INTERNATIONAL RECOMMENDATION

OIML R 62

Edition 1985 (E)

Performance characteristics of metallic resistance strain gauges

Caractéristiques de performance des extensomètres métalliques à résistance

OIML R 62 Edition 1985 (E)

ORGANISATION INTERNATIONALE DE MÉTROLOGIE LÉGALE

INTERNATIONAL ORGANIZATION OF LEGAL METROLOGY

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This publication – reference OIML R 62 (E), edition 1985 – which is under the responsibility of TC 10/SC 6 *Strain gauges*, was sanctionned by the International Conference of Legal Metrology in 1984.

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INTRODUCTION

This Recommendation is concerned with metallic resistance strain gauges of the type used for determining the mechanical properties of materials, for stress analysis of structures, and as sensing elements in a variety of measuring instruments.

Metrological controls for strain gauges are important so that States can be assured the values of performance characteristics stated are within acceptable levels of uncertainty. Achieving this goal is complicated because performance testing of strain gauges must be by sampling.

The Recommendation deals with these matters directly and includes terminology, conditions and methods of testing, statistical methods to be used (including criteria for acceptance), data presentation requirements, a suggested user verification test, and a bibliography.

TERMINOLOGY

The vocabulary included has been chosen so that specialized terms in the strain gauge field will be clearly defined. Other terms used in this Recommendation have generally understood meanings. A typical strain gauge nomenclature is provided in Appendix A.

1. Strain, linear

   The unit elongation induced in a specimen either by a stress field (mechanical strain) or by a temperature change (thermal expansion).

2. Strain gauge, resistive, bonded (see Figure 1)

   A sensing device attached along its entire length to a surface and whose resistance changes will vary as the surface is deformed.

3. Grid (see Figure 1)

   That portion of the strain-sensing material of the strain gauge that is primarily responsible for resistance change due to strain.

4. Matrix (see Figure 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.

5. Type

   A group of strain gauges which are nominally identical with respect to physical and manufacturing characteristics.

6. Lot

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

7. 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).

8. Measurement axis (grid) (see Figure 1)

   That axis which is parallel with the grid lines.

9. Gauge factor

   The ratio between the unit change of strain gauge resistance due to strain and the measurand.

   The gauge factor is dimensionless and is expressed as follows :

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

where :
K is the gauge factor
R is the strain gauge resistance at test strain
R_0 is the strain gauge resistance at zero or reference strain
L is the test structure length under the strain gauge at test strain
L_0 is the test structure length under the strain gauge at zero or reference strain

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

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

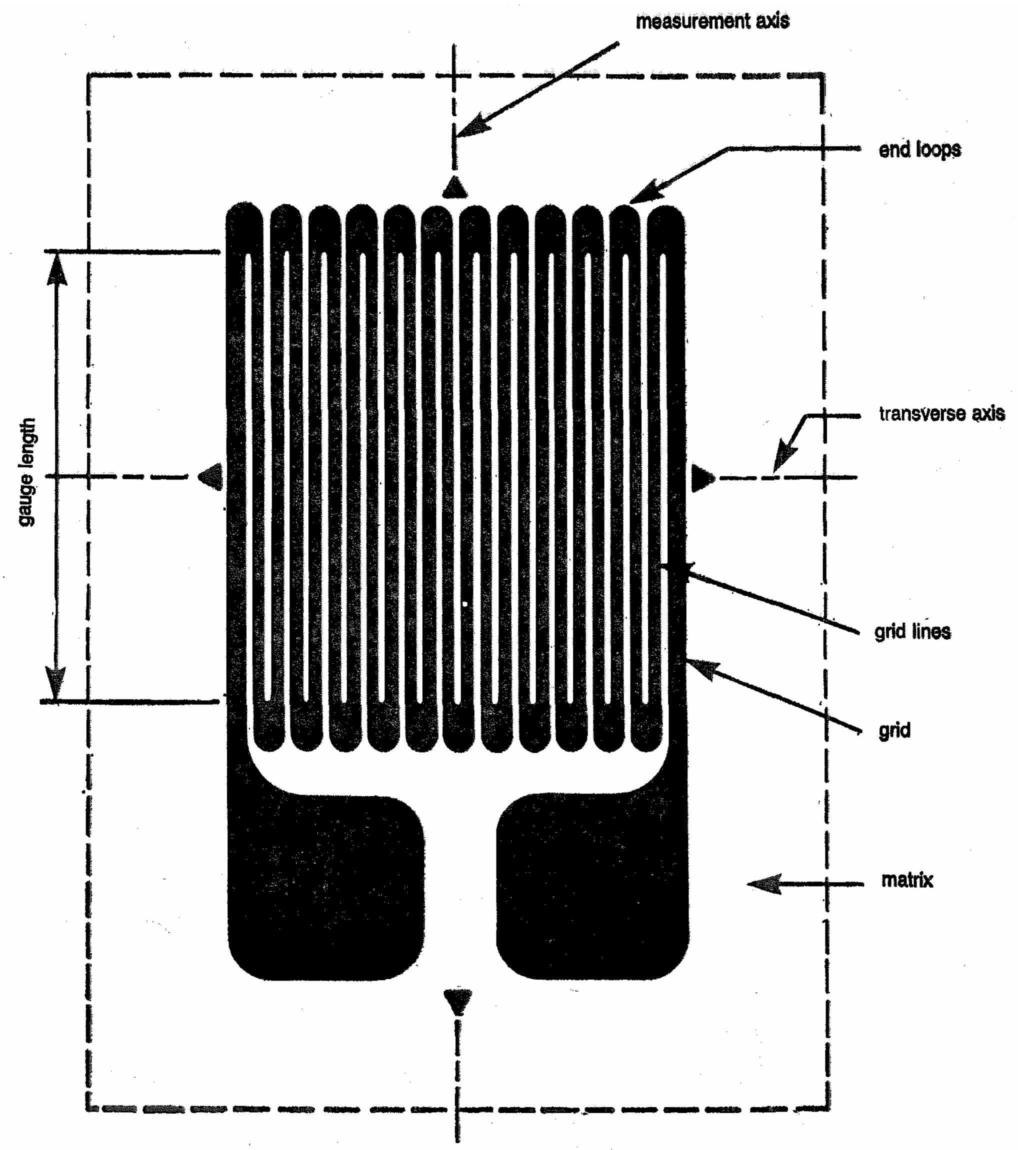


Figure 1. Typical foil strain gauge

10. Gauge length (see Figure 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.

11. Transverse axis (see Figure 1)

The strain gauge axis at 90° to the measurement axis.

12. 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).

13. Thermal expansion

The dimensional change of an unconstrained specimen subject to a change in temperature which is uniform throughout the material.

