related to a change in the strain gage resistance from a known reference value.

1.3.2 Gage factor is the transfer function of a strain gage. It relates resistance change in the strain gage and strain to which it is subjected. Accuracy of strain gage data can be no better than the accuracy of the gage factor.

1.3.3 Changes in gage factor as temperature varies also affect accuracy although to a much lesser degree since variations are usually small.

1.3.4 Transverse sensitivity is a measure of the strain gage's response to strains perpendicular to its measurement axis. Although transverse sensitivity is usually much less than 10 % of the gage factor, large errors can occur if the value is not known with reasonable precision.

1.3.5 Thermal output is the response of a strain gage to temperature changes. Thermal output is an additive (not multiplicative) error. Therefore, it can often be much larger than the strain gage output from structural loading. To correct for these effects, thermal output must be determined from strain gages bonded to specimens of the same material on which the tests are to run, often to the test structure itself.

1.4 Metallic bonded resistance strain gages differ from extensometers in that they measure average unit elongation ($\Delta L/L$) over a nominal gauge length rather than total elongation between definite gauge points. Practice E83 is not applicable to these strain gages.

1.5 These test methods do not apply to transducers, such as load cells and extensometers, that use bonded resistance strain gages as sensing elements.

1.6 Strain gages are part of a complex system that includes structure, adhesive, strain gage, lead wires, instrumentation, and (often) environmental protection. As a result, many things affect the performance of strain gages, including user technique. A further complication is that strain gages once installed

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[1] These test methods are under the jurisdiction of ASTM Committee E28 on Mechanical Testing and are the direct responsibility of Subcommittee E28.01 on Calibration of Mechanical Testing Machines and Apparatus.

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normally cannot be reinstalled in another location. Therefore, strain gage characteristics can be stated only on a statistical basis.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E6 Terminology Relating to Methods of Mechanical Testing

E83 Practice for Verification and Classification of Extensometer Systems

E228 Test Method for Linear Thermal Expansion of Solid Materials With a Push-Rod Dilatometer

E289 Test Method for Linear Thermal Expansion of Rigid Solids with Interferometry

E1237 Guide for Installing Bonded Resistance Strain Gages

2.2 *Other Standards:*[3]

OIML International Recommendation No. 62 Performance Characteristics of Metallic Resistance Strain Gages

3. Terminology

3.1 The vocabulary included in these test methods have been chosen so that specialized terms in the strain gage field are clearly defined. A typical strain gage nomenclature is provided in Appendix X1.

3.2 *Definitions:Terms Common to Mechanical Testing*:

3.2.1 The terms accuracy, extensometer, extensometer system, lead wire, Poisson's ratio, precision, reduced section, residual stress, resolution, and verification are used as defined in Terminology E6. In addition, the following terms common to strain gages from Terminology E6 are defined.

3.2.2 *batch, n—for strain gages*, a group of strain gages of the same type and lot, manufactured as a set (made at the same time and under the same conditions).

3.2.3 *gage factor, n—for strain gages*, the ratio between the unit change in strain gage resistance due to strain and the causing strain.

3.2.3.1 *Discussion*—The gage factor is dimensionless and is expressed as follows:

$$K = \frac{\frac{R - R_0}{R_0}}{\frac{L - L_0}{L_0}} = \frac{\frac{\Delta R}{R_0}}{\varepsilon} \tag{1}$$

where:

K = the gage factor,

R = the strain gage resistance at test strain

R_0 = the strain gage resistance at zero or reference strain,

L = the test structure length under the strain gage at test strain,

L_0 = the test structure length under the strain gage at zero or reference strain,

ΔR = the change in strain gage resistance when strain is changed from zero (or reference strain to test strain),

ε = the mechanical strain $\frac{L - L_0}{L_0}$.

3.2.4 *lead wire, n—for strain gages*, an electrical conductor used to connect a strain gage to its instrumentation.

3.2.5 *lot, n—for strain gages*, a group of strain gages with grid elements from a common melt, subjected to the same mechanical and thermal processes during manufacturing.

3.2.6 *metallic resistance bonded strain gage, n*—(see Fig. 1)—a resistive element, with or without a matrix that is attached to a solid body by cementing, welding, or other suitable techniques so that the resistance of the element will vary as the surface to which it is attached is deformed.

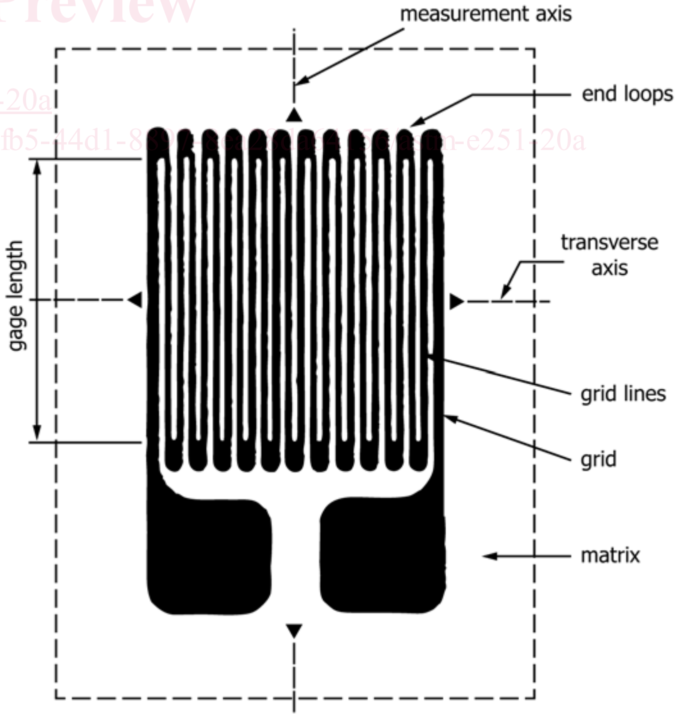

FIG. 1 Typical Strain Gage

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

[3] Available from OIML International Organization of Legal Metrology, BIML, 11, rue Turgot, F-75009 Paris, France, http://www.oiml.org/en

3.2.6.1 *Discussion*—These test methods apply to gages where the instantaneous gage resistance, R, is given by the equation:

$$R = R_o(1 + \varepsilon K) \tag{2}$$

where:

R_o = element resistance at reference strain and temperature levels (frequently initial test or balanced circuit conditions),
ε = linear strain of the surface in the direction of the measurement axis of the strain gage produced either by a stress field (mechanical strain) or by a temperature change (thermal expansion), and
K = the gage factor.

