**Designation: ~~E251 – 92 (Reapproved 2009)~~ E251 – 92 (Reapproved 2014)**

# Standard Test Methods for
# Performance Characteristics of Metallic Bonded Resistance Strain ~~Gauges~~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 ($\varepsilon$) 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~~"Performance Characteristics of Metallic Resistance Strain ~~Gauges.'~~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 ~~gauge"~~gage" and ~~"gauge"~~"gage" are to be understood to represent the longer, but more accurate, "metallic bonded resistance strain ~~gauges."~~gages."

## 1. Scope

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

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

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

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

1.3.3 Changes in ~~gauge~~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 ~~gauge's~~gage's response to strains perpendicular to its measurement axis. Although transverse sensitivity is usually much less than 10 % of the ~~gauge~~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 ~~gauge~~gage to temperature changes. Thermal output is an additive (not multiplicative) error. Therefore, it can often be much larger than the ~~gauge~~gage output from structural loading. To correct for these effects, thermal output must be determined from ~~gauges~~gages bonded to specimens of the same material on which the tests are to ~~run;~~run, often to the test structure itself.

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1.4 Bonded resistance strain ~~gauges~~gages differ from extensometers in that they measure average unit elongation (ΔL/L) over a nominal ~~gauge~~gage length rather than total elongation between definite gauge points. Practice E83 is not applicable to these ~~gauges.~~gages.

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

1.6 ~~Strain gauges~~strain gages are part of a complex system that includes structure, adhesive, ~~gauge, leadwires,~~ gage, lead wires, instrumentation, and (often) environmental protection. As a result, many things affect the performance of strain ~~gauges,~~gages, including user technique. A further complication is that strain ~~gauges~~gages once installed normally cannot be reinstalled in another location. Therefore, ~~gauge~~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 ~~*OIML International Recommendation No. 62:' Performance Characteristics of Metallic Resistance Strain Gauges*~~*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:*
~~3.1.1 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:~~

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

~~where:~~
~~$K$ = the gauge factor,~~
~~$R$ = the strain gauge resistance at test strain,~~
~~$R_o$ = the strain gauge resistance at zero or reference strain,~~
~~$L$ = 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,~~
~~$\Delta R$ = the change in strain gauge resistance when strain is changed from zero (or reference strain to test strain),~~
~~$\varepsilon$ = 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.~~

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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
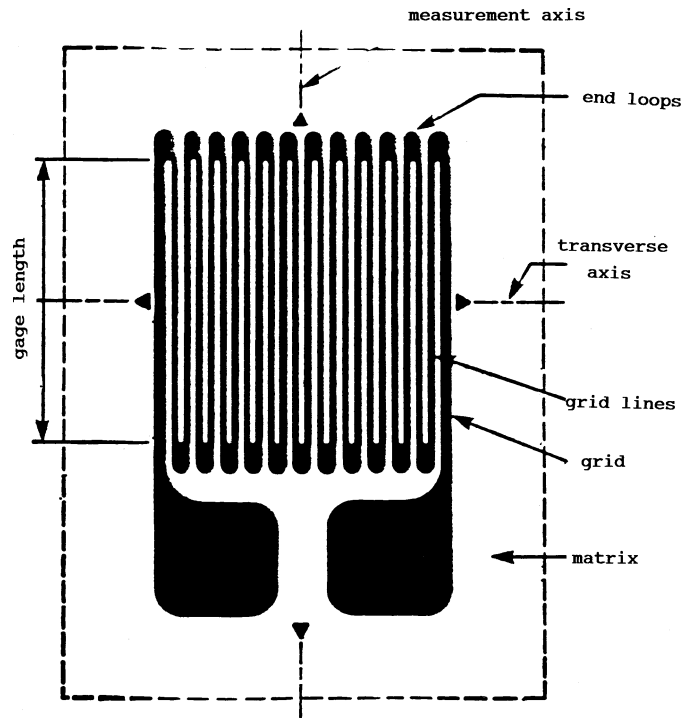
FIG. 1 Typical Strain ~~Gauge~~Gage

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 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),
$\varepsilon$ = 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.

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:

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

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, |
| $\Delta R$ | = | the change in strain gage resistance when strain is changed from zero (or reference strain to test strain), |
| $\varepsilon$ | = | 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.

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:

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

where:
$R_o$ = element resistance at reference strain and temperature levels (frequently initial test or balanced circuit conditions),
$\varepsilon$ = 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:

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

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.