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.

15. Temperature coefficient of gauge factor

The ratio of the unit variation of gauge factor to the temperature variation

$$\frac{K_{T_1} - K_{T_0}}{K_{T_0}} \cdot \frac{1}{T_1 - T_0}$$

where :
T_1 is the test temperature
T_0 is the reference temperature
K_{T_1} is the gauge factor at test temperature
K_{T_0} is the gauge factor at reference temperature

ALPHABETICAL LIST OF TERMS

Batch	Strain gauge, resistive, bonded
Gauge factor	Temperature coefficient of gauge factor
Gauge length	Thermal expansion
Grid	Thermal output
Lot	Transverse axis
Matrix	Transverse sensitivity
Measurement axis	Type
Strain, linear	

PERFORMANCE CHARACTERISTICS

of METALLIC RESISTANCE STRAIN GAUGES

1. Scope

1.1. This Recommendation deals with metallic resistance strain gauges of the type used for determining the mechanical properties of materials, for stress analysis of structures, and as sensing elements in a variety of measuring instruments (see Appendix A).

1.2. The Recommendation establishes requirements for testing and specifying strain gauge performance characteristics.

1.3. Tests of strain gauges are normally on a sampling basis, which means that statistical methods are necessary for data presentation and comparison. Required methods are given.

1.4. User controlled application techniques are especially critical to the performance of these instruments. Therefore, suggested methods for evaluating user application techniques and verifying strain sensitivity data furnished by suppliers are included.

2. Principles of the Recommendation

2.1. Strain gauges are part of a complex system which 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 installed normally cannot be reinstalled in another location, so gauge characteristics can be stated only on a statistical basis.

2.2. This Recommendation requires important performance characteristics of metallic resistance strain gauges to be specified and that the specified values of such characteristics be accompanied by properly stated uncertainties which have been arrived at using accepted statistical procedures.

2.3. This Recommendation provides uniform means for determining the characteristics of metallic resistance strain gauges which are subjected to metrological controls. References are given in Appendix D.

3. Performance characteristics

3.1. The following strain gauge characteristics shall be specified :

a) resistance,
b) gauge factor,
c) transverse sensitivity,
d) temperature coefficient of gauge factor,
e) thermal output.

3.1.1. The uncertainty, from all sources, of the gauge characteristics 3.1a to 3.1e shall be stated at a probability level of at least 95.5 % (that is to say, no less than two standard deviations).

3.1.2. The standard 23 °C temperature resistance of each 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 which have close resistance values. If combined in sets, each set shall have stated a nominal resistance value and the uncertainty from all sources.

3.1.3. The characteristics 3.1.b to 3.1.e are determined on non-reusable strain gauges ; therefore, data must be handled statistically.

3.2. All strain gauges packaged as a set shall be alike as to the manufacturer's gauge designation.

4. Test requirements

4.1. General environmental requirements

4.1.1. Ambient conditions at room temperature

The nominal temperature and relative humidity shall be 23 °C and 50 % respectively. In no case shall the temperature be less than 18 nor greater than 25 °C, 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.

4.1.2. Ambient conditions at elevated and lower temperatures

The temperature adjustment error shall not exceed ± 2 °C or ± 2 % of the deviation from room temperature, whichever is greater. The total uncertainty of temperature shall not exceed ± 2 °C, 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.

Note : this mixing ratio, independent of temperature, can be realized by a furnace that is well connected to an atmosphere meeting the conditions of point 4.1.1.

4.2. Test measurement requirements

4.2.1. Electrical measurements

4.2.1.1. The uncertainty of the strain gauge resistance measurement (points 3.1.a and 3.1.2) 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.

4.2.1.2. For gauge factor determination (point 3.1.b), the uncertainty of the relative resistance change measurement shall not exceed ± 2 μΩ/Ω or ± 0.1 % of the actual value, whichever is greater. For transverse sensitivity, temperature coefficient of gauge factor and thermal output (points 3.1.c, d and e) the uncertainty shall not exceed ± 5 μΩ/Ω or ± 0.1 % of the actual value, whichever is greater.

4.2.2. Mechanical measurements

4.2.2.1. If the influence of the flatness of the strain gauge on the resistance measurement (point 4.2.1.1) exceeds ± 0.1 % of the actual value, the gauge must be held in contact with a substantially flat surface using a suitable pressing device.

4.2.2.2. Determination of the gauge factor K (point 3.1.b) 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, ± 1 000 and ± 1 100 µm/m. 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 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 or ± 0.2 % of the actual value whichever is greater.

4.2.2.3. To determine the transverse sensitivity (point 3.1.c), mechanical equipment is required for producing uniform uniaxial strains of 0, 1 000, and 1 100 µm/m in the longitudinal direction of the specimen. The adjustment error shall be less than ± 50 µm/m. The strain at the various gauge stations shall differ by no more than ± 2 % of the actual strain in the longitudinal direction of the specimen and no more than ± 5 µm/m in the transverse direction. The uncertainty of the strain shall be no more than ± 10 µm/m in the longitudinal direction of the specimen and ± 1 µm/m in the transverse direction.

4.2.2.4. To determine the temperature coefficient of gauge factor (point 3.1.d), 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 + 1 000 µm/m. It is desirable that a strain of – 1 000 µm/m may be produced. Instead of the reference strain of zero, a small prestrain of between 20 and 100 µm/m may be used. The adjustment error shall be no more than ± 50 µm/m. The uncertainty of the mean strain should be less than ± 5 µm/m. 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.

4.2.2.5. For determination of the thermal output (point 3.1.e), a test specimen is required. It must be properly heat-treated and free of residual stresses. Its dimensions, especially the thickness, must be sufficient to prevent any distortion and thermal hysteresis greater than ± 5 µm/m for any temperature difference of 100 °C. This applies to the whole temperature range for which the thermal output has to be determined. If this temperature range is less than 100 °C, the requirements applied should be those for a minimum of 100 °C. The thermal expansion of the specimen must be known over the full temperature range with an uncertainty of less than ± 0.2 $(\mu m/m)\cdot{}^{\circ}C^{-1}$. If necessary, the thermal expansion must be determined using a dilatometer and the specimen itself or a test piece manufactured from the test specimen material.

4.3. Test procedure requirements

Some test procedure requirements are necessary to completely define the performance characteristics of strain gauges.

4.3.1. Storage and attachment requirements

4.3.1.1. The unpackaged strain gauges selected for testing should be stored under the ambient conditions described in point 4.1.1 for at least 72 hours before attachment to the test specimen or before and during resistance measurement.