3.2.7 *type, n—for strain gages*, a group of strain gages that are nominally identical with respect to physical and manufacturing characteristics.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *calibration apparatus, n*— equipment for determining a performance characteristic of a metallic bonded resistance strain gage by accurately producing the necessary strains, temperatures, and other conditions and by accurately measuring the resulting change of strain gage resistance.

3.3.2 *error, n—for strain gages*, the value obtained by subtracting the actual value of the strain, determined from the calibration apparatus, from the indicated value of the strain given by the strain gage output.

3.3.2.1 *Discussion*—Errors attributable to measuring systems are excluded.

3.3.3 *gage length , n*— (see Fig. 1)—the length of the strain sensitive section of a strain gage in the measurement axis direction.

3.3.3.1 *Discussion*—An approximation of the gage length is the distance between the inside of the strain gage end loops. Since the true gage length is not known, gage length may be measured by other geometries (such as the outside of the end loops) providing that the deviation is defined.

3.3.4 *grid, n*—(see Fig. 1)—that portion of the strain-sensing material of the strain gage that is primarily responsible for resistance change due to strain.

3.3.5 *matrix, n*—(see Fig. 1)—an electrically nonconductive layer of material used to support a strain gage grid.

3.3.5.1 *Discussion*—The two main functions of a matrix are to act as an aid for bonding the strain gage to a structure and as an electrically insulating layer in cases where the structure is electrically conductive.

3.3.6 *measurement axis, n*— (see Fig. 1)—the axis that is parallel with the grid lines.

3.3.7 *strain gage, n*—the term "strain gage" is equivalent to the longer, but more accurate, "metallic bonded resistance strain gage."

3.3.8 *temperature coefficient of gage factor*—the ratio of the unit variation of gage factor to the temperature variation, expressed as follows:

$$\left(\frac{K_{t1} - K_{t0}}{K_{t0}}\right) \cdot \left(\frac{1}{T_1 - T_0}\right) \tag{3}$$

where:

T_1 = the test temperature,
T_0 = the reference temperature,
K_{t1} = the gage factor at test temperature, and
K_{t0} = the gage factor at reference temperature.

3.3.9 *thermal expansion*—the dimensional change of an unconstrained specimen subject to a change in temperature that is uniform throughout the material.

3.3.10 *thermal output*—the reversible part of the temperature induced indicated strain of a strain gage installed on an unrestrained test specimen when exposed to a change in temperature.

3.3.11 *transverse axis* (see Fig. 1)—the strain gage axis at 90° to the measurement axis.

3.3.12 *transverse sensitivity*—the ratio, expressed as a percentage, of the unit change of resistance of a strain gage mounted perpendicular to a uniaxial strain field (transverse strain gage) to the unit resistance change of a similar gage mounted parallel to the same strain field (longitudinal strain gage).

4. Significance and Use

4.1 Strain gages are the most widely used devices for the determination of materials, properties and for analyzing stresses in structures. However, performance characteristics of strain gages are affected by both the materials from which they are made and their geometric design. These test methods detail the minimum information that must accompany strain gages if they are to be used with acceptable accuracy of measurement.

4.2 Most performance characteristics of strain gages require mechanical testing that is destructive. Since test strain gages cannot be used again, it is necessary to treat data statistically and then apply values to the remaining population from the same lot or batch. Failure to acknowledge the resulting uncertainties can have serious repercussions. Resistance measurement is non-destructive and can be made for each strain gage.

4.3 Properly designed and manufactured strain gages, whose performance characteristics have been accurately determined and with appropriate uncertainties applied, represent powerful measurement tools. They can determine small dimensional changes in structures with excellent accuracy, far beyond that of other known devices. It is important to recognize, however, that individual strain gages cannot be calibrated. If calibration and traceability to a standard are required, strain gages should not be employed.

4.4 To be used, strain gages must be bonded to a structure. Good results depend heavily on the materials used to clean the bonding surface, to bond the strain gage, and to provide a protective coating. Skill of the installer is another major factor in success. Finally, instrumentation systems must be carefully designed to assure that they do not unduly degrade the performance of the strain gages. In many cases, it is impossible to achieve this goal. If so, allowance must be made when considering accuracy of data. Test conditions can, in some instances, be so severe that error signals from strain gage systems far exceed those from the structural deformations to be measured. Great care must be exercised in documenting magnitudes of error signals so that realistic values can be placed on associated uncertainties.

5. Interferences

5.1 To assure that strain gage test data are within a defined accuracy, the strain gages must be properly bonded and protected with acceptable materials. It is normally simple to ascertain that strain gages are not performing properly. The most common symptom is instability with time or temperature change. If strain gages do not return to their zero reading when the original conditions are repeated, or there is low or changing resistance to ground, the installation is suspect. Aids in installation and verification of strain gage can be found in Guide E1237.

6. Hazards

6.1 In the specimen surface cleaning, strain gage bonding, and protection steps of strain gage installation, hazardous chemicals may be used. Users of these test methods are responsible for contacting manufacturers of these chemicals for applicable Material Safety Data Sheets and to adhere to the required precautions.

7. Test Requirements

7.1 *General Environmental Requirements:*

7.1.1 *Ambient Conditions at Room Temperature*—The nominal temperature and relative humidity shall be 23 °C (73 °F) and 50 %, respectively. In no case shall the temperature be less that 18 °C (64 °F) nor greater than 25 °C (77 °F) and the relative humidity less than 35 % nor more than 60 %. The fluctuations during any room temperature test of any strain gage shall not exceed ±2 °C and ±5 % RH.

7.1.2 *Ambient Conditions at Elevated and Lower Temperatures*—The temperature adjustment error shall not exceed ±2 °C (± 3.6 °F) or ±2 % of the deviation from room temperature, whichever is greater. The total uncertainty of temperature shall not exceed ±2 °C (±3.6 °F), or ±1 % of the deviation from room temperature, whichever is greater. At elevated temperatures the mixing ratio shall be constant, that means independent of temperature, at a nominal value of 0.009 g of water per 1 g of air at a pressure of 100 kPa (1 bar). This value corresponds to a relative humidity of 50 % at 23 °C (73 °F).

NOTE 1—This mixing ratio, independent of temperature, can be realized by a furnace that is well connected to an atmosphere meeting the conditions of 7.1.1.

7.2 *Test Measurement Requirements:*

7.2.1 Several methods are available for measuring the change of strain gage resistance with sufficient resolution and accuracy. In general, any of these methods that are convenient may be used after it has been shown that the particular combination of instruments or components used produce a system with the required accuracy.

