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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 terms "strain gage" and "gage" are to be understood to represent the longer, but more accurate, "metallic bonded resistance strain gages."

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 parameters:

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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 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 gage and strain to which it is subjected. Accuracy of strain gage data can be no better than the precision 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 gage output from structural loading. To correct for these effects, thermal output must be determined from gages bonded to specimens of the same material on which the tests are to run, often to the test structure itself.

1.4 Bonded resistance strain gages differ from extensometers in that they measure average unit elongation ($\Delta L/L$) over a nominal gage length rather than total elongation between definite gauge points. Practice E83 is not applicable to these 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, 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, 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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

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 herein has 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 of Terms Specific to This Standard:*

3.2.1 *batch*—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).

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

3.2.3 *error-strain gage*— 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.

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

3.2.4 *gage factor*— the ratio between the unit change in strain gage resistance due to strain and the causing strain.

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

$$K = \frac{\dfrac{R - R_o}{R_o}}{\dfrac{L - L_o}{L_o}} = \frac{\dfrac{\Delta R}{R_o}}{\varepsilon} \tag{1}$$

where:

K = the gage factor,

R = the strain gage resistance at test strain,

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

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

L_o = 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 $\frac{L - L_o}{L_o}$.

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

3.2.5.1 *Discussion*—An approximation of this 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.

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

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

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

3.2.8.1 *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.

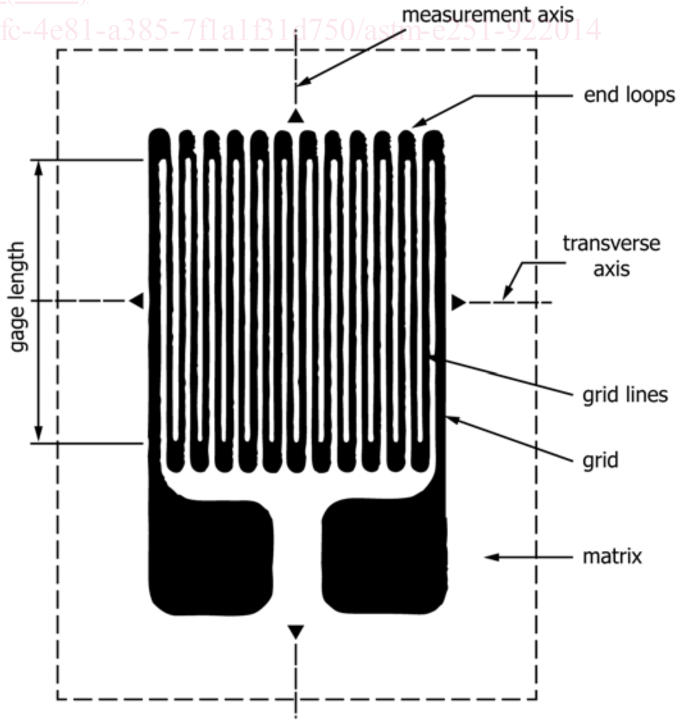

FIG. 1 Typical Strain Gage

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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

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

3.2.10 *strain gage, metallic, resistive, bonded* (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.

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

$$R = R_o(1+\varepsilon K) \qquad (2)$$

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 strain-sensitive axis of the gage, and
K = a proportionality factor (see gage factor).

3.2.11 *strain, linear*—the unit elongation induced in a specimen either by a stress field (mechanical strain) or by a temperature change (thermal expansion).

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

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

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.

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

3.2.14 *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.

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

3.2.16 *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 gage) to the unit resistance change of a similar gage mounted parallel to the same strain field (longitudinal gage).

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

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 parameters 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 parameters of strain gages require mechanical testing that is destructive. Since test 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 nondestructive and can be made for each gage.

4.3 Properly designed and manufactured strain gages, whose properties 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 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 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 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 strain gage installation and verification thereof can be found in Guide E1237.