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

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

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

4.4 To be used, strain ~~gauges~~gages must be bonded to a structure. Good results depend heavily on the materials used to clean the bonding surface, to bond the ~~gauge,~~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 ~~gauges.~~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 ~~gauge~~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.
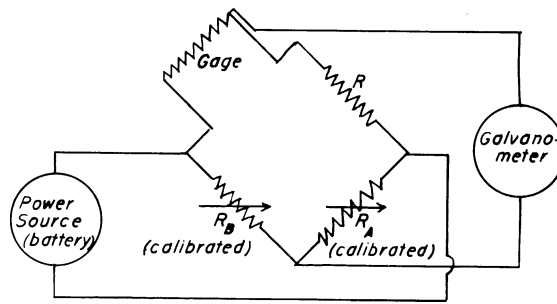
FIG. 2 Wheatstone-Bridge Circuit

## 5. Interferences

5.1 ~~In order to~~ To assure that strain ~~gauge~~gage test data are within a defined accuracy, the ~~gauges~~gages must be properly bonded and protected with acceptable materials. It is normally simple to ascertain that strain ~~gauges~~gages are not performing properly. The most common symptom is instability with time or temperature change. If strain ~~gauges~~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 ~~gauge~~gage installation and verification thereof can be found in Guide E1237.

## 6. Hazards

6.1 In the specimen surface cleaning, ~~gauge~~gage bonding, and protection steps of strain ~~gauge~~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 ~~gauge~~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 ~~gauge~~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 ~~gauge~~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
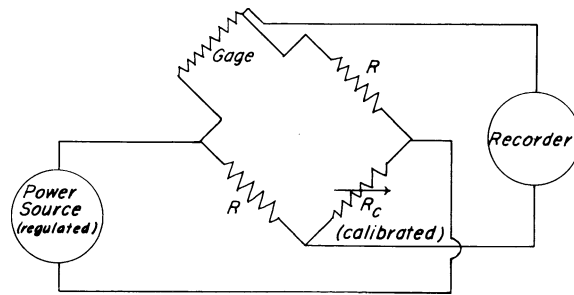$\Delta R$ = difference between the instantaneous resistance and $R_o$.

**FIG. 3 Unbalanced-Bridge Circuit**

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

7.3 *Strain ~~gauge~~Gage Attachment:*
7.3.1 The attachment conditions shall correspond exactly to the instructions published by the ~~gauge~~gage manufacturer.

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

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

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

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

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

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

9.3 Determination of the ~~gauge~~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 ~~gauge~~gage stations shall differ by no more ~~than±~~than ± 0.5 % of the mean value and the strain within a ~~gauge~~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 ~~gauge~~gage factor.
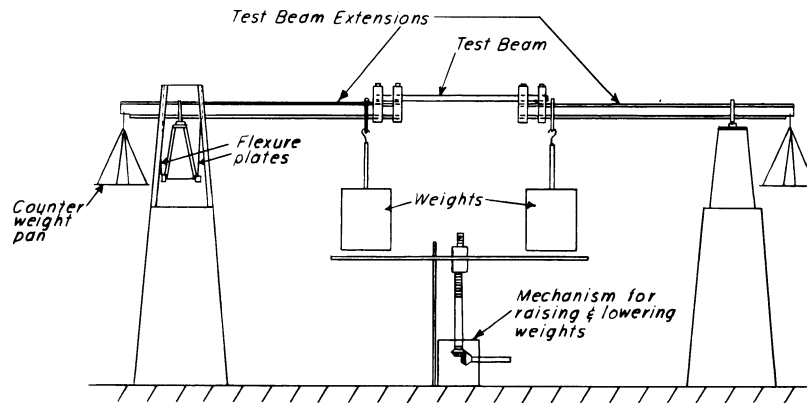
FIG. 4 Constant Bending-Moment Beam Method for ~~Gauge-Factor~~Gage-Factor Determination

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

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

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

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

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

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

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

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

for one half of the sample and strain cycles of:

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

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

for the other half of the sample.
The ~~gauge~~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 ~~gauges~~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
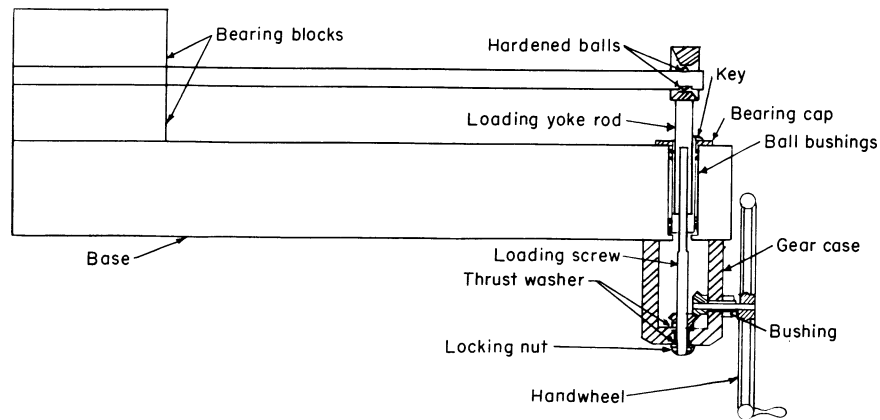
**FIG. 5 Constant-Stress Cantilever Beam Method for ~~Gauge-Factor~~Gage-Factor Determination**

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~~gage that has been calibrated by spanning with a Class A extensometer. The response of this reference ~~gauge~~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 ~~gauges~~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 ~~gauges~~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 ~~gauges~~gages in the loading system and test environment. After temperature equilibrium has been attained, follow the loading sequence in 9.5. Take readings from the strain ~~gauges~~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 ~~gauged~~gaged surface up. Obtain tension loads by mounting the beam with the ~~gauged~~gaged surface down.

9.6.1.6 Calculate the ~~gauge~~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 ~~gauges,~~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 ~~gauges,~~gages, using the best current techniques to ensure bonding integrity and ~~long-time~~long-term stability. These ~~references gauges~~reference gages shall be individually calibrated to determine their ~~gauge~~gage factor by placing a Class A extensometer (Practice E83) so as to span the ~~gauge,~~gage, bending the beam by means of the deflecting apparatus, and measuring the resulting change in ~~gauge~~gage resistance and strain. Readings shall be taken for the strain cycles stipulated in 9.5 and the ~~gauge~~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.~~9:1.

Note 3—For the reference ~~gauge,~~gage, the ~~gauge~~gage factor for compression strains may differ from the ~~gauge~~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 ~~gauges~~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 ~~gauges.~~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 ~~gauge~~gage do not exceed 10 μm/m (μin./in.) at a strain of 1000 μm/m (μin./in.) are acceptable for testing ~~gauges.~~gages. The beam shall be verified after each 50 uses or 6 months, whichever comes last.

9.6.2.4 *Procedure*—Install the ~~gauges~~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 ~~gauges~~gages shall be parallel to the center
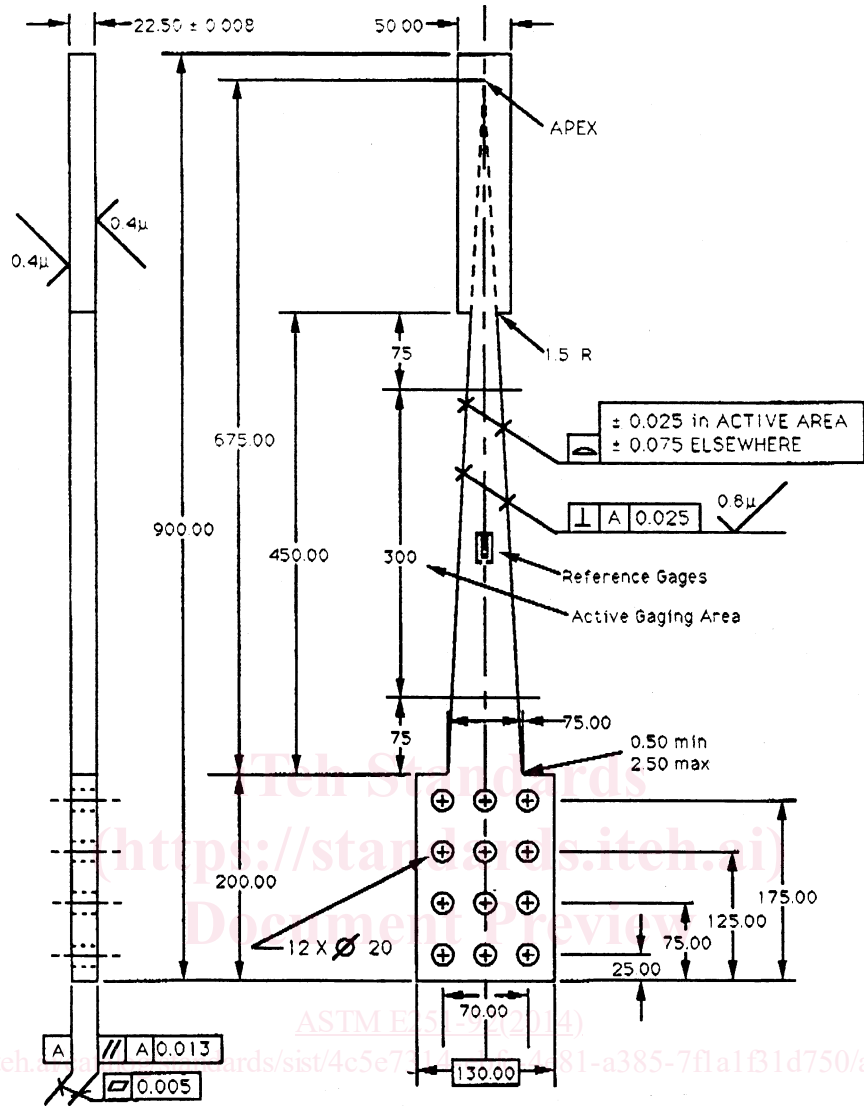
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FIG. 6 **Constant Stress Cantilever Beam**

line of the beam. A selector switch may be used to connect several ~~gauges~~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 ~~gauge~~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 successfully for both tension and compression loading. The strain ~~gauge~~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 ~~gauge.~~gage. The extensometer should have a gauge length as near that of the ~~gauge~~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 ~~gauge~~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 ~~gauge~~gage electrically to the resistance-measuring circuit, and mount the reference extensometer so as to span the ~~gauge.~~gage.

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