7.2.2 Examples of potentially satisfactory methods are as follows:

7.2.2.1 *Balanced Bridge Circuit*—In this circuit, a change in strain gage resistance is matched by an equal unit resistance change in a calibrated arm of a Wheatstone bridge circuit so as to produce a balanced condition with zero electrical output. This circuit is not sensitive to excitation voltage changes except for self-heating effects. A sensitive null detector (galvanometer) is required to obtain adequate resolution. Direct-current excitation is usually, but not necessarily, used. Thermal emfs generated within the circuit and reactive changes in the circuit may cause errors. This circuit is shown in Fig. 2.

7.2.2.2 *Unbalanced Bridge Circuit*—This circuit is similar to the balanced bridge circuit except that the bridge components are not adjusted after a nearly balanced initial condition is obtained. The output voltage of an unbalanced bridge circuit in which one arm is varying, E_o, is given by the equation:

$$E_o = E_i\left[\frac{\Delta R}{4R_o + 2\Delta R}\right] \tag{4}$$

where:

E_i = input voltage,
R_o = resistance required for initial bridge balance, and
ΔR = difference between the instantaneous strain gage resistance and R_o.

This circuit is readily adaptable to automatic recording of data. Either ac or dc excitation may be used, but errors due to thermal emfs and reactive changes are possible. Loading effects due to the impedance of the recording instruments may be significant and must be considered. To avoid the necessity of accurate absolute measurement of the input and output voltages, the readout (recording) system may be calibrated in terms of unit resistance change of a bridge arm by use of a calibrating resistor that can be varied so that the total arm resistance changes in accurately known steps. This resistor should be in the opposite arm of the bridge circuit from the strain gage. This circuit is shown in Fig. 3.

7.2.2.3 Several types of instruments are available for obtaining strain data directly from a strain gage. These instruments use various types of excitation and system indicators. Such strain indicators may be used only after their resolution, accuracy, and stability have been verified by connecting a resistor that can be varied in accurately known increments in place of the strain gage and calibrating the strain indicator over the entire range for which it will be used. The calibrating resistor steps shall be accurate to 0.1 % of the resistance change or 2×10^{-6} of the total resistance, whichever is greater. The effects of the following factors should be determined:

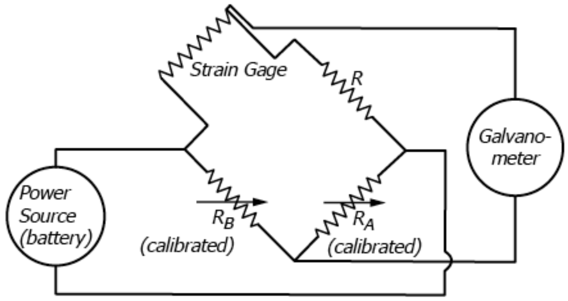

FIG. 2 Balanced Bridge Circuit

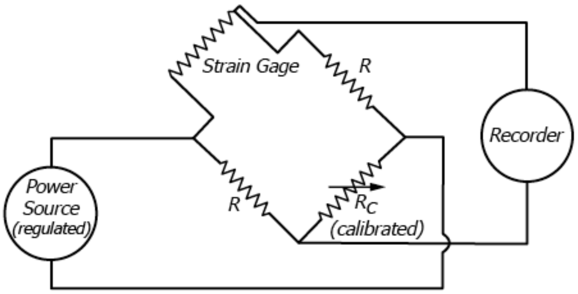

FIG. 3 Unbalanced Bridge Circuit

thermal emf's within the bridge circuit and within the lead wires to the strain gage; reactive changes within the bridge and lead wire circuits; initial bridge unbalance; and battery conditions or power line fluctuations.

7.3 *Strain Gage Attachment:*

7.3.1 The attachment conditions shall correspond exactly to the instructions published by the strain gage manufacturer.

8. Test Method for Determining Strain Gage Resistance at Ambient Conditions

8.1 The standard 23 °C (73 °F) temperature resistance of each unbonded strain gage shall be measured and stated. Alternatively, strain gages may be combined in sets (4, 5, or 10, for example) from the same batch that have close resistance values. All strain gages combined in sets shall fall within the stated nominal resistance value and uncertainty from all sources.

8.2 The unpackaged strain gages selected for testing should be stored under the ambient conditions described in 7.1.1 for at least 72 h before and during resistance measurement.

8.3 The uncertainty of the strain gage resistance measurement shall be less than ±0.1 %. Repeated measurements shall have a range no greater than ± 0.04 % of the measured value. The influence of the measuring current on the strain gage shall not be greater than ±0.1 % of the resistance value.

8.4 For the resistance measurement no particular mechanical requirements are necessary. However, if the influence of the flatness of the strain gage on the resistance measurement exceeds ±0.1 % of the actual value, the strain gage must be held in contact with a substantially flat surface using a suitable pressing device. Care must be exercised to ensure that the probes used to contact the tabs of strain gages without lead wires do not damage foil areas.

9. Test Methods for Determining the Gage Factor of Strain Gages at a Reference Temperature

9.1 These test methods describe procedures for the determination of the gage factor of strain gages. It is suggested that gage factor values be obtained for at least five strain gage installations of one type.

9.2 For gage factor determination, the uncertainty of the relative resistance change measurement shall not exceed ±2 µΩ/Ω or ±0.1 % of the actual value, whichever is greater. Any of the test methods described in Section 7 may be used. In addition, special circuits designed to compare the strain gages being tested to a calibrated reference strain gage may be used if it is shown that equal accuracy is obtained.

9.3 Determination of the gage factor K requires calibration apparatus consisting of a test specimen and a loading device capable of producing a uniform uniaxial stress in the test specimen corresponding to nominal mean principal strain values of 0 µm/m (µin./in.), ±1000 µm/m (µin./in.) and ±1100 µm/m (µin./in.). The Poisson's ratio of the test specimen shall be 0.28 ±0.01 or suitable corrections must be made. The mean principal strain shall be within ±50 µm/m (µin./in.) of the nominal value. The strain at the various strain gage stations shall differ by no more than ±0.5 % of the mean value and the strain within a strain gage station shall vary by no more than ±0.5 % of the nominal value. The uncertainty of the mean strain measurement shall be less than ±2 µm/m (µin./in.) or ±0.2 % of the actual value, whichever is greater. Any test apparatus that meets these criteria may be used for determination of gage factor.