4.3.1.2. The attachment conditions should correspond exactly to the instructions published by the gauge manufacturer.

4.3.1.3. To the extent possible, test specimens with attached strain gauges for tests of the gauge factor, transverse sensitivity and temperature coefficient of gauge factor (points 3.1.b, c and d) should be stored under the ambient conditions described in point 4.1.1 for at least 72 hours before being tested. For the determination of the thermal output (point 3.1.e) storage over silica gel or P_2O_5 in a desiccator is preferred.

4.3.2. Measurements

4.3.2.1. For the resistance measurement (point 3.1a), no particular requirements are necessary.

4.3.2.2. For the determination of the gauge factor (point 3.1.b), 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, + 1 100 µm/m, – 1 100 µm/m,
+ 1 100 µm/m, – 1 100 µm/m,
+ 1 100 µm/m, – 1 100 µm/m,
0, + 1 000 µm/m, 0, – 1 000 µm/m, 0.

If possible, one half of the sample 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 + 1 000 µm/m and – 1 000 µm/m.

Although less desirable, it is permissible to use the strain cycles of :

0, + 1 100 µm/m, 0, + 1 100 µm/m,

0, + 1 100 µm/m, 0, + 1 000 µm/m, 0

for one half of the sample

and strain cycles of :

0, – 1 100 µm/m, 0, – 1 100 µm/m,
0, – 1 100 µm/m, 0, – 1 000 µm/m, 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 + 1 000 µm/m and 0 and – 1 000 µm/m.

If this is not possible, it is permissible to use a strain in only one direction for the whole sample.

When strain cycling, other than the first method of this point is used, the differences must be described. For a simple verification test see Appendix C.

4.3.2.3. For the determination of the transverse sensitivity (point 3.1.c), the strain gauges under test should be prestrained three times to a maximum transverse strain of 1 100 µm/m, and then the test strain of 1 000 µm/m should be applied. The transverse sensitivity must be determined from the slope of the straight line between the measurement points at 0 and 1 000 µm/m.

4.3.2.4. For the determination of the temperature coefficient of gauge factor (point 3.1.d), the equipment should be prestrained three times at room temperature to a maximum strain of + 1 000 µm/m for one half of the sample and to – 1 000 µm/m for the other half of the sample. The test temperature should then be adjusted, and, after the temperature balance has occurred, the measuring strain cycle of 0, 1 000 µm/m, 0 respectively should be applied. The temperature coefficient should be calculated from the slope of the straight line between the measurement points of 0 and ± 1 000 um/m, with room temperature values as a reference. If a small pre-strain is used, calculations should be adjusted accordingly.

4.3.2.5. For the determination of the thermal output (point 3.1.e), the test specimens with the attached strain gauges should be heated to the upper end of the temperature range. As the temperature decreases, in steps or continuously but eventually with sufficient heat balance and without perceptible oxidation, the strain indication versus temperature is measured. At least five measurements should be taken over the temperature range :

— between 0 and 100 °C, at temperature intervals of about 20 °C with a maximum of 30 °C (roughly 5 measurements per 100 °C),

— above 100 °C and below 0 °C, at temperature intervals of about 25 °C with a maximum of 40 °C (at least 5 measurements per 200 °C).

More measurements should be made if the thermal output changes rapidly.

The ambient conditions shall be in accordance with point 4.1.2, and the test specimen material (point 4.2.2.5) shall be particularly specified ; at least the linear coefficient of expansion and the nonlinear part of the thermal expansion must be known. If the strain gauges are of the self-compensated type, the thermal coefficient of expansion for which the strain gauges are compensated shall be specified.

5. Data reduction and statistics

Since strain gauges used to determine values of performance characteristics are generally not reusable, the data obtained from a sample of such gauges are used to predict values of these characteristics for all other gauges of the same batch. Well established statistical methods can be used to make such predictions of values and the uncertainties associated with those values. These methods require that tests be made upon a sample taken at random from the batch, and generally assume that the test results will have a normal, i.e. Gaussian, distribution. For purposes of verification of reported values, it will be assumed that these reported values are equivalent to those obtained from a sample of thirty gauges and that systematic errors in these reported values are negligible or have been corrected for.

For each characteristic to be verified, a sample of strain gauges shall be tested using procedures described in point 4. The control sample shall consist of at least five strain gauges although a sample of ten or more gauges would be preferred. The results of the several tests made on one gauge shall be averaged, and these average values shall be used in the following computations to determine if the average performance or variability of the control sample differs from the reported values at the 95 percent confidence level.

A two-sided t-test is used to compare the manufacturer's statement of the value for a particular characteristic, V_R , shown on the gauge package, and the average value from the control tests, V_C. The standard deviation of the reported value, S_R, is taken as $T_R/2$ where T_R is the tolerance given on the package. The standard deviation of the control value, S_C, is calculated from the control test data using the familiar relationship :

$$S_C = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{n-1}} \quad (1)$$

where :
X_i is the average value for ith gauge
$\overline{X}$ is the average value for all gauges in the control sample
n is the number of gauges in control sample.

The manufacturer's reported value, V_R, is considered to be verified if:

$$|V_R - V_C| \leq t \cdot \sqrt{\left[\frac{29\,S^2_R + (n-1)\,S^2_C}{28+n}\right] \times \left[\frac{30+n}{30n}\right]} + e_s \qquad (2)$$

where :
t is the value from Table 1 corresponding to n
e_s is the estimate of systematic error in the control value, V_C.

An « equal tail » test is used to compare the variability reported with the gauges and the variability of the control sample. The reported tolerance, T_R, shall be considered verified

if :

$$A \leq (S^2_R / S^2_C) \leq B \qquad (3)$$

where :
$S_R = T_R/2$
Sc is the standard deviation of control sample
A and B are the values from Table 1 corresponding to the number of gauges in the control sample, n.

An example is presented in Appendix B.

Table 1. Values used to compare reported and control test values of average gauge performance and variability

Number of gauges in control sample n	Factor for comparing average values (*) t	Values for comparing variability (**) A	B
5	2.036	0.306	8.47
10	2.025	0.386	3.57
15	2.018	0.424	2.74
20	2.013	0.448	2.40
30	2.002	0.476	2.10

6. Presentation of information

6.1. The following information (as a minimum) shall be supplied within a sealed package containing the strain gauges :
a) gauge type,
b) lot number,
c) batch number,

(*) Obtained by interpolation for $t_{.975}$ from a table of percentiles of the t distribution assuming that S_R is based upon a sample of 30.

