Designation: E251 – 92(Reapproved 2009)

Standard Test Methods for Performance Characteristics of Metallic Bonded Resistance Strain Gauges[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 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 Gauges.' 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 gauge" and "gauge" are to be understood to represent the longer, but more accurate, "metallic bonded resistance strain gauges."

1. Scope

1.1 The purpose of this standard is to provide uniform test methods for the determination of strain gauge performance characteristics. Suggested testing equipment designs are included.

1.2 Test Methods E251 describes methods and procedures for determining five strain gauge parameters:

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1.3 Strain gauges 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 gauge 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 gauge resistance from a known reference value.

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

1.3.3 Changes in gauge 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 gauge's response to strains perpendicular to its measurement axis. Although transverse sensitivity is usually much less than 10 % of the gauge 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 gauge to temperature changes. Thermal output is an additive (not multiplicative) error. Therefore, it can often be much larger than the gauge output from structural loading. To correct for these effects, thermal output must be determined from gauges 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 gauges differ from extensometers in that they measure average unit elongation (ΔL/L) over a nominal gauge length rather than total elongation between definite gauge points. Practice E83 is not applicable to these gauges.

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

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

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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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installed normally cannot be reinstalled in another location. Therefore, gauge 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 *OIML International Recommendation No. 62:' Performance Characteristics of Metallic Resistance Strain Gauges*

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 The vocabulary included herein has been chosen so that specialized terms in the strain gauge field will be clearly defined. A typical strain gauge nomenclature is provided in Appendix X1.

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

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

3.1.1.3 *error-strain gauge*—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 gauge output. Errors attributable to measuring systems are excluded.

3.1.1.4 *gauge factor*—the ratio between the unit change in strain gauge resistance due to strain and the causing strain. The gauge factor is dimensionless and is expressed as follows:

$$K = \frac{R - R_o}{R_o} / \frac{L - L_o}{L_o} = \frac{\Delta R}{R_o} / \varepsilon \qquad (1)$$

where:

K = the gauge factor,

R = the strain gauge resistance at test strain,

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

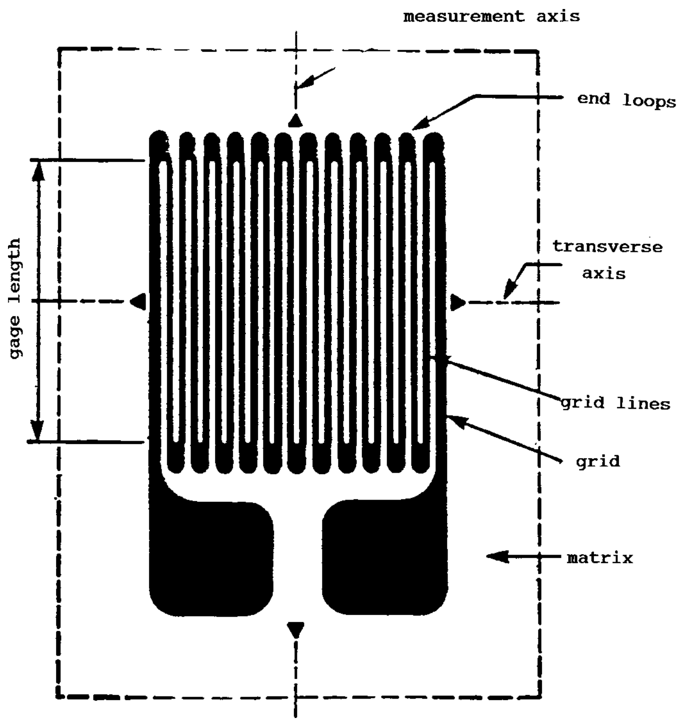

FIG. 1 Typical Strain Gauge

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

L_o = the test structure length under the strain gauge at zero or reference strain,

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

ε = the mechanical strain $L - L_o / L_o$.

3.1.1.5 *gauge length* (see Fig. 1)—the length of the strain sensitive section of a strain gauge in the measurement axis direction. An approximation of this length is the distance between the inside of the strain gauge end loops. Since the true gauge length is not known, gauge length may be measured by other geometries (such as the outside of the end loops) providing that the deviation is defined.