9.4 To the extent possible, test specimens with attached strain gages for tests of the gage factor should be stored under the ambient conditions described in 7.1.1 for at least 72 h before being tested

9.5 For the determination of the gage factor, the strain gages under test should be prestrained three times with strain cycles similar to the ones used for the measurement, but with maximum strain levels about 10 % higher. That means that the strain cycle should nominally be:

$$\begin{array}{rl} 0\ \mu\text{m/m}(\mu\text{in./in.}), & \\ +1100\ \mu\text{m/m}(\mu\text{in./in.}), & -1100\ \mu\text{m/m}(\mu\text{in./in.}), \\ +1100\ \mu\text{m/m}(\mu\text{in./in.}), & -1100\ \mu\text{m/m}(\mu\text{in./in.}), \\ +1100\ \mu\text{m/m}(\mu\text{in./in.}), & -1100\ \mu\text{m/m}(\mu\text{in./in.}), \\ 0\ \mu\text{m/m}(\mu\text{in./in.}), & +1000\ \mu\text{m/m}(\mu\text{in./in.}), \\ 0\ \mu\text{m/m}(\mu\text{in./in.}), & -1000\ \mu\text{m/m}(\mu\text{in./in.}), \\ 0\ \mu\text{m/m}(\mu\text{in./in.}). & \end{array} \tag{5}$$

If possible, one half of the group of strain gages to be tested should be strained this way and the other half of the sample should be subjected to strains of the same magnitude but opposite sign. The gage factor is determined from the slope of the straight line between the measurement points at +1000 µm/m (µin./in.) and −1000 µm/m (µin./in.). Although less desirable, it is permissible to use the strain cycles of:

$$\begin{array}{ll} 0\ \mu\text{m/m}(\mu\text{in./in.}) & +1100\ \mu\text{m/m}(\mu\text{in./in.}) \\ 0\ \mu\text{m/m}(\mu\text{in./in.}) & +1100\ \mu\text{m/m}(\mu\text{in./in.}) \\ 0\ \mu\text{m/m}(\mu\text{in./in.}) & +1100\ \mu\text{m/m}(\mu\text{in./in.}) \\ 0\ \mu\text{m/m}(\mu\text{in./in.}) & +1000\ \mu\text{m/m}(\mu\text{in./in.}) \\ 0\ \mu\text{m/m}(\mu\text{in./in.}) & \end{array} \tag{6}$$

for one half of the sample and strain cycles of:

$$\begin{array}{ll} 0\ \mu\text{m/m}(\mu\text{in./in.}) & -1100\ \mu\text{m/m}(\mu\text{in./in.}) \\ 0\ \mu\text{m/m}(\mu\text{in./in.}) & -1100\ \mu\text{m/m}(\mu\text{in./in.}) \\ 0\ \mu\text{m/m}(\mu\text{in./in.}) & -1100\ \mu\text{m/m}(\mu\text{in./in.}) \\ 0\ \mu\text{m/m}(\mu\text{in./in.}) & -1000\ \mu\text{m/m}(\mu\text{in./in.}) \\ 0\ \mu\text{m/m}(\mu\text{in./in.}) & \end{array} \tag{7}$$

for the other half of the sample.

The gage factor is determined from the average of the slopes, of the straight lines between the measurement points at

0 µm/m (µin./in.) and +1000 µm/m (µin./in.) and
0 µm/m (µin./in.) and −1000 µm/m (µin./in.).

9.6 As a guide, three separate test methods are described, the choice of the test method used being determined by the particular application and by the facilities that are available. These test methods do not classify strain gages according to accuracy or other performance characteristics. The three test methods that are described differ primarily in the manner of producing an accurately known surface strain, and they are thereby classified. These test methods are described in the following sections:

9.6.1 *Constant Bending Moment Beam Test Method:*

9.6.1.1 *Summary of Test Method*—This test method uses a strain on the surface of a test bar produced by loading it as a constant moment beam by the application of dead-weight forces.

9.6.1.2 *Calibration Apparatus*—A typical calibration apparatus is shown in Fig. 4. The test beam may be of any suitable material that meets the requirements of 9.3, and shall have minimum dimensions of 19 mm by 25 mm by 760 mm (0.75 in. by 1 in. by 30 in.). The minimum distance between the pivot points on the supports shall be 2.45 m (96 in.). The beam assembly shall be symmetrical about a vertical line through its midpoint. The positions of the pivots and the weight values shall be adjusted to provide the required strains. The strain over the usable section of the beam shall vary by not more than 1 % of the strain at the reference point. The usable portion of the beam shall be at least one half of the exposed length.

9.6.1.3 *Verification*—The need for measuring calibration strain directly during each test is eliminated by maintaining a calibration of the calibration apparatus. Such a calibration is made by measuring with a Class A extensometer system (see Practice E83) the actual strain produced on the surface of the beam when it is loaded. Measurements shall be made with the extensometer system centered over each station of the beam. At least three measurements shall be made at each station to verify the strain distribution over the width of the beam. The dimensions of the beam shall be checked at each station periodically. A change of 0.2 % in the thickness at any station shall disqualify that station. Other dimensional changes that would cause a change of surface strain of 0.2 % shall disqualify the beam. The strain at the reference station shall be determined each time the beam is used either with a Class A extensometer system, or with a carefully selected, permanently mounted strain gage that has been calibrated by spanning with a Class A extensometer system. The response of this reference strain gage shall be verified periodically to assure compliance with specifications using a Class A extensometer system. The beam shall be completely recalibrated after 50 applications or 6 months, whichever comes later.

9.6.1.4 *Procedures*—Mount test strain gages with any appropriate installation technique that will not change the characteristics of the test beam (for example, excessive cure temperatures could be damaging). Mount the strain gages at the stations on the beam where the strain level has been determined by the calibration procedure outlined in 9.6.1.3.

9.6.1.5 Install the test specimen bearing previously unstrained strain gages in the calibration apparatus and test environment. After temperature equilibrium has been attained, follow the strain cycle of 9.5. Take readings from the strain gages before applying the load, with the load applied, and after the load is removed for each strain cycle. Obtain compression strains by mounting the beam with the strain-gaged surface up. Obtain tension strains by mounting the beam with the strain-gaged surface down.

9.6.1.6 Calculate the gage factors.

9.6.2 *Constant Stress Cantilever Beam Test Method:*

9.6.2.1 *Summary of Test Method*—This test method produces strain on the surface of a cantilever beam that is designed to have a constant stress over the major portion of its length when loaded in the prescribed manner.