(**) Obtained by interpolation from a table of percentiles of the F distribution for $F_{.975}$, assuming that S_R JS based upon a sample of 30.

d) gauge resistance with uncertainty,
e) gauge factor with uncertainty,
f) transverse sensitivity with uncertainty,
g) temperature coefficient of gauge factor, over recommended temperature range, to be expressed either graphically or numerically with uncertainty,
h) thermal output versus temperature to be expressed either graphically or numerically with uncertainty. The thermal output data or graph must include a statement concerning whether the test was run at fixed stable temperature steps or with continuous but uniform temperature changes and recording of data.

Items d, e and f must be accompanied by statements of the temperature and relative humidity during testing.

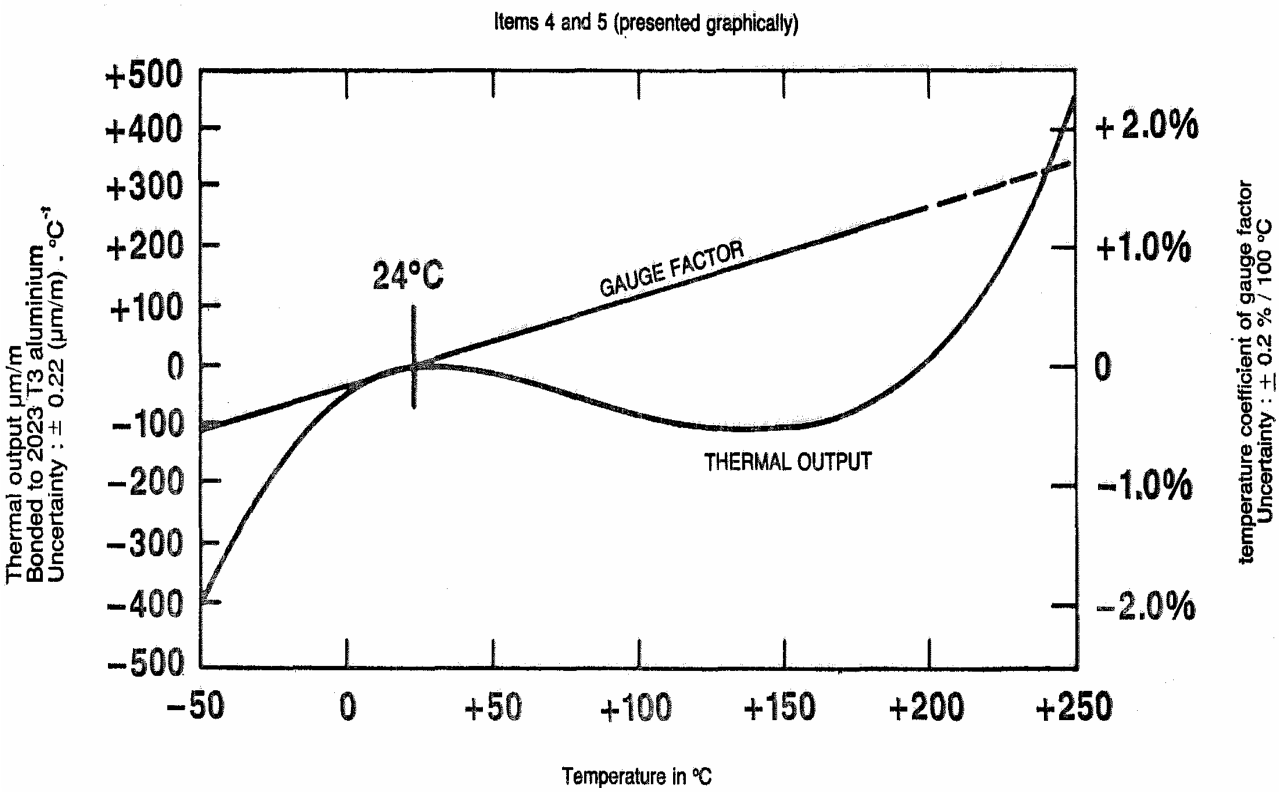
6.2. A format for presenting the information, either graphically or numerically, is given below :

EXAMPLE : PACKAGE INFORMATION

GAUGE TYPE : RLX-25PB-8764
LOT: 36D91L
BATCH : 6143

PERFORMANCE CHARACTERISTIC	VALUE	
1. Gauge resistance at 24 °C and 50 % RH	350 Ω ± 0.2 %	
2. Gauge factor at 24 °C and 50 % RH	2.05 ± 1 %	
3. Transverse sensitivity at 24 °C and 50 % RH	(– 0.6 ± 0.2) %	
4. Temperature coefficient of gauge factor (if expressed numerically)	(+ 0.9 ± 0.2) % /100 °C	(*)
5. Thermal output in µm/m versus temperature in °C (if expressed numerically). Bonded to 2023-T3 aluminium. Temperature change and data are continuous	$-45.1 + 3.32\,T - 6.76 \cdot 10^{-2}\,T^2 + 3.20 \cdot 10^{-4}\,T^3 - 2.86 \cdot 10^{-7}\,T^4$ µm/m ± 0.22 (µm/m) · $°C^{-1}$	(*)

(*) see figure hereafter for graphical presentation.



6.3. The gauge type designation used shall be unique in nature so that, from published literature, the following can be determined :

a) strain gauge geometry,

b) type of strain sensing alloy,

c) type of matrix material, if used,

d) approximate matrix size,

e) type of leads, terminals, solder dots or other « optional » features, if included,

f) the coefficient of expansion of the material for which the strain gauge is to provide compensated minimum thermal output, if applicable.

In addition, information shall be maintained on test equipment, procedures, results, and test data used to report the strain gauge characteristics. This information must be available on request.

7. Liability to legal metrological controls

This Recommendation prescribes the performance characteristics which must be specified for metallic resistance strain gauges and the methods of their determination. States may, through legislation, impose metrological controls which verify that the stated values of these performance characteristics are in accordance with the Recommendation and have assigned values for each characteristic within acceptable levels of uncertainty. Such controls, when imposed, may include pattern evaluation and initial verification.

APPENDIX A
GAUGE DESIGNS

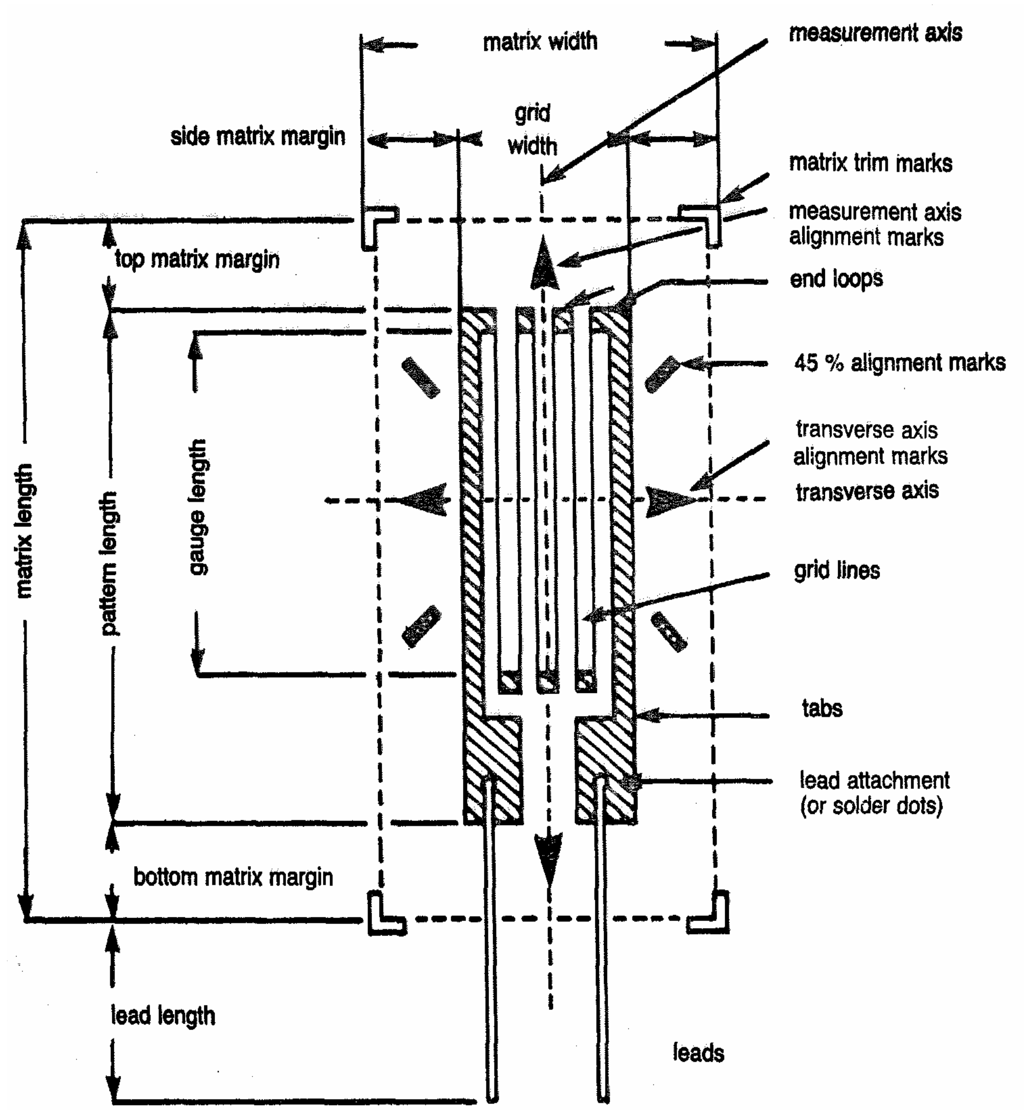


Figure 2. Typical foil strain gauge

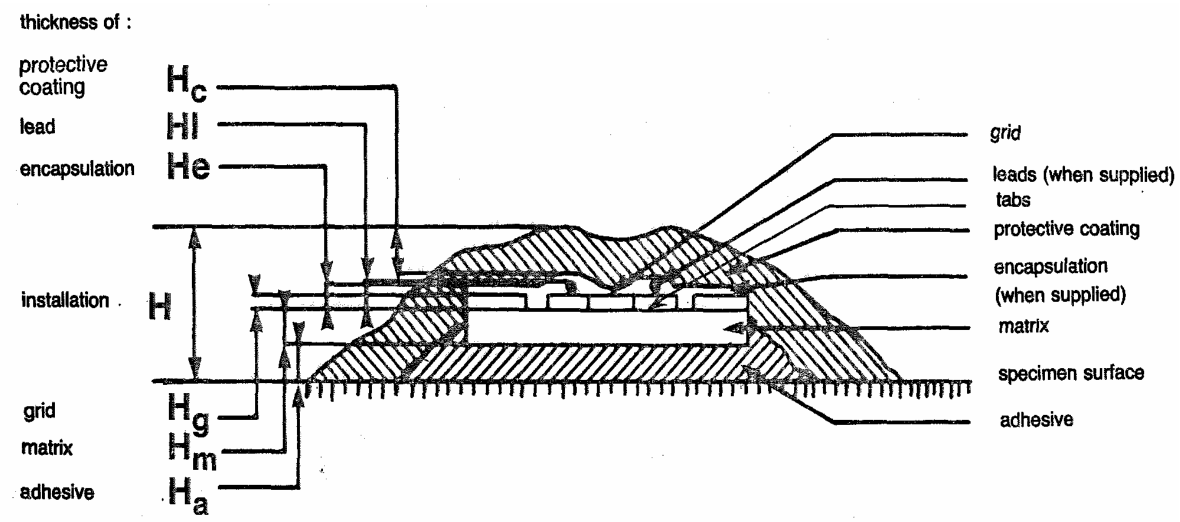


Figure 3. Typical strain gauge installation

Displacement of grid from specimen surface :

$H_d = H_a + H_m + 1/2\ H_g$

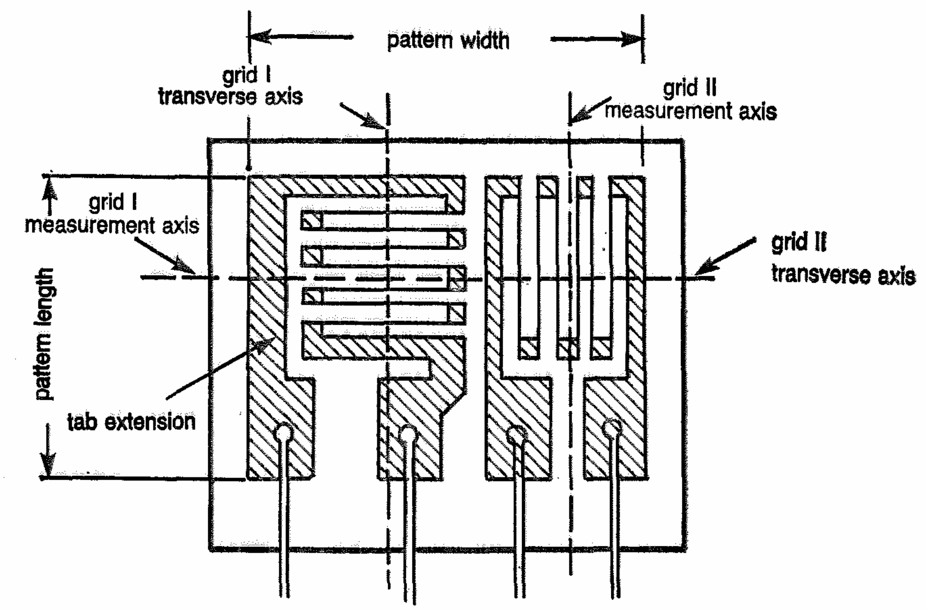


Figure 4 Typical multiple grid strain gauge

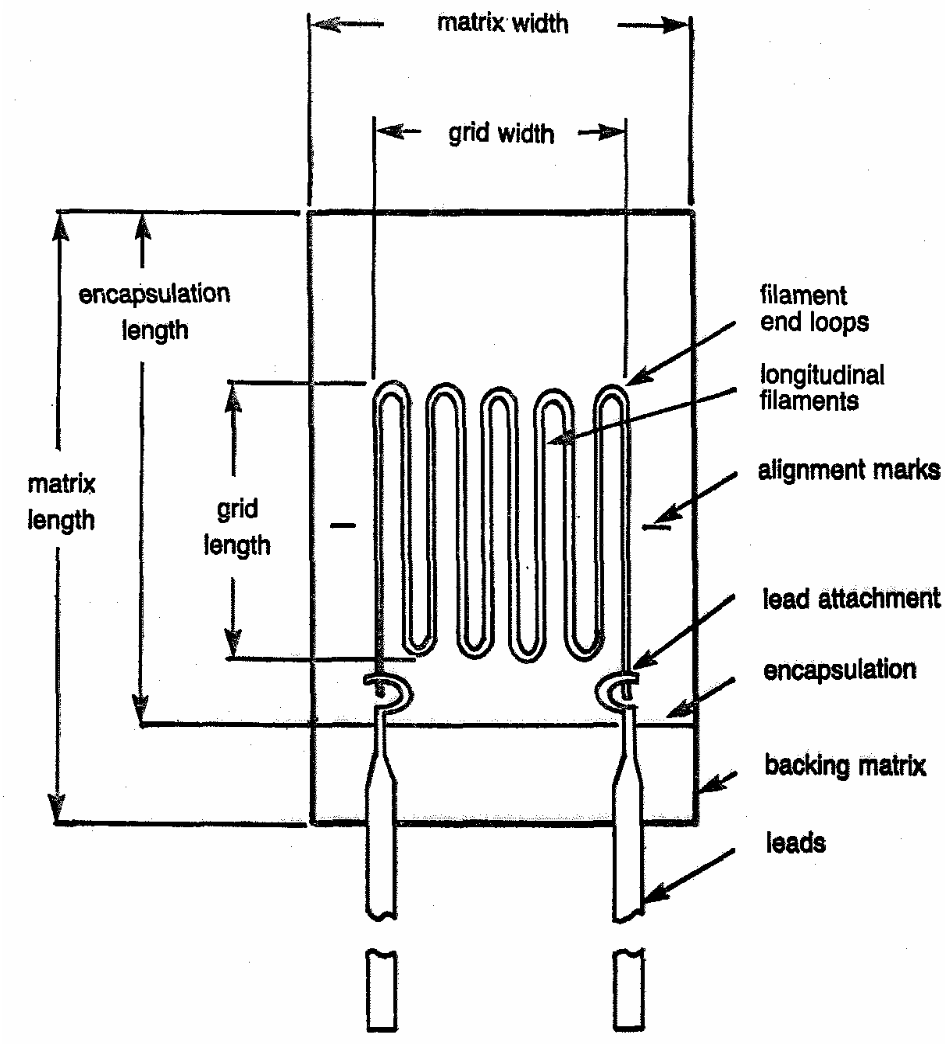


Figure 5. Typical wire strain gauge

APPENDIX B

COMPARISON OF REPORTED AND CONTROL VALUES

EXAMPLE

The following example is given to show how values and tolerances furnished with a shipment of strain gauges can be compared to values obtained from a sample tested by a control laboratory to determine whether the reported values properly describe the supplied gauges. The gauge factor K is the characteristic used in this example, but the process would be the same for other characteristics.

B.1. Assume that the gauge factor value furnished with the gauges is 2.024 ± 0.5 %, reported in accordance with this Recommendation.

B.2. A sample of ten gauges is selected at random from the shipment.

B.3. The gauges of the sample are tested using the procedures described in point 4. Each gauge is tested in both tension and compression. The test plan (Table B.1) gives the same number of data points for each direction of loading.

B.4. The results of the tests are tabulated as shown in Table B.1. Note that the values given in this table were obtained using random number techniques and may not be representative of actual data from strain gauges.

B.5. An average gauge factor K_i is calculated for each gauge tested. Average values are used in the subsequent calculations since gauge performance and not the effects of the test procedure are of interest. The average value is the best estimate of the gauge factor of that particular gauge. These average values are shown in Table B.1.

B.6. An average gauge factor for the sample, K_c, is calculated :

$$K_c = \frac{1}{n} \sum_{i=1}^{n} K_i \qquad (1)$$

This value is shown in Table B.1.

B.7. An estimate of the standard deviation for the sample, S_C, is calculated as :

$$S_C = \sqrt{\frac{\sum_{i=1}^{n} (K_i - K_C)^2}{n-1}} \qquad (2)$$

This value is shown in Table B.1.

B.8. An estimate of the systematic error in K_C is made from the characteristics of instruments, test apparatus, test procedures, operators, etc. This estimate is influenced by the experience of the laboratory. Note that this does not include systematic effects for which corrections have been made, for example, instrument calibration corrections. For this example, the systematic error e_s is estimated to be 0.05 %.

B.9. The gauge factor value, K_C, obtained from (1), is compared to the value furnished with the gauges, K_R , using the equation :

$$|K_R - K_C| \overset{?}{\leq} t \sqrt{\left[\frac{29\, S^2{}_R + (n-1)\, S^2{}_C}{28+n}\right] \left[\frac{30+n}{30\, n}\right]} + e_S \qquad (3)$$

Using values from Table B.1 in this equation gives :

$$|2.024 - 2.020| \overset{?}{\leq} 2.025 \sqrt{\left[\frac{29 \times 0.0051^2 + 9 \times 0.0064^2}{38}\right] \left[\frac{40}{300}\right]} + 0.001$$

$0.004 \leq 0.005$

Since this statement is true, there is no reason to believe that the two values are different at the 95 percent confidence level, and the value of K is therefore verified.

B.10. The variability of the sample is compared to the tolerance furnished with the gauges using equation (3) of point 5 :

$$A \overset{?}{\leq} (S^2{}_R \,/\, S^2{}_C) \overset{?}{\leq} B$$

Using values from Table 1 (point 5) in this equation gives :

$$0.386 \leq \left[\frac{0.0051^2}{0.0064^2} = 0.635\right] \leq 3.57$$

Since this statement is true, there is no reason to believe that the variabilities are different at the 95 percent confidence level, and the value of T_R is therefore verified.

TABLE B.1

Odd numbered gauges — Runs 1, 2 and 3 in tension ; Runs 4 and 5 in compression

Even numbered gauges — Runs 1, 2 and 3 in compression ; Runs 4 and 5 in tension

GAUGE No	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	AVG. K_i	$K_i - K_C$	$(K_i - K_C)^2$
1	2.039	2.040	2.012	2.040	2.005	2.027	+.0068	4.624×10^{-5}
2	2.008	2.015	2.013	2.022	2.019	2.015	—.0052	2.704×10^{-5}
3	2.038	2.039	2.001	2.040	2.000	2.024	+.0038	1.444×10^{-5}
4	2.002	2.014	2.036	2.003	2.005	2.012	—.0082	6.724×10^{-5}
5	2.013	2.022	2.027	2.037	2.048	2.029	+.0088	7.744×10^{-5}
6	2.000	2.021	2.046	2.008	2.034	2.022	+.0018	0.324×10^{-5}
7	2.007	2.027	2.004	2.039	2.011	2.018	—.0022	0.484×10^{-5}
8	2.047	2.005	2.047	2.001	2.028	2.026	+.0058	3.364×10^{-5}
9	2.013	2.008	2.007	2.015	2.011	2.011	—.0092	8.464×10^{-5}
10	2.005	2.010	2.036	2.003	2.034	2.018	—.0022	0.484×10^{-5}
						20.202		36.36×10^{-5}

Control Values (Calculated) :

$$K_C = \frac{\Sigma K_i}{n} = \frac{20.202}{10} = 2.0202 \quad (1)$$

$$S_C = \sqrt{\frac{\Sigma(K_i - K_C)^2}{n-1}} = \sqrt{\frac{3.636 \cdot 10^{-4}}{9}} = 0.0064 \quad (2)$$

$e_s = 0.0005\ K_C = 0.0010$

Reported values (from package) :

$K_R = 2.024$

$$S_R = \frac{T_R}{2} = \frac{0.005 \cdot 2.024}{2} = 0.0051$$

APPENDIX C

USER GAUGE EVALUATION

RECOMMENDED METHOD

C.1. Summary of the method

Many applications for strain gauges involve environmental and other conditions which make it difficult to assess expected strain gauge performance during actual testing. In these cases it is often wise to check a sample of gauges on a test set-up subjected to conditions similar to those of the expected application. Such testing is often done. In other cases comparison of gauge performance with standard calibrated gauges under controlled conditions is the best indication of purchased gauge quality combined with user ability to produce adequate strain gauge installations.

The following suggested procedure is designed to permit this comparison and serve as a continuing quality assurance procedure for both incoming strain gauges and installer qualifications.

The test consists in comparing the strain gauge being tested with a calibrated reference gauge on a high quality but simple and inexpensive cantilever test beam. Dead weight loading is used to ensure repeatability.

C.2. Apparatus

The equipment to be used is shown in Figure 6. The test bar shown in Figure 7 is known to perform well under the described testing procedure. The test bars are clamped to the base frame shown and loaded as a cantilever beam. Loading is by means of dead weights to produce approximately a 1 000 µm/m strain at the gauge location. Note that the described beam produces a linearly varying stress along its surface when loaded.

Each beam should have installed on it one reference strain gauge. Calibration factor and uncertainty of the gauge-beam combination must be known.

C.3. Procedure

The gauge to be evaluated is bonded on the steel beam, aligned with the marks as shown in Figure 7. Alignment should be accurate and the bonding techniques used should be as near those to be used in field testing as possible.

A room temperature gauge factor is determined by comparing the output of the test gauge with that of the calibration gauge, with and without the test load. Corrections must be made for misalignment of the gauge and for thickness of the installation.

Note : No correction for the reference gauge is needed if it is properly calibrated.

Gauges may be tested in both tension and compression simply by turning over the beam in the test stand. Gauge factor of the gauges being tested should be within the manufacturer's tolerance after allowing for the accuracy and uncertainty of the user gauge test rig.

Using the statistical methods outlined in point 6 and Appendix B, the data should be reduced and compared with the expected results. It must be remembered that there are tolerances in many areas of this simple form of testing and accuracy cannot be expected to compare with that of more precise equipment used to determine the gauge factor. If used in the most careful manner, it is expected that the test rig systematic and random errors will not exceed 11 µm/m in a typical test. Repeated loadings with the same weight and environment should result in differences in reference gauge indications no greater than 5 µm/m. Failure to obtain such repeatability should be cause to investigate the gauge characteristics, the installations or the test techniques.

Figure 8 is a graph of the maximum overall system error expected.

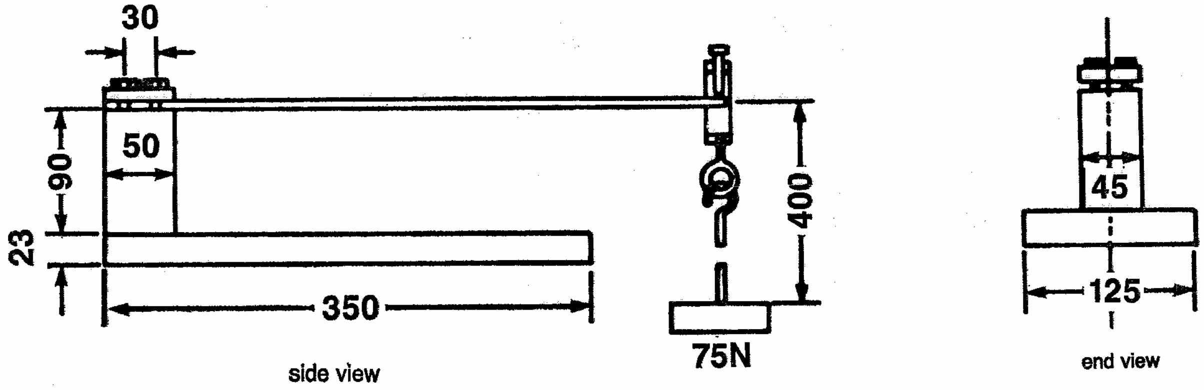


Figure 6. User gauge evaluation test rig

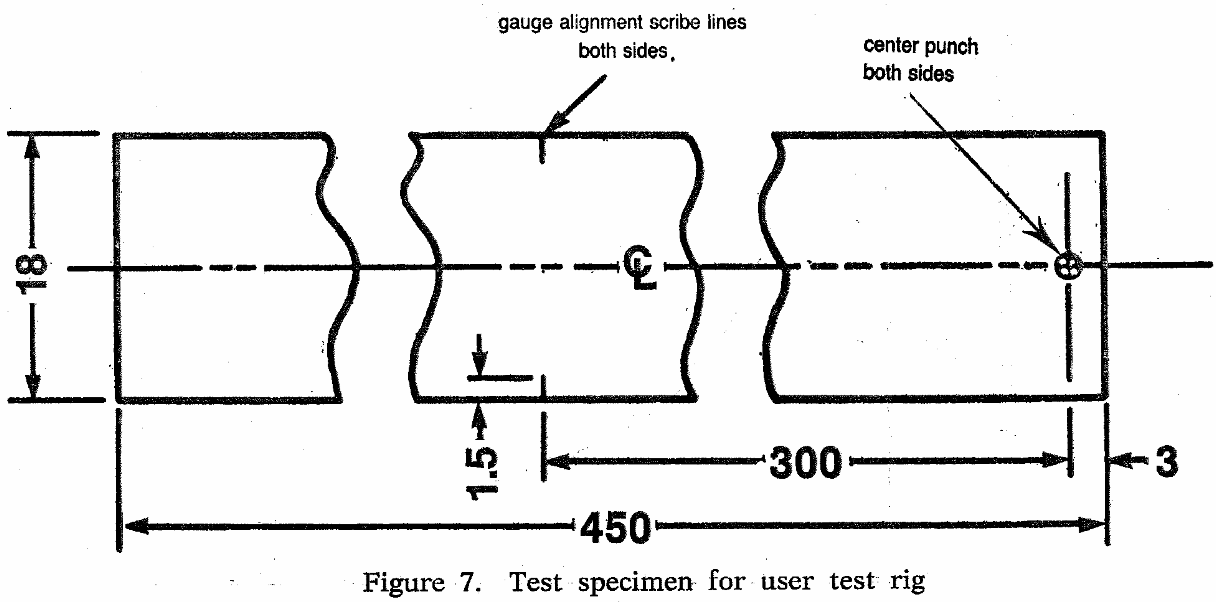


Figure 7. Test specimen for user test rig

Notes : Suggested material : 6 mm thick tool steel, ground all four faces ; center punch marks and scribe lines made before hardening ; harden to HRC 45 minimum.

Notes on Figures 6 and 7 :

1. The dimensions are given in mm.

2. The designs which differ in dimensions or materials from those shown may be equally as dependable and accurate. However, as the thickness of the bar diminishes, errors from various sources increase rapidly.

3. The approximate specimen surface strain in the beam at the test location is calculated as follows :

$$\varepsilon = \frac{\sigma}{E} = \frac{6 \cdot M}{b \cdot h^2 \cdot E}$$

where :

ε is the strain in m/m

σ is the stress in N/m^2

E is the modules of elasticity in N/m^2

M is the bending moment in N · m

b is the beam width in m

h is the beam thickness in m

$$\varepsilon = \frac{6 \cdot [75 \ \text{N}] \cdot [0.3 \ \text{m}]}{[0.018 \, \text{m}] \cdot [0.006^2 \ \text{m}^2] \cdot [207 \cdot 10^9 \text{N/m}^2]} = 0.001006 \ \ \text{m/m} = 1006 \ \ \mu\text{m/m}$$

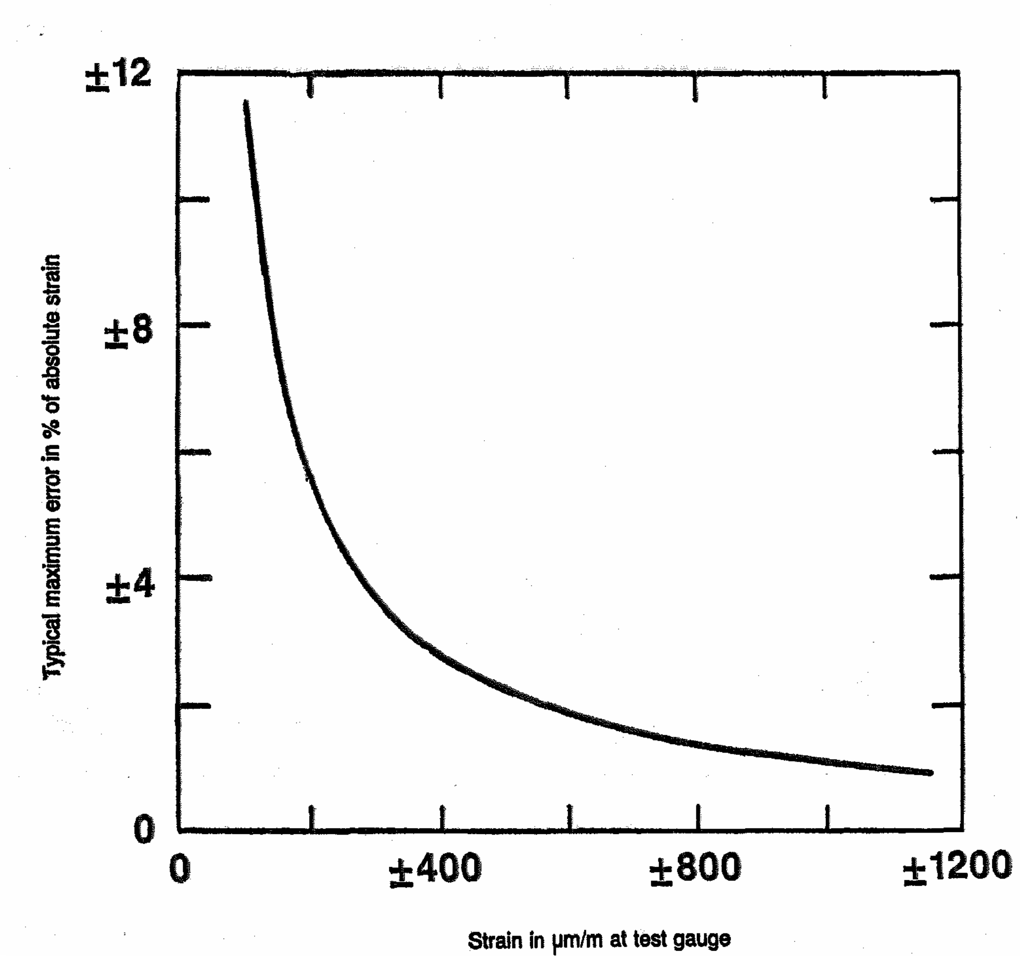


Figure 8. Typical system accuracy of user gauge evaluation test rig

APPENDIX D

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