6. Hazards

6.1 In the specimen surface cleaning, 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 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 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 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 gage resistance is matched by an equal unit resistance change in a calibrated arm of the 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 Wheatstone bridge 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:

$$E_o = E_i[\Delta R/(4R_o+2\Delta R)] \tag{4}$$

where:

E_i = input voltage,
R_o = resistance required for initial bridge balance, and
ΔR = difference between the instantaneous 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 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 resistance strain gage. These instruments use various types of excitation and read-out systems. Such 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 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 ppm of the total resistance, whichever is greater. The effects of the following factors should be determined: thermal emf's within the bridge circuit and within the leads to the gage; reactive changes within the bridge and lead 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 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 gages combined in sets shall fall within the stated nominal resistance value and uncertainty from all sources.

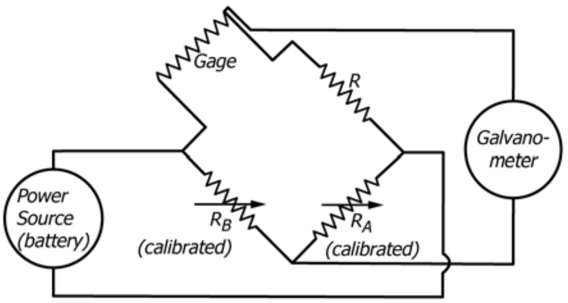

FIG. 2 Wheatstone-Bridge Circuit

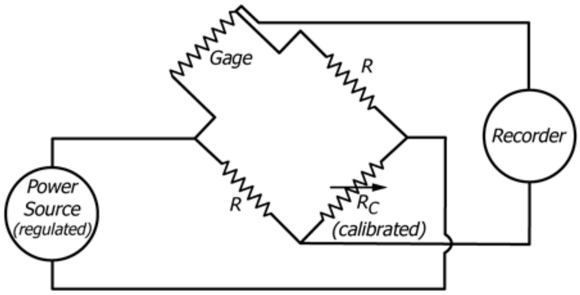

FIG. 3 Unbalanced-Bridge Circuit

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 gage must be held in contact with a substantially flat surface using a suitable pressing device. Care must be exercised to assure that the probes used to contact the tabs of gages without leads do not damage foil areas.

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

9.1 These test methods describe procedures for the determination of the gage factor of bonded resistance strain gages. It is suggested that gage factor values be obtained for at least five 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 gages being tested to a calibrated reference gage may be used if it is shown that equal accuracy is obtained.

9.3 Determination of the gage factor K requires mechanical equipment 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, ± 1000 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 gage stations shall differ by no more than ± 0.5 % of the mean value and the strain within a 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 loading cycle should nominally be:

$$\begin{gathered} 0, +1100\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}), -1100\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}), \\ +1100\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}), -1100\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}), \\ +1100\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}), -1100\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}), \\ 0, +1000\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}),\ 0, -1000\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}),\ 0. \end{gathered} \tag{5}$$

If possible, one half of the sample (group of 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:

$$\begin{gathered} 0, +1100\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}),\ 0, +1100\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}) \\ 0, +1100\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}),\ 0, +1000\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}),\ 0 \end{gathered} \tag{6}$$

for one half of the sample and strain cycles of:

$$\begin{gathered} 0, -1100\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}),\ 0, -1100\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}) \\ 0, -1100\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}),\ 0, -1000\ \mu\mathrm{m/m}\ (\mu\mathrm{in./in.}),\ 0 \end{gathered} \tag{7}$$

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 and + 1000 μm/m (μin./in.) and 0 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 utilizes a strain on the surface of a test bar produced by loading it as a constant moment beam by the application of dead-weight loads.

9.6.1.2 *Mechanical System*—A typical mechanical system 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 by 25 by 760 mm (0.75 by 1 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 system. Such a calibration is made by measuring with a Class A extensometer (see Practice E83) the actual strain produced on the surface of the beam when it is loaded. Measurements shall be made with the extensometer 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

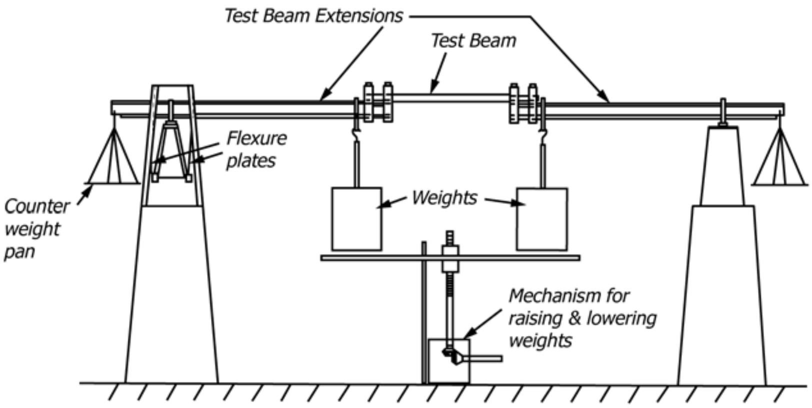

FIG. 4 Constant Bending-Moment Beam Method for Gage-Factor Determination

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, or with a carefully selected, permanently mounted resistance strain gage that has been calibrated by spanning with a Class A extensometer. The response of this reference gage shall be verified periodically to assure compliance with specifications using a Class A extensometer. The beam shall be completely recalibrated after 50 applications or 6 months, whichever comes last.

9.6.1.4 *Procedures*—Mount test 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 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 gages in the loading system and test environment. After temperature equilibrium has been attained, follow the loading sequence 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 loading cycle. Obtain compression loads by mounting the beam with the gaged surface up. Obtain tension loads by mounting the beam with the 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 *Mechanical System*—A typical mechanical system 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 strain gages, for use as reference standards, 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 gages, using the best current techniques to ensure bonding integrity and long-term stability. These reference gages shall be individually calibrated to determine their gage factor by placing a Class A extensometer (Practice E83) so as to span the gage, bending the beam by means of the deflecting apparatus, and measuring the resulting change in gage resistance and strain. Readings shall be taken for the strain cycles stipulated in 9.5 and the gage factor computed (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 reference gage, the gage factor for compression strains

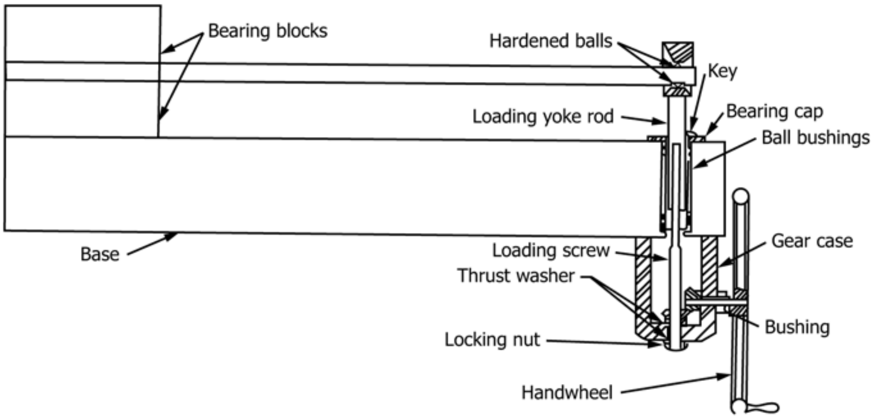

FIG. 5 Constant-Stress Cantilever Beam Method for Gage-Factor Determination

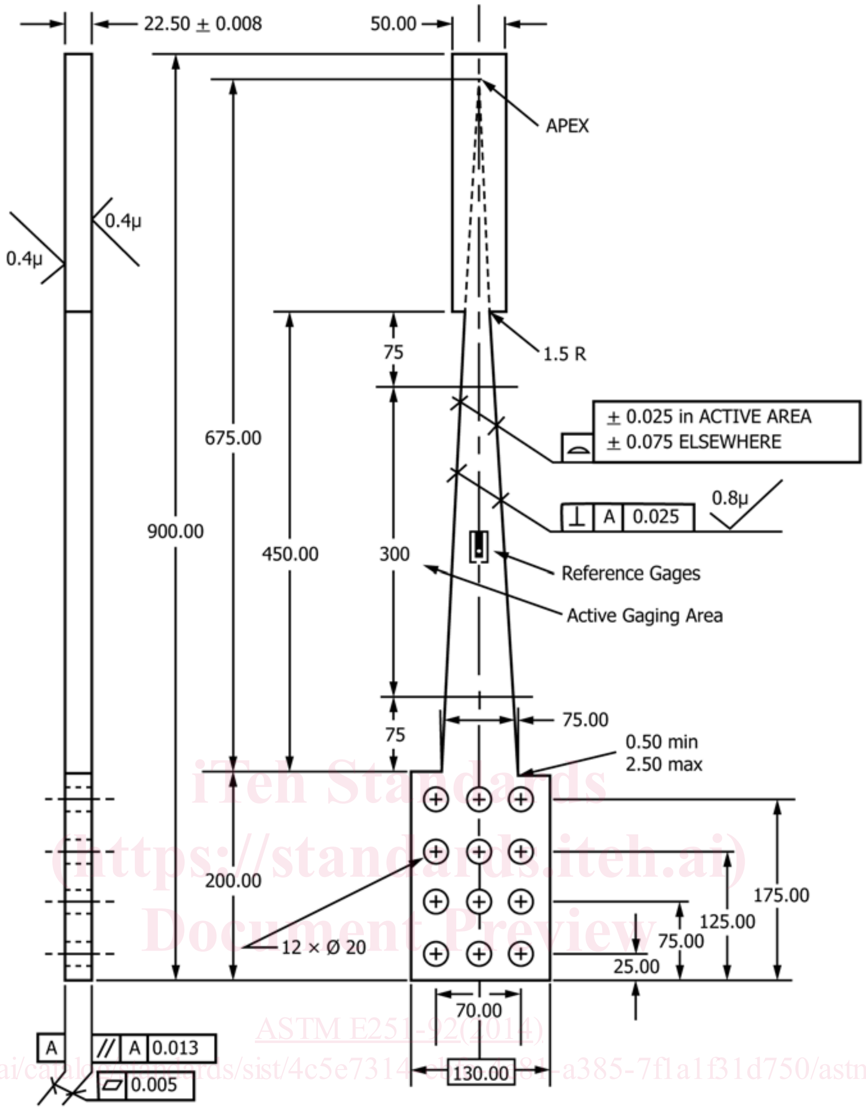

FIG. 6 Constant Stress Cantilever Beam

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 Beam*—The constant-stress area of the beam shall be explored with a Class A extensometer to determine the area where the strain is the same as that experienced by the reference 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 reference gage do not exceed 10 µm/m (µin./in.) at a strain of 1000 µm/m (µin./in.) are acceptable for testing gages. The beam shall be verified after each 50 uses or 6 months, whichever comes last.

9.6.2.4 *Procedure*—Install the 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 active axes of the gages shall be parallel to the center line of the beam. A selector switch may be used to connect several 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 loading schedule 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 loads to the bar.

9.6.3.2 *Mechanical System*—A typical mechanical system 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 load to the specimen. The horizontal position of the bar is convenient for mounting the reference extensometer, but it is not necessary. The load may be applied by hydraulic, mechanical, or other means, but care must be taken to prevent any twisting or bending of the bar. Twisting in the mechanical system of Fig. 7 is prevented by the torque arm. Fig. 8 shows a test bar that has been used

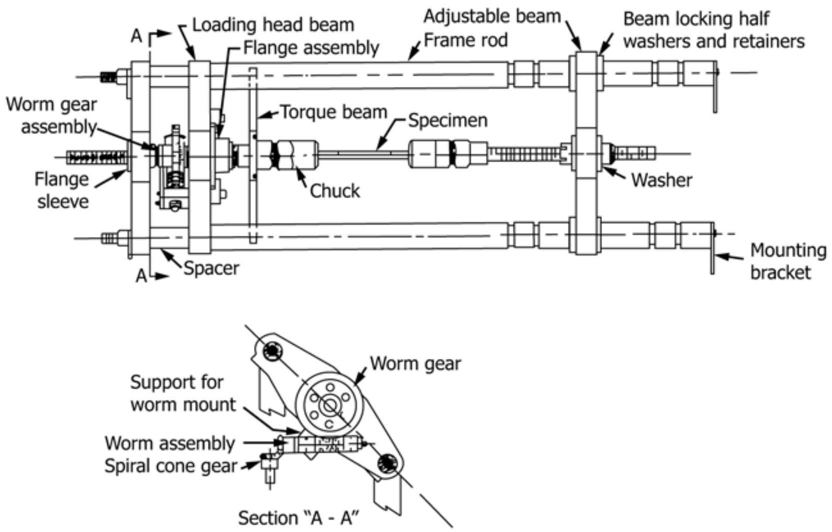

FIG. 7 Testing Machine for Gage-Factor Measurements

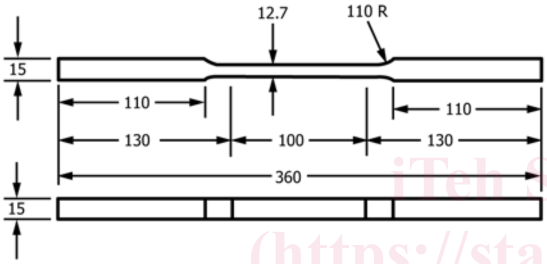

FIG. 8 Test Bar for Gage Factor Test

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 extensometer shall be mounted so as to span the gage. The extensometer should have a gauge length as near that of the gage as possible in order to minimize the effect of nonuniform strain along the length of the bar.

9.6.3.3 *Verification*—Since the calibration strain is measured during each test, no calibration of the system 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 gage by any appropriate technique so that the center of its sensitive portion coincides with the center line of the bar. Mount the bar in the loading device taking care to avoid bending or loading of the bar. Connect the gage electrically to the resistance-measuring circuit, and mount the reference extensometer so as to span the gage. Follow the loading cycle in 9.5 (plus or minus strains only) except that preload, not exceeding 5 % of the maximum load, may be applied to align the bar in the machine, to remove backlash, etc. Take readings simultaneously from the electrical circuit and the extensometer. Calculate gage factors. Repeat for strains in the opposite direction.

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

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

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 gage in tension, the other in compression) by mounting two gages opposite each other and connecting them in a half bridge. This practice helps to eliminate errors from drift and leadwires. If gages are tested individually, a three-lead wiring arrangement 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 loading device, and a furnace for producing the temperatures needed. It must be possible to adjust the strain in the specimen to mean values of 0 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 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 gage stations shall differ by no more than ± 2 % of the actual strain and the strain within a 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 bonded resistance 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 making use of measurements made under static strain and static temperature conditions, and the other test method making use of 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] utilizes 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 Typical equipment used to produce the strain and a typical test beam are shown in Fig. 9. The 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 beam) of the beam. The frame is designed to hold the base of the beam rigidly and provide a base for the sliding-stepped block. The rider on the beam is attached at the apex of the angle formed by the beam sides. The frame must be much more rigid than the beam to prevent errors due to bending of the frame. The stepped block can provide several deflection steps, 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 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 beam and the rider. To avoid differential expansion problems, all parts of the test rig, and the specimen, should be made from the same material, selected to assert 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 gage or 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 gage(s) as practicable and at each end of the constant-stress area. Mount the beam in the frame, and connect the gages electrically to the read-out instruments.

10.5.1.5 With the loading apparatus in the furnace or cryostat and the 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 gage output. Then move the sliding block so as to increase the beam deflection and take 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 gage output due to strain for each step as the average of the differences from the value at the lowest step for all loading cycles.

10.5.1.6 Bring the temperature of the test fixture and beam 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, compute the temperature coefficient of gage factor (see 3.2.4).

10.5.2 *Dynamic Test Method:*

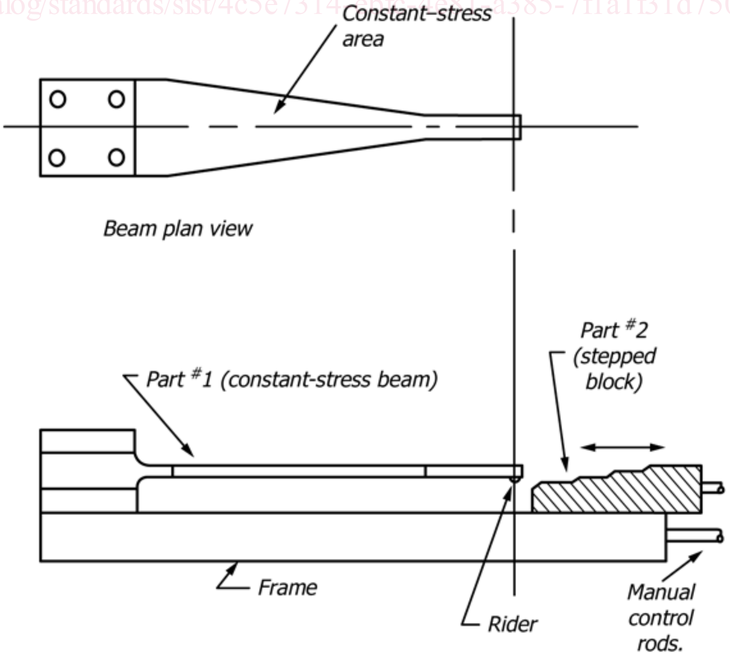

FIG. 9 Apparatus for Static Determination of Gage-Factor Variation Versus Temperature

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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.

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 resistance 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 gages,
ε = strain to which the gages are subjected, and
N = number of active gages.

If such a bridge circuit is connected to a constant d-c voltage source and the 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 radient 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 Equipment 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 to 12 V to the 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 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 gage circuit must be constant during the test.

10.5.2.7 Mount two resistance 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 gages as adjacent arms of a bridge circuit, the other arms being stable resistors of approximately the same resistance as the gages and chosen so that the bridge circuit is nearly balanced when the

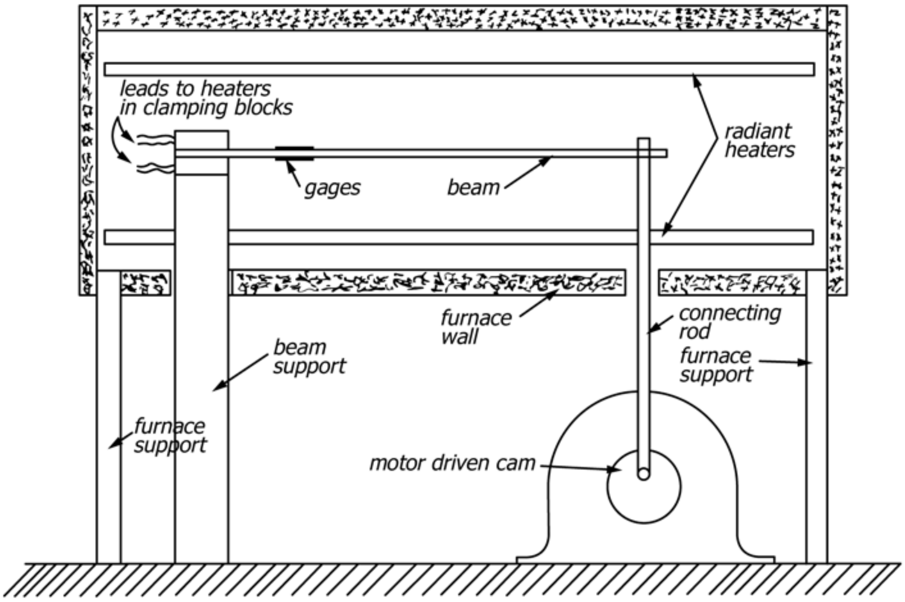

FIG. 10 Dynamic Apparatus for Determining Variation of Gage Factor