9.6.2.2 *Calibration Apparatus*—A calibration apparatus is shown in Fig. 5 and detailed design of a beam that has been used satisfactorily is shown in Fig. 6 (Note 2). The size and arrangement of the equipment must be such that the beam may be bent sufficiently in either direction to produce a surface strain of at least 1100 µm/m (µin./in.). Two or more carefully selected calibrated reference strain gages, shall be permanently bonded to the constant-stress section of the beam as shown in Fig. 6. Great care must be taken to install these strain gages, using the best current techniques to ensure bonding integrity and long-term stability. These calibrated reference strain gages shall be individually calibrated to determine their gage factor

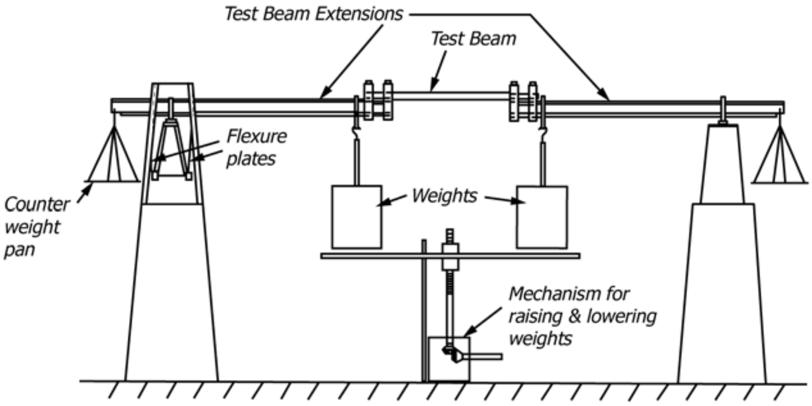

FIG. 4 Constant Bending-Moment Beam Method for Gage Factor Determination

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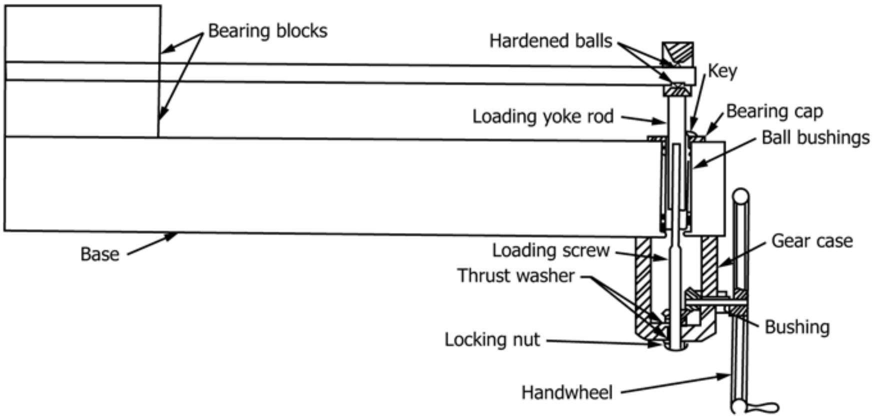

FIG. 5 Constant-Stress Cantilever Beam Method for Gage Factor Determination

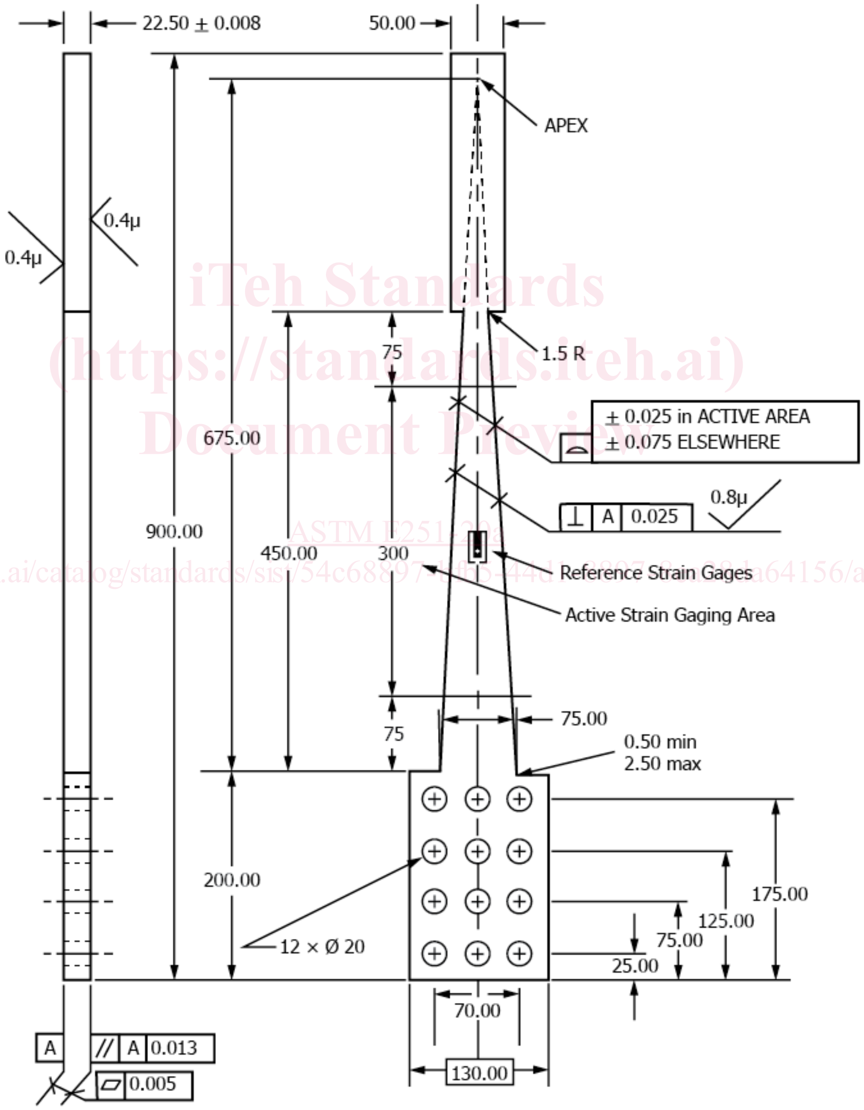

FIG. 6 Constant Stress Cantilever Beam

by placing a Class A extensometer system (Practice E83) so as to span the strain gage, bending the beam by means of the deflecting apparatus, and measuring the resulting change in strain gage resistance and strain. Readings shall be taken for the strain cycles stipulated in 9.5 and the gage factor calculated (Note 3 and Note 4).

NOTE 2—In order for the beam to fulfill the requirements of a constant-stress beam, the drive rod must be attached to the beam at the apex of the angle formed by the sides of the beam. The ratio of the free length of the beam to width at the base should not be less than 9:1.

NOTE 3—For the calibrated reference strain gage, the gage factor for compression strains may differ from the gage factor for tension strains and it must be determined for both directions of loading.

NOTE 4—It may be convenient to obtain strain of the beam surface as a function of the deflection of the end of the beam as measured by a dial gauge while the strain gages are being calibrated.