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

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

3.1.1.8 *matrix* (see Fig. 1)—an electrically nonconductive layer of material used to support a strain gauge grid. The two main functions of a matrix are to act as an aid for bonding the strain gauge to a structure and as an electrically insulating layer in cases where the structure is electrically conductive.

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

3.1.1.10 *strain gauge, 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

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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.

vary as the surface to which it is attached is deformed. These test methods apply to gauges where the instantaneous gauge 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 strain-sensitive axis of the gauge, and

K = a proportionality factor (see gauge factor).

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

3.1.1.12 *temperature coefficient of gauge factor*—the ratio of the unit variation of gauge 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 gauge factor at test temperature, and

K_{t0} = the gauge factor at reference temperature.

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

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

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

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

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

4. Significance and Use

4.1 Strain gauges are the most widely used devices for the determination of materials, properties and for analyzing stresses in structures. However, performance parameters of strain gauges 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 gauges if they are to be used with acceptable accuracy of measurement.

4.2 Most performance parameters of strain gauges require mechanical testing that is destructive. Since test gauges 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 gauge.

4.3 Properly designed and manufactured strain gauges, 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 gauges cannot be calibrated. If calibration and traceability to a standard are required, strain gauges should not be employed.

4.4 To be used, strain gauges must be bonded to a structure. Good results depend heavily on the materials used to clean the bonding surface, to bond the gauge, 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 gauges. 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 gauge 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 In order to assure that strain gauge test data are within a defined accuracy, the gauges must be properly bonded and protected with acceptable materials. It is normally simple to ascertain that strain gauges are not performing properly. The most common symptom is instability with time or temperature change. If strain gauges 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 gauge installation and verification thereof can be found in Guide E1237.

6. Hazards

6.1 In the specimen surface cleaning, gauge bonding, and protection steps of strain gauge 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 gauge 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

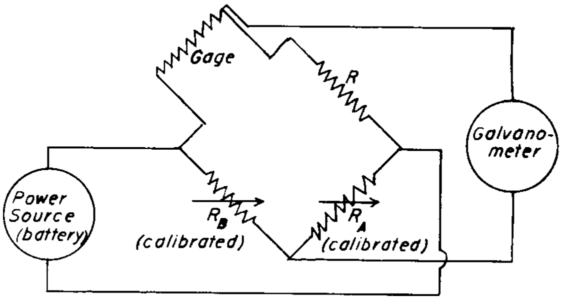

FIG. 2 Wheatstone-Bridge Circuit

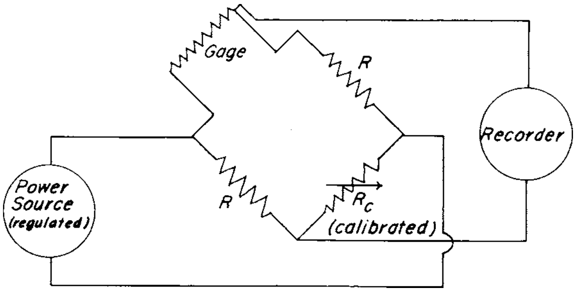

FIG. 3 Unbalanced-Bridge Circuit

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 gauge 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 gauge 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:

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

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 gauge. 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 gauge. 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 gauge 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 gauge; reactive changes within the bridge and lead circuits; initial bridge unbalance; and, battery conditions or power line fluctuations.

7.3 *Strain gauge Attachment:*

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

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

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

8.2 The unpackaged strain gauges 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 gauge 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 gauge 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 gauge on the resistance measurement exceeds ± 0.1 % of the actual value, the gauge 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 gauges without leads do not damage foil areas.

9. Test Methods for Determining the gauge Factor of Resistance Strain gauges at a Reference Temperature

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

9.2 For gauge factor determination, the uncertainty of the relative resistance change measurement shall not exceed ± 2 µohm/ohm 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 gauges being tested to a calibrated reference gauge may be used if it is shown that equal accuracy is obtained.

9.3 Determination of the gauge 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 gauge stations shall differ by no more than± 0.5 % of the mean value and the strain within a gauge 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 gauge factor.

9.4 To the extent possible, test specimens with attached strain gauges for tests of the gauge 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 gauge factor, the strain gauges 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:

$$0, +1100\ \mu\text{m/m}\ (\mu\text{in./in.}), -1100\ \mu\text{m/m}\ (\mu\text{in./in.}), \tag{5}$$

$$+1100\ \mu\text{m/m}\ (\mu\text{in./in.}), -1100\ \mu\text{m/m}\ (\mu\text{in./in.}),$$

$$+1100\ \mu\text{m/m}\ (\mu\text{in./in.}), -1100\ \mu\text{m/m}\ (\mu\text{in./in.}),$$

$$0, +1000\ \mu\text{m/m}\ (\mu\text{in./in.}), 0, -1000\ \mu\text{m/m}\ (\mu\text{in./in.}), 0.$$

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

$$0, +1100\ \mu\text{m/m}\ (\mu\text{in./in.}), 0, +1100\ \mu\text{m/m}\ (\mu\text{in./in.}) \tag{6}$$

$$0, +1100\ \mu\text{m/m}\ (\mu\text{in./in.}), 0, +1000\ \mu\text{m/m}\ (\mu\text{in./in.}), 0$$

for one half of the sample and strain cycles of:

$$0, -1100\ \mu\text{m/m}\ (\mu\text{in./in.}), 0, -1100\ \mu\text{m/m}\ (\mu\text{in./in.}) \tag{7}$$

$$0, -1100\ \mu\text{m/m}\ (\mu\text{in./in.}), 0, -1000\ \mu\text{m/m}\ (\mu\text{in./in.}), 0$$

for the other half of the sample.

The gauge 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 gauges 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 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 gauge that has been calibrated by spanning with a Class A extensometer. The response of this reference gauge shall be verified periodically to assure compliance with specifications using a Class A

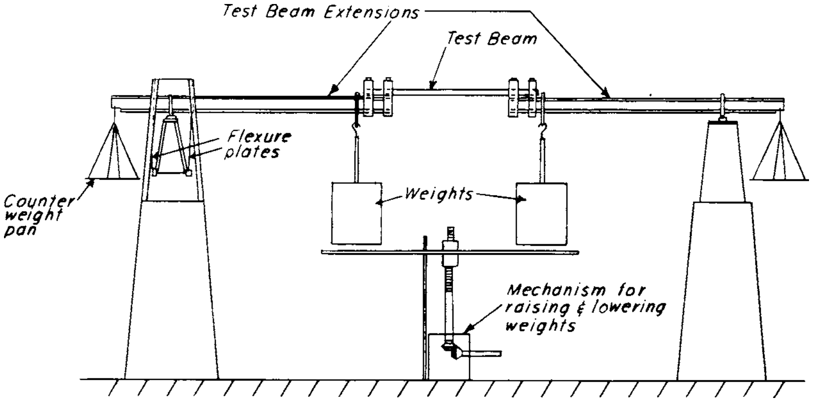

FIG. 4 Constant Bending-Moment Beam Method for Gauge-Factor Determination

extensometer. The beam shall be completely recalibrated after 50 applications or 6 months, whichever comes last.

9.6.1.4 *Procedures*—Mount test gauges 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 gauges 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 gauges 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 gauges 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 gauged surface up. Obtain tension loads by mounting the beam with the gauged surface down.

9.6.1.6 Calculate the gauge 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 gauges, 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 gauges, using the best current techniques to ensure bonding integrity and long-time stability. These references gauges shall be individually calibrated to determine their gauge factor by placing a Class A extensometer (Practice E83) so as to span the gauge, bending the beam by means of the deflecting apparatus, and measuring the resulting change in gauge resistance and strain. Readings shall be taken for the strain cycles stipulated in 9.5 and the gauge 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 gauge, the gauge factor for compression strains may differ from the gauge 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 gauges 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 gauges. 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 gauge do not exceed 10 µm/m (µin./in.) at a strain of 1000 µm/m (µin./in.) are acceptable for testing gauges. The beam shall be verified after each 50 uses or 6 months, whichever comes last.

9.6.2.4 *Procedure*—Install the gauges 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 gauges shall be parallel to the center line of the beam. A selector switch may be used to connect several gauges 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 gauge 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 successfully for both tension and compression loading. The strain gauge under test shall be mounted at the center of the

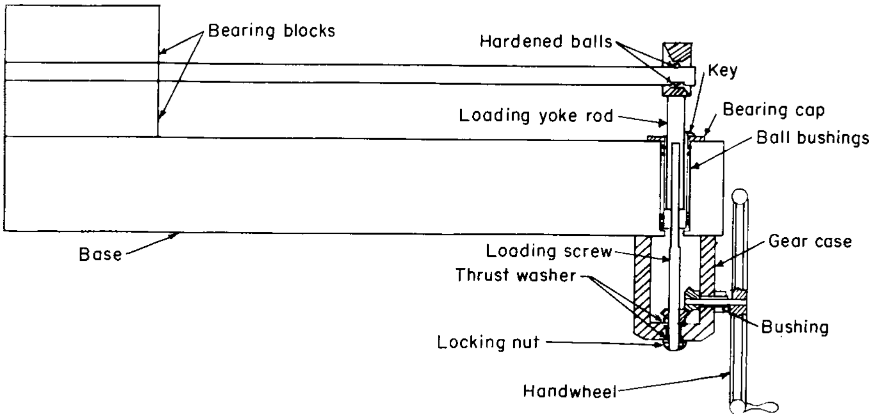

FIG. 5 Constant-Stress Cantilever Beam Method for Gauge-Factor Determination

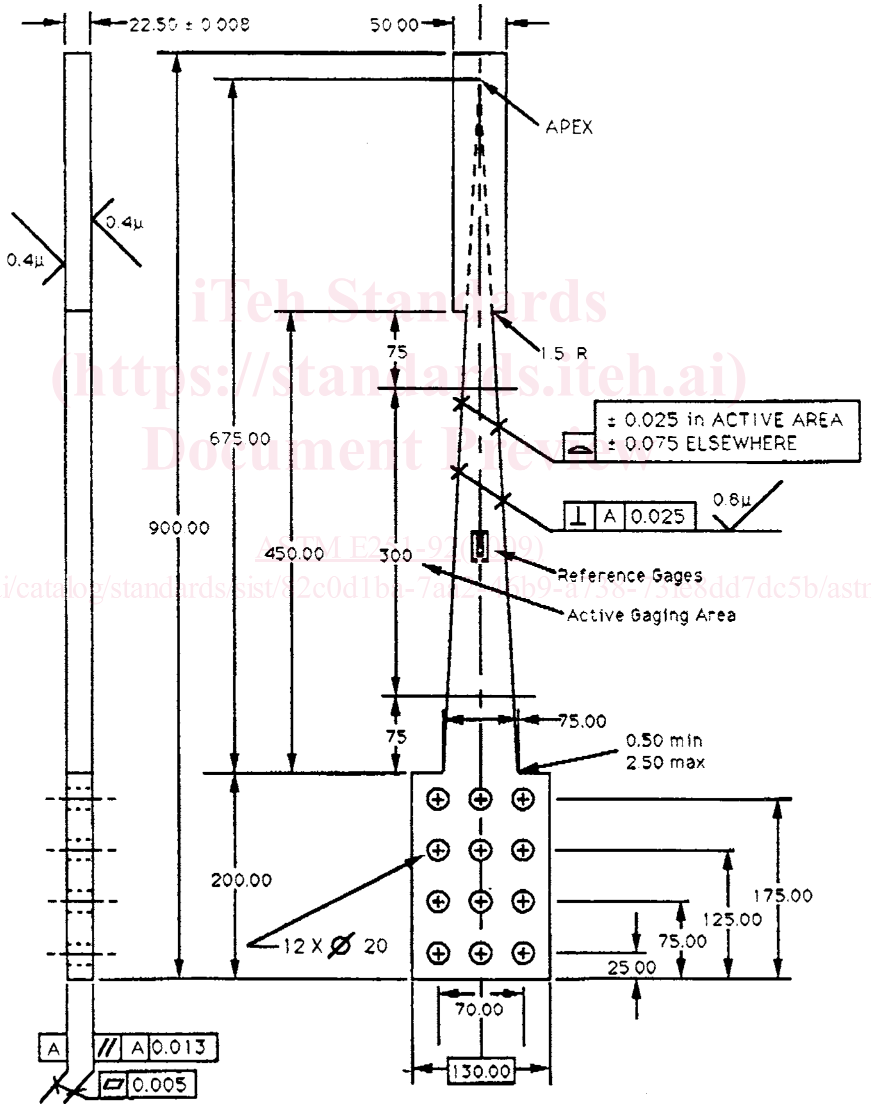

FIG. 6 Constant Stress Cantilever Beam

reduced section; and a Class A extensometer shall be mounted so as to span the gauge. The extensometer should have a gauge length as near that of the gauge 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

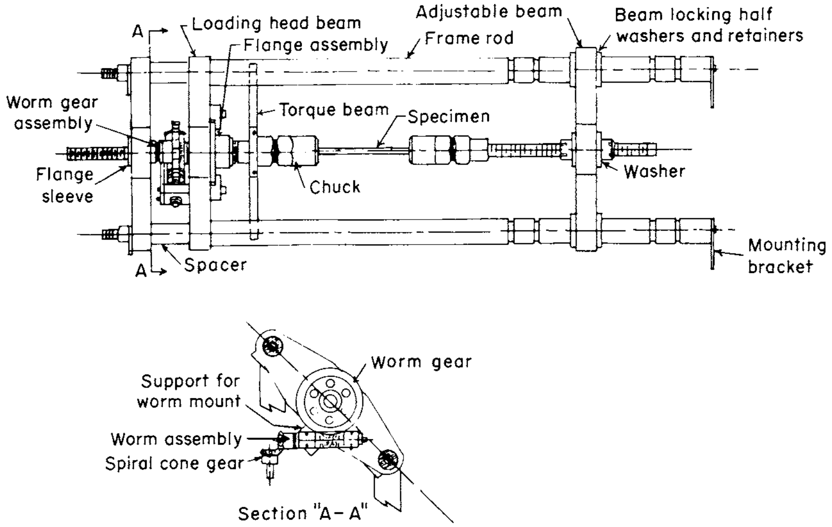

FIG. 7 Testing Machine for Gauge-Factor Measurements

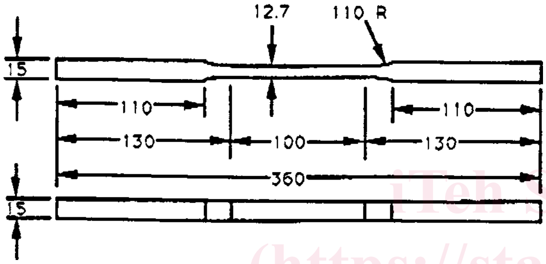

FIG. 8 Test Bar for Gauge Factor Test

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 gauge 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 gauge electrically to the resistance-measuring circuit, and mount the reference extensometer so as to span the gauge. 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 gauge factors. Repeat for strains in the opposite direction.

10. Test Methods for Determining the Temperature Coefficient of gauge Factor of Resistance Strain gauges

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

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

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

10.4 To determine the temperature coefficient of gauge 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 gauge stations shall differ by no more than ± 2 % of the actual strain and the strain within a gauge station shall vary by no more than ± 2 % of the nominal value.

10.5 Two test methods for determining the temperature coefficient of gauge factor of bonded resistance strain gauges 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[3] utilizes a constant-stress cantilever beam that is forcibly deflected

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

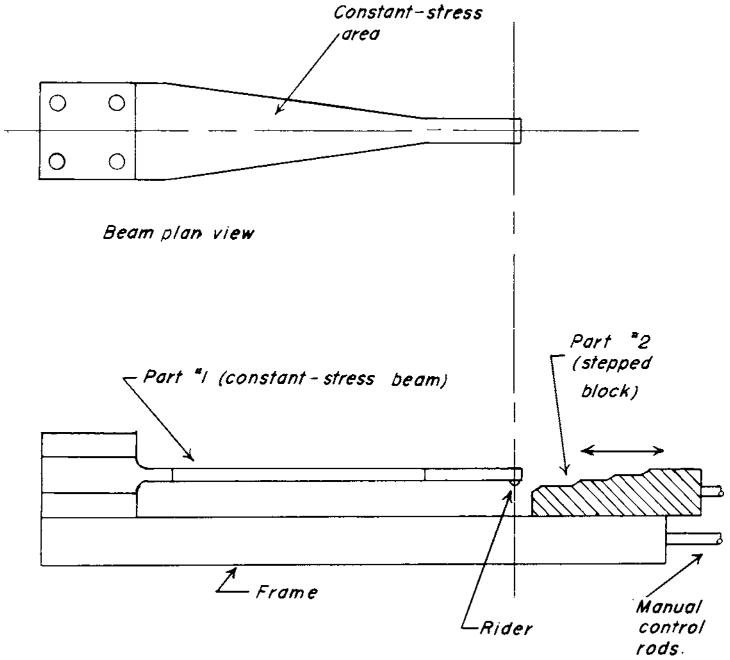

FIG. 9 Apparatus for Static Determination of Gauge-Factor Variation Versus Temperature

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 gauge or gauges 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 gauge(s) as practicable and at each end of the constant-stress area. Mount the beam in the frame, and connect the gauges electrically to the read-out instruments.

10.5.1.5 With the loading apparatus in the furnace or cryostat and the gauge 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 gauge output. Then move the sliding block so as to increase the beam deflection and take gauge 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 gauge 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 gauge factor (see section 3.12).

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 resistance strain gauges:

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

where:

E_0 = output voltage from bridge circuit,

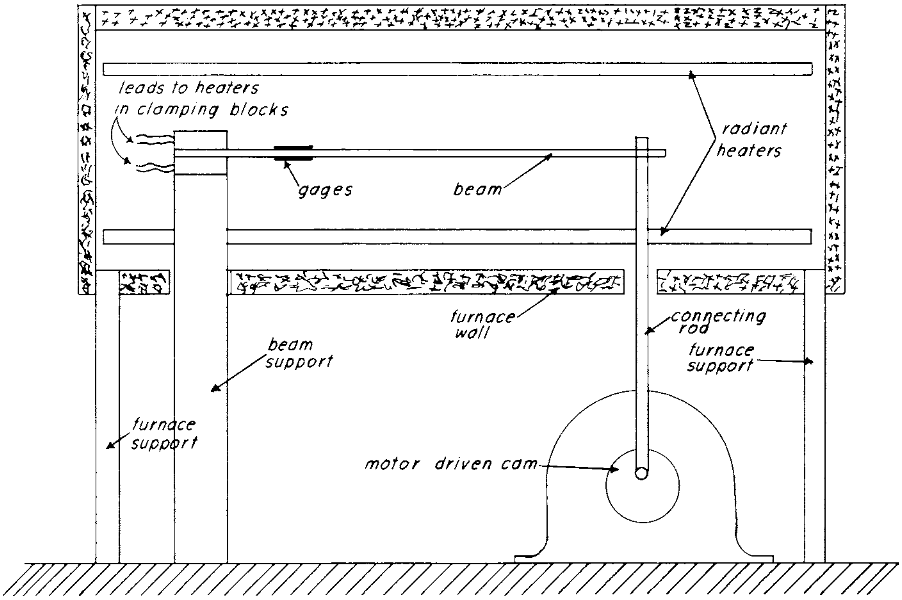

FIG. 10 Dynamic Apparatus for Determining Variation of Gauge Factor

E_1 = input voltage to bridge circuit,
K = gauge factor of the gauges,
ε = strain to which the gauges are subjected, and
N = number of active gauges.

If such a bridge circuit is connected to a constant d-c voltage source and the gauges are subjected to a sinusoidal strain of constant amplitude, the change in the alternating output voltage will be a measure of the change of gauge 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 gauge 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 gauge 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 gauge 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 gauge circuit must be constant during the test.

10.5.2.7 Mount two resistance strain gauges 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 gauges as adjacent arms of a bridge circuit, the other arms being stable resistors of approximately the same resistance as the gauges 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 suppressing voltage to give zero output to the recorder. Obtain the recorder sensitivity in terms of change of gauge-circuit output voltage by varying the input voltage to the gauge circuit in known steps. The change of output voltage due