9.6.2.3 *Verification of the calibration apparatus*—The constant-stress area of the beam of the calibration apparatus shall be explored with a Class A extensometer system to determine the area where the strain is the same as that experienced by the calibrated reference strain gages. The gauge length of the extensometer shall not exceed 25 mm (1 in.). Only areas of the beam where differences between the strains indicated by the extensometer and the calibrated reference strain gage do not exceed 10 µm/m (µin./in.) at a strain of 1000 µm/m (µin./in.) are acceptable for testing strain gages. The beam of the calibration apparatus shall be verified after each 50 uses or 6 months, whichever comes last.

9.6.2.4 *Procedure*—Install the strain gages to be tested on the beam in the areas that have been found to be satisfactory; connect them to instruments for measuring their change of resistance. The measurement axes of the strain gages shall be parallel to the center line of the beam. A selector switch may be used to connect several strain gages into the measuring circuits if it is shown that repeated switchings do not change indicated strain readings by more than 2 µm/m (µin./in.).

9.6.2.5 Follow the strain cycle of 9.5 and calculate gage factors.

9.6.3 *Direct Tension or Compression Test Method:*

9.6.3.1 *Summary of Test Method*—This test method produces strain in a test bar by applying direct tensile or compressive forces to the bar.

9.6.3.2 *Calibration Apparatus*—A typical calibration apparatus is shown in Fig. 7. In this system the test bar is strained directly in tension or compression by a testing machine or other device capable of applying an axial force to the specimen. The horizontal position of the bar is convenient for mounting the reference extensometer, but it is not necessary. The force may be applied by hydraulic, mechanical, or other means, but care must be taken to prevent any twisting or bending of the test bar. Twisting in the calibration apparatus of Fig. 7 is prevented by the torque arm. Fig. 8 shows a test bar that has been used successfully for both tension and compression loading. The strain gage under test shall be mounted at the center of the reduced section; and a Class A reference extensometer system shall be mounted so as to span the strain gage. The reference extensometer should have a gauge length as near that of the strain gage as possible in order to minimize the effect of nonuniform strain along the length of the test bar.

9.6.3.3 *Verification*—Since the calibration strain is measured during each test, no calibration of the calibration apparatus is necessary. The thickness and width of the test bar must be uniform within ±0.25 % of their average values over a length extending 13 mm (0.5 in) beyond the extensometer gauge points in each direction. The absence of twisting and bending of the test bar must be verified.

9.6.3.4 *Procedure*—Mount a test strain gage by any appropriate technique so that the measurement axis coincides with the center line of the test bar. Mount the test bar in the loading device taking care to avoid bending or loading of the test bar. Connect the strain gage electrically to the resistance-measuring circuit, and mount the reference extensometer so as to span the strain gage. Follow the strain cycle in 9.5 (plus or minus strains only) except that preload, not exceeding 5 % of the maximum force, may be applied to align the test bar in the machine, to remove backlash, etc. Take readings simultaneously from the electrical circuit and the reference extensometer. Calculate gage factors. Repeat for strains in the opposite direction.

10. Test Methods for Determining the Temperature Coefficient of Gage Factor of Strain Gages

10.1 These test methods describe procedures for the determination of temperature coefficient of gage factors of strain gages.

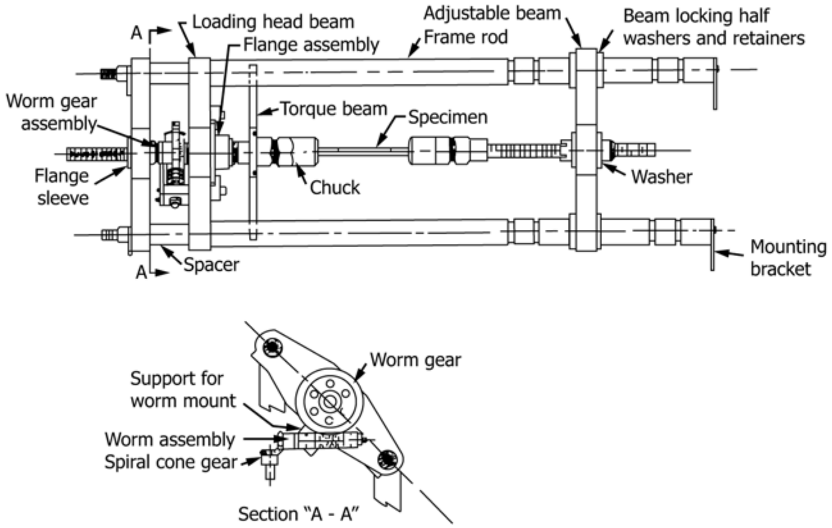

FIG. 7 Testing Machine for Determining the Gage Factor using the Direct Tension of Compression Method

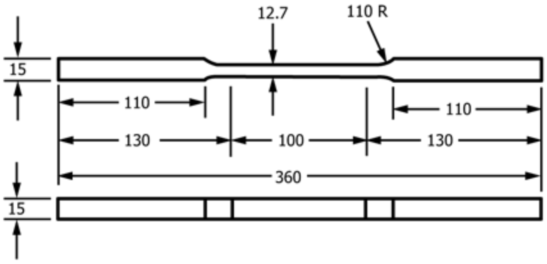

FIG. 8 Test Bar for Determining the Gage Factor using the Direct Tension of Compression Method

10.2 For temperature coefficient of gage factor determination, the uncertainty of the relative resistance change measurement shall not exceed ±5 µΩ/Ω or ±0.1 % of the actual value, whichever is greater.

10.3 If convenient, strain gages may be tested in tension/compression half bridges (one strain gage in tension, the other in compression) by mounting two strain gages opposite each other and connecting them in a half bridge. This practice helps to eliminate errors from drift and lead wires. If strain gages are tested individually, an arrangement of three lead wires is used (see Fig. 2 and Fig. 3).

10.4 To determine the temperature coefficient of gage factor, it is necessary to have equipment consisting of a test specimen, a calibration apparatus, and a furnace for producing the temperatures needed. It must be possible to adjust the strain in the test specimen to mean values of 0 µm/m (µin./in.) and +1000 µm/m (µin./in.). It is desirable that a strain of −1000 µm/m (µin./in.) may be produced. Instead of the reference strain of zero, a small prestrain of between 20 µm/m (µin./in.) and 100 µm/m (µin./in.) may be used. The adjustment error shall be no more than ±50 µm/m (µin./in.). The uncertainty of the mean strain should be less than ±5 µm/m (µin./in.). The strain at the various strain gage stations shall differ by no more than ±2 % of the actual strain and the strain within a strain gage station shall vary by no more than ±2 % of the nominal value.

10.5 Two test methods for determining the temperature coefficient of gage factor of strain gages are given: a static method and a dynamic method. The choice of test method will be determined by the temperature range, ultimate user needs, and the number of tests to be conducted. The two test methods differ in the manner in which the strain is produced. One test method uses measurements made under static strain and static temperature conditions, and the other test method uses measurements made under dynamic strain and transient temperature conditions.

10.5.1 *Static Test Method:*

10.5.1.1 *Summary of Test Method*—This test method[4] uses a constant-stress cantilever beam that is forcibly deflected in a series of fixed, accumulative steps that can be accurately repeated at various temperatures of interest.

10.5.1.2 A typical calibration apparatus used to produce the strain and a typical test beam are shown in Fig. 9. The test beam is designed to have a considerable area of uniform stress that is directly proportional to the deflection of the end point (the apex of the angle formed by the sides of the test beam) of the test beam. The frame is designed to hold the base of the test beam rigidly and provide a base for the sliding stepped block. The rider on the test beam is attached at the apex of the angle formed by the test beam sides. The frame must be much more rigid than the test beam to prevent errors due to bending of the frame. The stepped block can provide several deflection steps,

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[4] This test method is based on apparatus and techniques proposed by McClintock, R.M., "Strain Gage Calibration Device for Extreme Temperatures," *Review of Scientific Instruments*, Vol 30, No. 8, 1959, p. 715.

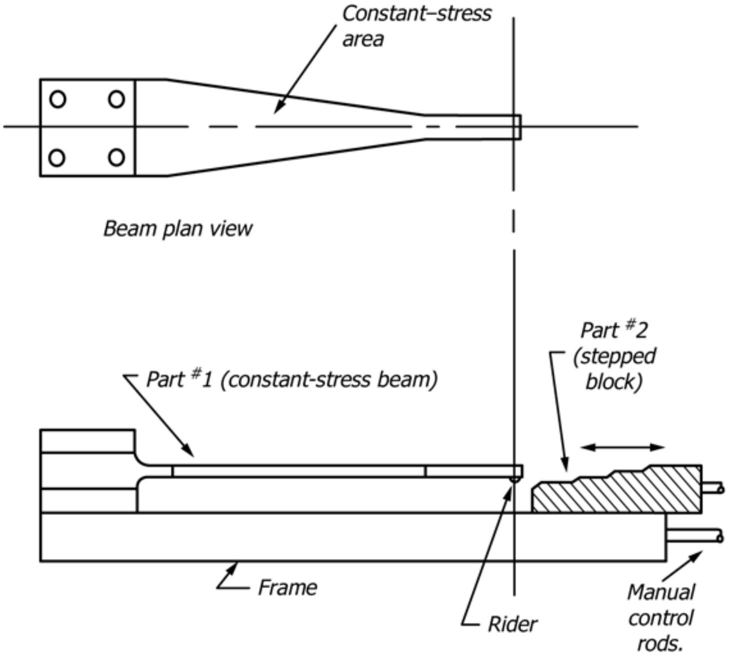

FIG. 9 Calibration Apparatus for Static Determining of Temperature Coefficient of Gage Factor

as shown in Fig. 9. However, it is sufficient that the maximum deflection produces a surface strain on the beam of (1000 ±50) µm/m (µin./in.). The stepped surfaces must be parallel to each other and to the opposite sliding surface of the block. The calibration apparatus must be designed so the beam end is deflected about 2 % of its total planned deflection when the rider is in contact with the lowest step of the sliding block. This is to ensure that contact is always maintained between the test beam and the rider. To avoid differential expansion problems, all parts of the calibration apparatus, and the specimen, should be made from the same material, selected to ensure proper operation over the entire temperature span to be encountered.

10.5.1.3 A furnace or cryostat capable of producing the desired temperature conditions is required but not shown.

10.5.1.4 Mount the strain gage or strain gages to be tested on the beam so they are symmetrically centered on the constant-stress area and aligned with the longitudinal center line of the beam. Mount temperature sensors as near the strain gage(s) as practical and at each end of the constant-stress area. Mount the beam in the frame, and connect the strain gages electrically to the read-out instruments.

10.5.1.5 With the loading calibration apparatus in the furnace or cryostat and the strain gage connected to its read-out instrumentation, allow the beam to come to temperature equilibrium at the reference temperature (usually room temperature). With the rider resting on the lowest step of the block, take a measurement of the strain gage output. Then move the sliding block so as to increase the beam deflection and take strain gage output readings at each step. Again take readings as the deflection is decreased in steps. Repeat this procedure to obtain three sets of readings. Take the strain gage output due to strain for each step as the average of the differences from the value at the lowest step for all strain cycles.

10.5.1.6 Bring the temperature of the calibration apparatus to each of the preselected temperatures of interest and repeat the procedure. Take care to ensure that the temperature has stabilized. Make tests at a minimum of five nearly equally spaced temperatures over the temperature range of interest.

10.5.1.7 Calculate the temperature coefficient of gage factor (see 3.2.3).

10.5.2 *Dynamic Test Method:*

10.5.2.1 *Summary of Test Method*—This test method depends upon the output voltage from a bridge circuit composed of stable resistors and one or more strain gages:

$$E_0 \approx E_1 K (N/4) \varepsilon \tag{8}$$

where:

E_0 = output voltage from bridge circuit,
E_1 = input voltage to bridge circuit,
K = gage factor of the strain gages,
ε = strain to which the strain gages are subjected, and
N = number of active strain gages.

If such a bridge circuit is connected to a constant dc voltage source and the strain gages are subjected to a sinusoidal strain of constant amplitude, the change in the alternating output voltage will be a measure of the change of gage factor.

10.5.2.2 This test method requires a means of vibrating a constant-stress cantilever beam at a constant amplitude; varying the temperature of the beam at a nearly uniform rate; and measuring the output voltage, or change of output voltage, of the bridge circuit as a function of temperature. These operations must be done simultaneously.

10.5.2.3 The beam vibration may be conveniently produced by a motor-driven cam or by an electromechanical vibrator. If the vibrator is used, a method of maintaining the amplitude of vibration constant is required. Monitoring the vibration amplitude by means of a velocity sensing pick-up may not be satisfactory because of changes in the vibration frequency.

10.5.2.4 The temperature environment is conveniently produced by radiant heaters of the tungsten filament quartz tube type. Power may be supplied to these heaters by a temperature programming unit or by manual control with an autotransformer. In order to maintain a nearly uniform temperature over the length of the beam, supplemental heat must be supplied to the clamped end of the beam. This may be done by resistance-wire heating elements built into the clamping fixture.

10.5.2.5 The calibration apparatus for producing the vibratory motion, by means of a cam, and temperature environment is shown in Fig. 10. The control units for the heating elements are not shown. Care must be taken in the design of the apparatus to prevent changes in the rigidity of the beam support and clamping with time or temperature. The design of the beam is shown in Fig. 11.

10.5.2.6 Measuring the ac output of the strain gage circuit and obtaining changes by taking differences of measured values will not usually be satisfactory because of the small differences of large values involved. However, the change of ac voltage may be measured directly by use of circuits such as those shown in Fig. 12 and Fig. 13. The input circuit, Fig. 12, provides a selected constant voltage of 4 V to 12 V to the strain gage circuit, and also provides means for varying this input voltage over a range of ±10 % of the nominal value in known steps. After the ac output voltage from the strain gage circuit has been amplified to about 5 V and filtered to remove all signals except that of the vibration frequency, it becomes the input signal to the output circuit, Fig. 13. The signal is rectified, filtered to remove ripple, and suppressed by a bucking voltage from a stable dc voltage source. The difference between the rectified signal and the suppressing voltage is recorded as a function of test-beam temperature. The dc voltage input to the strain gage circuit must be constant during the test.

10.5.2.7 Mount two strain gages on opposite sides of the constant-stress cantilever beam as shown in Fig. 11. Clamp the wide end of the beam firmly to the rigid mount, and connect the narrow end to equipment for producing sinusoidal deflections of constant amplitude. Make the connection to this equipment at the apex of the angle made by the sides of the main portion of the beam. Connect the strain gages as adjacent arms of a bridge circuit, the other arms being stable resistors of approximately the same resistance as the strain gages and chosen so that the bridge circuit is nearly balanced when the beam is in a neutral position. With the input terminals of the bridge circuit connected to a constant-voltage source, vibrate the beam to produce a strain of about ±500 µm/m (µin./in.). Adjust the

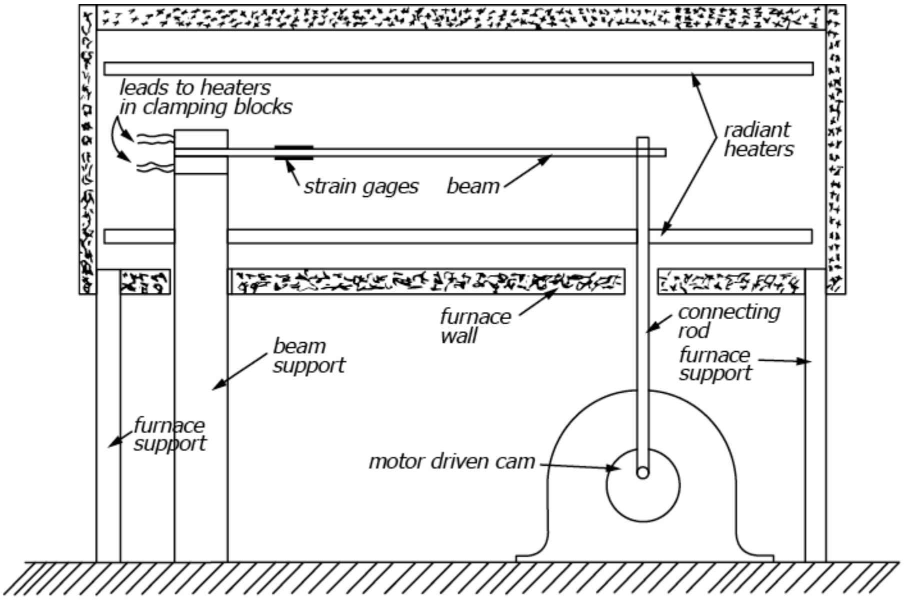

FIG. 10 Calibration Apparatus for Determining Temperature Coefficient Gage Factor by the Dynamic Method

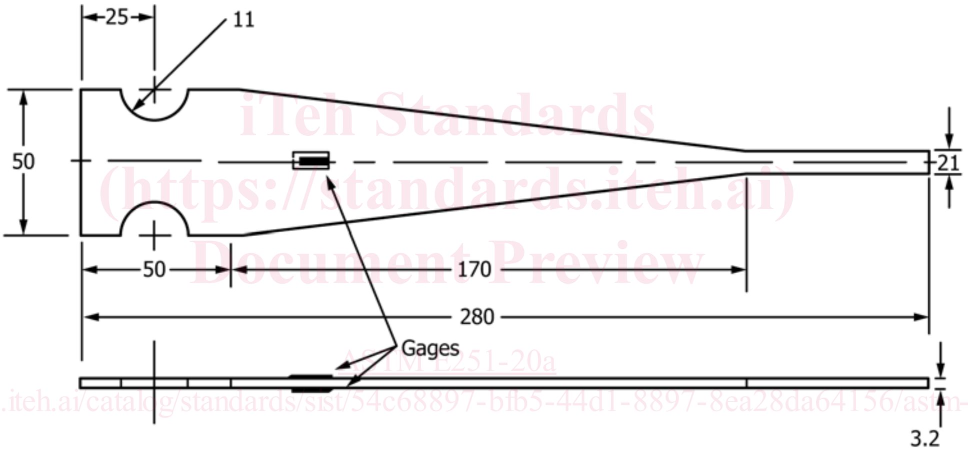

FIG. 11 Constant- Stress Cantilever Beam Used for Determining Temperature Coefficient of Gage Factor Using the Dynamic Method

suppressing voltage to give zero output to the recorder. Obtain the recorder sensitivity in terms of change of strain gage-circuit output voltage by varying the input voltage to the strain gage circuit in known steps. The change of output voltage due to a change in input voltage is the same as would be caused by the same percentage change of gage factor, the strain amplitude remaining constant.

10.5.2.8 After the recorder sensitivity has been determined, return the input voltage to its nominal value, and increase the temperature of the beam of the calibration apparatus at a uniform rate to the maximum desired temperature. During this time record the difference between the rectified strain gage circuit output and the suppressing voltage as a function of the test beam temperature. Obtain the temperature from a temperature sensor mounted as near the strain gage installation as practicable. A heating rate of 10 °C⁄min (20 °F⁄min) has been used satisfactorily. During the test keep the temperature gradient over the area of the beam near the strain gages small. Measure this temperature gradient by the difference between two temperature sensors, one mounted near the clamping fixture and the other mounted an equal distance the other side of the strain gage installation. The temperature difference between these points should not exceed 3 °C (5 °F) or 1 % of the beam temperature. The power to the heaters in the clamping fixture can be adjusted to minimize this temperature difference. Calculate the temperature coefficient of gage factor.

10.5.2.9 Since both the length and thickness of the beam change with temperature, the recorded output should be corrected for the resulting change in strain. Applying this correction gives: