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AERONAUTICAL RESEARCH LABORATORIES

MELBOURNE, VICTORIA

A STRAIN GAUGE MANUAL

S.W. GEE and L. CONDER

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Structures Technical Memorandum 378

A STRAIN GAUGE MANUAL

by

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SUMMARY

The electrical resistance strain gauge is a very
reliable sensor, much used in structural and mechanical
testing. This document has been prepared to assist the
inexperienced technician in selecting and using these gauges.
General recommendations are made regarding gauge types,
adhesives, proofing materials and gauge techniques for a
variety of environmental conditions.

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CONTENTS

1. INTRODUCTION

The following notes are intended to briefly summarise current strain gauge techniques at ARL for the inexperience technician. They are not presented as a course in strain gauging, but as a collection of useful information on the subject.

Terminology is explained in the simplest terms and general recommendations are made regarding gauge types, adhesives, proofing materials and gauge techniques.

Manufacturers names and some well known products are mentioned in the text as good examples of suitable materials. It should be emphasised that equivalent products by other manufacturers may be as good as, or superior to these described. More detailed information may be found by searching available literature, such as that suggested in the references.

2. STRAIN, RESISTANCE CHANGE AND STRAIN FACTOR

Strain is the fractional change in length of a material under the action of an applied force. Referring to Fig. 1, if the original length of the bar was L and its length increased by ΔL under the action of load P, the tensile strain would be $\Delta L/L$.

Likewise, if a strain gauge were bonded to this bar, its resistance R, Ohms, would change by an amount ΔR under the action of the applied strain, so the fractional resistance change would be $\Delta R/R$

it can be shown that   Strain $\dfrac{\Delta L}{L} = \dfrac{1}{K}\dfrac{\Delta R}{R}$.

Where K is a constant called the strain factor, or gauge factor, of the gauge values of both R, the gauge resistance and K the strain factor are already marked on each packet of strain gauges and must be recorded wherever gauges are used, to permit calculation of the strain.

3. STRAIN GAUGE SELECTION

A vast selection of strain gauges are available, one manufacturer alone producing some 40,000 different gauge options. In selecting the correct gauge for a given task, the following points should be considered.

3.1 Duration of the Test

For short term tests and general laboratory use, the cheaper gauges by Japanese manufacturers such as TML, Kyowa and Shinkoh have proved satisfactory. For aircraft flight tests and for long term fatigue tests, where gauges may be required to last the full lifeof the test specimen, American gauges by Micro-Measurements or BLH are preferred in these laboratories. The WA series of gauges by Micro-Measurements are an excellant example. They have an epoxy fibre-

glass backing, are fully encapsulated, are fitted with dual high-
endurance lead wires and have excellant long term stability and
long fatigue life.

Gauges with epoxy fibre-glass backing, full
encapsulation and dual high-endurance lead wires are preferred
for long-term stability and long fatigue life.

3.2 Gauge Length

Gauge lengths are available from 0.3 mm to 150 mm.
The very small gauges down to 0.3 mm are used only in the areas of
highstrain gradients and stress concentrations, or where minimal
space exists to attach gauges. For stability, low bridge voltages
must be used with these gauges, which reduces the output from the
gauge bridge. Medium length gauges 3 mm to 12 mm gauge lengths are
used for all general purpose gauging on homogeneous materials such
as metals. The most commonly used types at ARL have 3 mm and 6 mm
gauge lengths.

Long gauges with 20 mm gauge length or greater, are
used for measurements on non homogeneous materials such as fibre
reinforced plastics, concrete etc.

As a general rule, the medium size gauges are the
easiest gauges to handle during attachment, and are more stable and
reliable than the miniature types, so should be used whenever pract-
icable.

3.3 Gauge Configuration

Referring to Fig. 2, Linear strain gauges are used
for all general purpose work where directions of the principle strains
are known and the gauges can be accurately aligned in the correct
directions.

Shear gauges are used to measure shear strain when
the directions of the principle strains are known and the elements of
the gauge can be aligned at 45 degrees to these directions. The
stacked shear gauge is used only where strain gradients are severe
or where space is limited. Flat shear gauges are used in all other
cases.

Rosette gauges are used when the principle strain
directions are not known as magnitude and direction of the principle
strains when the strains in the 3 elements have been measured separately.

Stacked rosettes are used only where strain gradients
are severe or space is limited.

Flat rosette gauges are used in all other cases.

3.4 Gauge Resistance

The most commonly available gauges have a resistance
of 120 Ohms. At ARL they are used for all structural testing, plus
some transducers and wind tunnel balances. For flight test aircraft
and special load transducers, 350 Ohms strain gauges are used. One
thousand ohm gauges are used, for dynamic tests on rotating
machinery, which involve the use of slip rings. They reduce the
effect of the slip ring noise in the bridge circuit because, their
high output, due to large bridge voltages, increases the signal-to-
noise ratio.

3.5 Self Temperature Compensation

Gauges are supplied self temperature compensated for
use on specific materials such as structural steel, stainless steel
and aluminium alloys. The compensation number is normally given as
part of the identification number for the gauge type. In general
the correct gauge type should be used for the material. Compensation
numbers for the above 3 materials are tabulated in Table 1.
Compensation normally applies over a fairly limited temperature range
around ambient temperature.

If the gauges are to be used mainly at low or at high
temperatures, better compensation can often be achieved by deliberately
mis-matching the gauge and material coefficients. For example, if an
aluminium compensated gauge is used on a stainless-steel specimen, it
will give much better compensation at low temperatures than a stainless
steel compensated gauge on the stainless stell specimen. The graph
Fig. 3, shows typical temperature curves for gauges compensated for
structural steel, stainless-steel and aluminium when they are attached
to a stainless-steel specimen.

3.6 High Strains

Where very high strain levels are expected, post-yield
gauges should be used.

3.7 Adverse Temperatures

If very high or very low temperatures are encountered,
special gauges and special adhesives are required. Gauge manufacturers
recommendations should be closely followed.

For temperatures up to +80°C normal gauges and adhesives
are satisfactory. If the range extends to +300°C, epoxy fibre glass
gauges and high temperature epoxy adhesives are available. The gauges
must be clamped during the curing cycle which must be carried out at
elevated temperatures to set the adhesive. Polyester gauges and
adhesives are produced by several manufacturers such as Philips and
TML, which have the advantage that the adhesive will set at ambient
temperature, although clamping is still required. Gauge installations
with these adhesives should be post cured at temperatures above the
maximum operating temperature of the specimen. For temperatures to

+600°C, ceramic cements are available for use with free filament or strippable backing gauges, as well as asbestos based gauges and adhesives.

For extreme temperatures or particularly hostile environments, the sealed weldable gauges similar to Hitec or Ailtech are recommended. These may be purchased as single gauges or half bridges for use at temperatures from -270°C to +800°C. Installation is by spot welding the mounting flange of the gauge to the specimen at closely spaced intervals.

3.8 Strong Magnetic Fields

Special non-inductive strain gauges are available for use in strongly varying magnetic fields. These gauges consist of two identical grids mounted back to back and connected in series, so that the excitation current passes through them in opposite directions. As the grids are very close together, induced voltages are almost equal and of opposite signs in the two elements, rendering the gauge almost immune to magnetic fields. Manufacturers include Micro-Measurements and Shinkoh-BLH.

3.9 Wet Environment

Normal strain gauges properly waterproofed are suitable for damp or submerged installations. Waterproofing is usually simpler and more positive, however, if fully encapsulated gauges fitted with integral waterproof leads of one metre or more in length, are used. Manufacturers include Kyowa, Shinkoh-BLH and TML. The sealed weldable gauges by Ailtech and Hitec are also excellent under water, at high pressures, but are much more expensive than the above gauges.

3.10 Embedment in Concrete or Similar Materials

Special embedment gauges are produced by several manufacturers, such as Kyowa, Hottinger, Shinkoh-BLH and TML for embedment in concrete and have excellent long term stability.

3.11 "One Side" Bending Measurements

Gauges are available from TML, which measure both the bending and tensile strains when bonded to one surface of a plate or beam. They are specifically intended for use where only one side of the test piece is accessible such as in closed box constructions.

4. ADHESIVES

In general only adhesive recommended by the gauge manufacturer should be used to attach strain gauges. Cheap super-glues, or epoxies purchased from the local hardware store are definitely not recommended by manufacturers or serious research workers for reliable gauging.

Cyano-acrylate adhesives are used for virtually all general purpose gauging at ARL. Types similar to Micro Measurement M Bond 200 where adhesive is applied to one surface and a catalyst to the other before mating them together are preferred for their ease of application and long-term performance.

Two-part, ambient-temperature setting, epoxy adhesives are preferred for use with special strain gauges such as the Columbia strain sensors used for flight fatigue monitoring by the RAAF. Adhesives such as BLH type EPY-150 are supplied in small sealed plastic pouches with removable dividers separating the two components. To mix, the divider is removed and the bag kneaded between the fingers for several minutes, a simple fool proof mixing system which minimises the possibility of glue contamination in the field as well as eliminating the need for clean mixing vessels and accurate weighing of components.

For high quality transducers or temperatures up to 600°F (315°C) high temperature 2 or 3 part epoxies similar to Micro Measurements M Bond 600 or 610 are recommended, when used with the appropriate gauges. The gauges must be clamped during their curing cycle which must be carried out at elevated temperatures.

Polyester adhesives such as those by TML are recommended for use with polyester or polyamide backed gauges only. They are suitable for temperatures up to 250°C and require minimal clamping but do not bond readily to epoxy or bakelite backed gauges. They cure at ambient temperatures, but post curing is advisable before use at elevated temperatures.

For high temperature work up to 400°C, ceramic adhesives used with the recommended ceramic or strippable backing gauges are suggested. Flame spray techniques require specialised equipment and skills not normally available to the inexperienced technician.

5. STRAIN GAUGE TERMINALS

The reliability of strain gauge installations is enhanced by using special strain gauge terminals, supplied by the gauge manufacturers in sizes to suit all gauge types. The terminals are bonded to the test piece in a similar manner to the gauges, and serve to anchor the relatively heavy instrumentation wiring, thus relieving unwanted loads from the delicate gauge leads. Fig. 4 illustrates the correct use of such terminals. An alternative is to use Micro-Measurements series CEA strain gauges which are equipped with integral copper coated terminals, which provide optimum capability for direct lead wire attachment.

6. GAUGE WIRING

For normal laboratory and field testing where temperatures do not exceed 80°C, multi-strand, PVC covered hook up wire, size 14/019 or similar is adequate for the internal and external bridge wiring.

For adverse environments including temperatures from
-269!C to +260°C, silver plated teflon covered wiring should be used.
For extreme temperatures from -269°C to +480°C, solid nickel plated
copper wire with fibre glass insulation is available from Micro-
Measurements. It should be noted that special high temperature
solders or welded connections are necessary for gauge connections
at high temperatures.

Wiring of flight test aircraft at ARL is usually
carried out using insulated shielded pairs cable such as Raychem
type 44A1121-22-9-9 ~ 1936A-STB. Two cables are taken to each 4 arm
bridge, one pair for bridge power and the other for signal output.

7.   GAUGE PROTECTION

Gauge installations are normally protected from
moisture, oil, dirt and light mechanical damage by some form of
flexible coating. A series of special strain gauge coatings by
the strain gauge manufacturers can be highly recommended. For
indoor usage, two or more coats of Micro-Measurements M Coat A,
M Coat D or equivalent are usually adequate.

With flight test aircraft and test pieces exposed to
rugged environments, gauge installations are usually painted with
two or more coats of M Coat D, followed by two coats of Selleys
PR1422B polysuphide rubber compound, or equivalent. This gives
enhanced moisture and mechanical protection, but the rubber compound
must overlap the edges of the M Coat D. They system has several
advantages. M Coat D dries rapidly, is an excellant insulator and
provides rapid light protection from dirty environments. It also
protects the gauge installation from the slow curing rubber compound,
which tends to short curcuit gauges to earth while curing. While the
rubber bonds tenaciously to clean metal, it does not stick readily
to M Coat D, so if gauge faults occur, the rubber compound may be
cut and peeled off the M Coat D which in turn may be disolved with
acetone for easy access to the faulty gauge.

Whatever coating is used over the gauges, it should
overlap the installation by at least 2 cm to prevent the ingress of
moisture at the metal-proofing interface. Another proofing system
which provides excellent protection under severe environments, is
provided by Micro-Measurements in their M Coat F protective coating
kit, which is suitable for underwater installations in tunnels, ships
and similar applications.

8.   GAUGE LAYOUTS

Figures 6 to 10 illustrate the normal positioning of
strain gauges to measure tension, compression, bending and shear,
together with their corresponding bridge circuits and bridge factors
for calculating strain. For a single strain gauge at the test piece,
the 3 wire circuit of Fig. 6 should be used if the lead length exceeds
50 cm, to ensure correct temperature compensation of the copper lead

wires. A rosette gauge is treated as 3 separate linear gauges,
each element being wired into its own bridge circuit and read
separately during the tests.

9. WHEATSTONE BRIDGE CIRCUIT

The standard Wheatstone bridge circuit for wiring
strain gauges is shown in Fig. 5, the condition for resistive balance
being that $R_1.R_3 = R_2.R_4$. For laboratory tests where temperatures
are relatively stable, single, self-temperature compensated gauges
may be used on the test piece, with the 3 remaining gauges built
into the measuring equipment. For transducers, or where temperature
changes are likely to exceed 20°C, half bridges or full bridges
should be used. Poissons ratio bridges or bending bridges, where
all the gauges are mounted on the one test piece, give optimum
temperature compensation.

For flight test work, 4 arm bridges are always used
at each gauge station, four wires being taken from each bridge to
the instrumentation pack. This ensures good temperature compensation
maximum output from the gauge bridges and permits a defective gauge
bridge to be readily disconnected from the instrumentation pack, thus
preventing interference with the other gauge channels. Six wire
bridge circuits may be necessary to achieve maximum accuracy if long
lead lengths in excess of say 6 metres are used between the gauges
and the measuring equipment.

10. DUMMY PLATES

Care should be taken to ensure that dummy plates have
the same coefficient of thermal expansion as the test piece and are
in good thermal contact with it. A small smear of heat sink compound
under the plate helps with the heat transfer. Plates should be bonded
along one edge only as shown in Fig. 11 to ensure that no mechanical
strain is transmitted to the dummy gauges. Care must be exercised
while waterproofing to ensure that proofing compound does not flow
over the edges of the dummy plate, effectively bonding it to the test
piece.

11. GAUGE VOLTAGE

When voltage is applied to a gauge bridge, the gauge
elements are heated. Too high a voltage produces excessive temperature
rises, which result in gauge instability, creep, hysteresis and
possibly the destruction of the gauge. Appropriate bridge voltages
vary with the gauge type, resistance, physical size and the substrate
to which the gauge is bonded. In general, 120 Ω miniature gauges and
120 Ω gauges attached to plastic materials require small voltages in
the order of 0.5 to one volts for best performance. Medium to large
gauges require 3 to 6 volts when attached to metal. For detailed
information, Micro-Measurements Tech Note 127 titled "Optimising
Strain Gauge Excitation Levels", is recommended and provides an excellent
set of graphs to determine the optimum bridge voltage for a given case.

12. SURFACE PREPARATION

Success or failure in attaching strain gauges depends mainly on the correct preparation and absolute cleanliness of the bonding surface. Micro-Measurements Instruction Bulletin B-129 titled "Surface Preparation for Strain Gauge Bonding" gives comprehensive information on surface preparations for most materials. A brief summary of the method for general gauging is as follows.

12.1   Grease, oil and dirt are first removed from the gauge area and its surroundings with clean cloth and solvents such as Alcohol, Acetone or Chlorathene NU.

12.2   The gauge area is outlined with masking tape and any paint anodising or plating is removed.

12.3   Gauge positions are now marked out on the surface, using a 4H pencil or a ball point pen and extending the centre line outside the gauge area.

12.4   The cleaned area is now abraided with 200 to 300 grit, wet or dry, aluminium oxide paper using a circular motion to produce a criss-cross pattern of scratches, which provides optimum keying for the adhesive.

12.5   The surface is now cleaned and conditioned by rubbing with cotton buds dipped in surface conditioner (mild etchant), being careful to wipe off the residue with clean tissues, after each application. Conditioner type A by Micro-Measurements is preferred at ARL.

12.6   The prepared surface is finally neutralized by successive applications of neutralizer, the residue again being removed with clean tissues after each application. Micro-Measurements Neutralizer S is recommended.

Gauging should be carried out as soon as possible after cleaning, care being taken not to contaminate the prepared surface with dirt or by touching with the finger tips. If gauging is delayed by more than 30 minutes, steps 5 and 6 should be repeated.

13. ATTACHMENT TECHNIQUES

Instructions from the gauge and adhesive manufacturer should be strictly followed. They are guaranteed to give satisfactory results. A variation of the normal procedure for attaching gauges with cyanoacrylate adhesive, has been favoured at ARL for some 15 years. The recommended method is to apply a thin film of catalyst to the gauge and the adhesive to the test specimen, then press the gauge into position. At ARL this procedure is reversed, i.e. the catalyst is applied to the test piece and the adhesive to the gauge. This has several advantages.

(a) The correct amount of adhesive to fully cover a gauge surface is readily applied to any sized gauge with no risk of a shortage or excess of adhesive on the test piece.

(b) The adhesive can be seen to fully wet the gauge surface before attachment.

(c) The test piece, usually metal, absorbs less catalyst than the more porous surface of the gauge, resulting in a stronger bond and better long term performance of the adhesive, particularly under fatigue conditions.

It should be stressed, that any deviations from the recommended methods should be checked in a laboratory before being used for structural testing.

14. GAUGE INSTALLATION CHECK OUT

The strain gauges should be checked after their attachment and wiring to their terminals, after connection to the instrumentation cables and after the final protective coatings are applied.

14.1 Resistance Measurements

Each attached strain gauge must be checked for correct terminal resistance and correct insulation from earth, with a gauge installation tester. Gauge resistance should be within the tolerance specified on the gauge packet and resistance to earth greater than 10,000 megohms. Minimum acceptable resistance to earth of each complete gauge bridge is 100 megohms.

Note:- It is essential to use a meter with low test voltage of say 15 to 20 volts for the earth resistance check. Using a Megger for this task, will result in the certain destruction of the gauges.

14.2 Gauge and Circuit Integrity

Proper installation of the gauge bridges should be checked with a static strain measuring meter. Each completed bridge should be connected to the meter as per the manufacturers instructions and the zero reading checked. This should be within ±1500 microstrain of the strain meters true zero balance and remain steady with no drift.

To test that the gauges are properly attached, the strain meter is adjusted to the null balance condition. A piece of teflon or plastic sheet should then be placed over the gauge. Pressing on the plastic sheet with a finger should result in a deflection of the strain meter, which should return to zero when the pressure is removed. Each gauge should be checked in this manner. This method may also be used, to check that each gauge bridge is connected to its correct instrumentation channel by pressing each gauge bridge in turn and ensuring that only the correct recorder channel responds.

15. DOCUMENTATION

The relevant resistances and strain meter readings from the above tests should be recorded for future reference, together with details of the gauge type, makers resistance, gauge factor, batch number and location of the bridge on the test piece. Photographs of gauge locations should also be taken before final proofing and carefully labelled for further use.

16. FAULT FINDING

If the null balance of the strain gauge bridge is outside the meter range, check that the circuit connections, the solder joints and the individual gauges are correct and rectify any errors. Should the strain meter reading be unstable, the solder joints should be examined and the strain gauges checked to ensure there are no air bubbles under the gauge grid. If bubbles are present under the gauge or the meter reading does not return to zero after pressing on the gauge, the gauge must be replaced.

17. SHUNT CALIBRATION

Compressive strain in a gauge may be simulated by shunting the gauge with the appropriate calibration resistor. The formulae for calculating the strain, equivalent to this cal resistor is derived and shown in Appendix 1. The lower the resistance of the shunt, the higher the strain it represents. A 60,000 Ω shunt, across a 120 Ω gauge, is equivalent to a strain of 1000 micro-strain when the gauge factor is 2.00. For a load cell, the approximate value of shunt resistance, which is equivalent to a given load can be calculated from the formulae,

$$R \ cal = \left(\frac{25000 Rb}{Kx}\right) - Rb$$

where Rb = Load cell resistance Ω
K = Load cell sensitivity mV/V
X = Percent of full scale load of the load cell for which the resistor is required.

If the calibration resistor is located in the instrumentation pack, which is a long distance from the gauge bridge, the lead resistance should be measured and an allowance made for lead effects.

18. VOLTAGE OUTPUT

The voltage output from a strain gauge bridge is very small and frequently requires amplification. It may be calculated from the formulae,

$$\delta V \simeq \frac{V.\varepsilon.K.B}{4}$$

where δV = Voltage output
V = Voltage applied to the bridge
ε = Applied strain
K = Gauge factor of gauge
B = Bridge factor of bridge

Bridge output is independant of the resistance of the strain gauges, but directly proportional to the bridge voltage. Higher resistence gauges permit higher bridge volts to be applied, with the subsequent increase in output, while still retaining adequate stability. A strain of 1000 micro-strain applied to a single active gauge, with a bridge excitation of 4 volts gives an output of approx. 2 millivolts. A resolution of one micro-strain or 2 micro-volts is frequently required.

19. CALCULATION OF STRESSES FROM ROSETTE GAUGES

The relationship between strain rosette readings and principal stresses are as given in Table 2. These formulae permit the calculation of principal stresses and the angle between the maximum principal stress and the gauge one axis.

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Baldwin Lima Hamilton (BLH) (U.S.A.)
Hottinger Baldwin Messtechnik (Germany)
Hewlett Packard Pty. Ltd. (U.S.A.)
Kyowa Strain Gauges (Japan)

Strain Equivalent of a Shunt Calibration Resister

R = Strain gauge resistance ΔR = Strain gauge resistance change
Re = Shunt calibration resistance   K = Strain factor of gauge

Now Strain $\varepsilon = \dfrac{\Delta L}{L} = \dfrac{\Delta R}{R} \cdot \dfrac{1}{K}$

From this, $\Delta R = \varepsilon \cdot R \cdot K$ Equation.1.

where ΔR = Resistance change in gauge due to strain ε
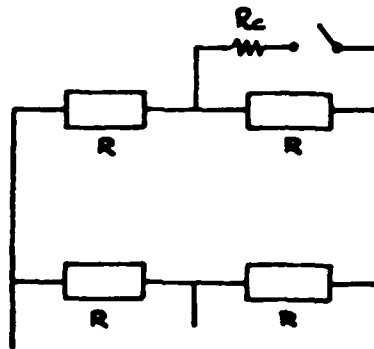
For a shunt calibration ΔR = Resistance change in the bridge arm shunted by Rc

$$\Delta R = R - \frac{R \cdot Re}{(R + Re)}$$ Equation.2.

To calculate the strain which would produce the same resistance change as the cal resistor, substitute Equation.1. for ΔR in Equation.2.

$$\varepsilon \cdot R \cdot K = R - \frac{R \cdot Re}{(R + Re)}$$

Divide both sides by R $\varepsilon \cdot K = \dfrac{1 - Re}{(R + Re)}$

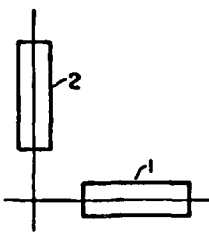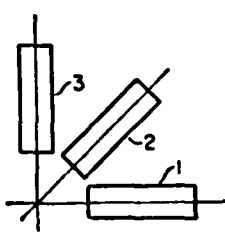$$\varepsilon = \frac{1}{K}\left[\frac{R + Re - Re}{(R + Re)}\right]$$

∴ Strain Equivalent $\varepsilon = \dfrac{1}{K} \cdot \dfrac{R}{(R + Re)}$ for a single active gauge.

$\varepsilon = \dfrac{1}{K} \cdot \dfrac{R}{(R + Re)} \cdot \dfrac{1}{B}$ for more than one active gauge where B is the bridge factor.

	Structural Steel	Stainless Steel	Aluminium
American Gauges	06	09	12
Japanese & European Gauges	11	17	23

TABLE 1.   TEMPERATURE COMPENSATION NUMBERS

Rosette types → Required solution ↓	Two-gage	Rectangular
Maximum normal stress σ_{max}	$\dfrac{E}{1-\mu^2}(\epsilon_1 + \mu\epsilon_2)$	$\dfrac{E}{2}\left\{\dfrac{\epsilon_1 + \epsilon_3}{1-\mu} + \dfrac{1}{1+\mu}\sqrt{(\epsilon_1 - \epsilon_3)^2 + [2\epsilon_2 - (\epsilon_1 + \epsilon_3)]^2}\right\}$
Minimum normal stress σ_{min}	$\dfrac{E}{1-\mu^2}(\epsilon_2 + \mu\epsilon_1)$	$\dfrac{E}{2}\left\{\dfrac{\epsilon_1 + \epsilon_3}{1-\mu} - \dfrac{1}{1+\mu}\sqrt{(\epsilon_1 - \epsilon_3)^2 + [2\epsilon_2 - (\epsilon_1 + \epsilon_3)]^2}\right\}$
Maximum shearing stress τ_{max}	$\dfrac{E}{2(1+\mu)}(\epsilon_1 - \epsilon_2)$	$\dfrac{E}{2(1+\mu)}\sqrt{(\epsilon_1 - \epsilon_3)^2 + [2\epsilon_2 - (\epsilon_1 + \epsilon_3)]^2}$
Angle from gage 1 axis to maximum normal stress axis φ_p	0	$\dfrac{1}{2}\tan^{-1}\left[\dfrac{2\epsilon_2 - (\epsilon_1 + \epsilon_3)}{\epsilon_1 - \epsilon_3}\right]$

E = Modulus of Elasticity (Youngs modulus)
μ = Poissons Ratio
$\epsilon_1, \epsilon_2, \epsilon_3$ = Strains in Gauges 1, 2 & 3.

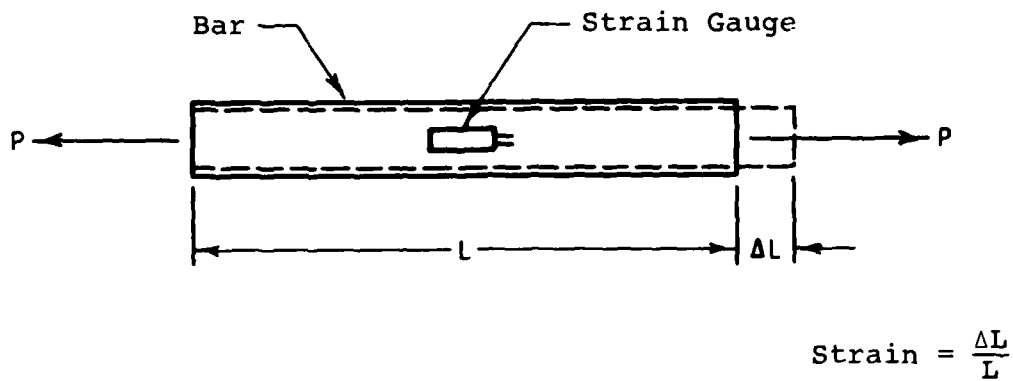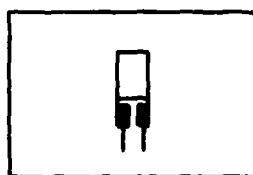TABLE 2.   RELATIONS BETWEEN STRAIN ROSETTE READINGS AND PRINCIPAL STRESSES

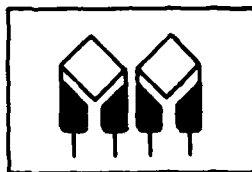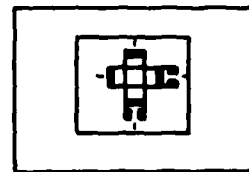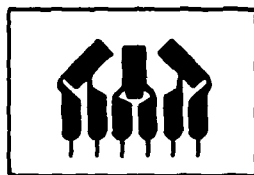Strain $= \dfrac{\Delta L}{L}$

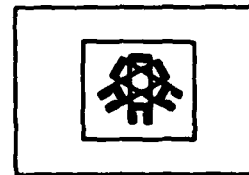FIG. 1.   TEST BAR

Linear Gauge

Flat Shear
Gauge

Stacked Shear
Gauge

Flat Rosette

Stacked Rosette
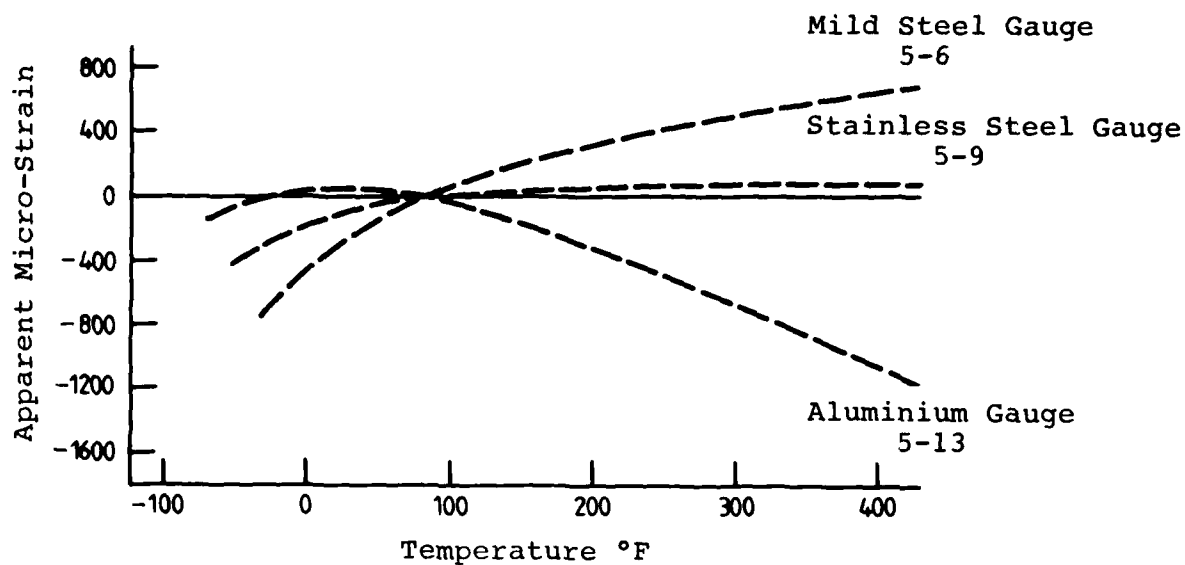
FIG. 2. GAUGE CONFIGURATIONS

FIG. 3. APPARENT STRAIN VERSUS TEMPERATURE FOR GAUGES
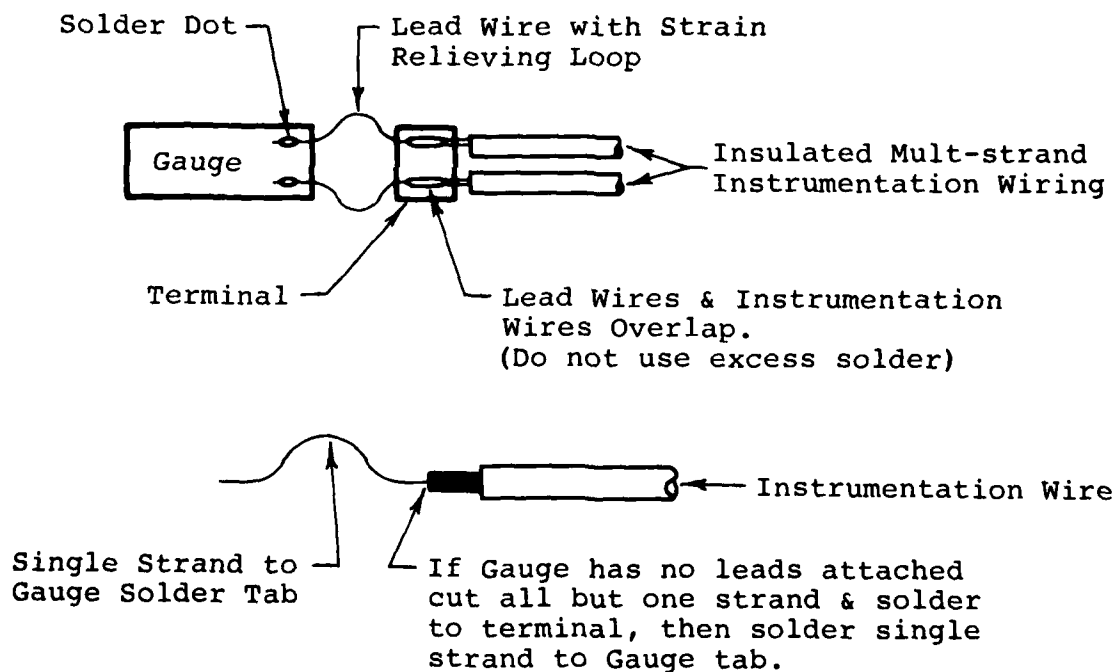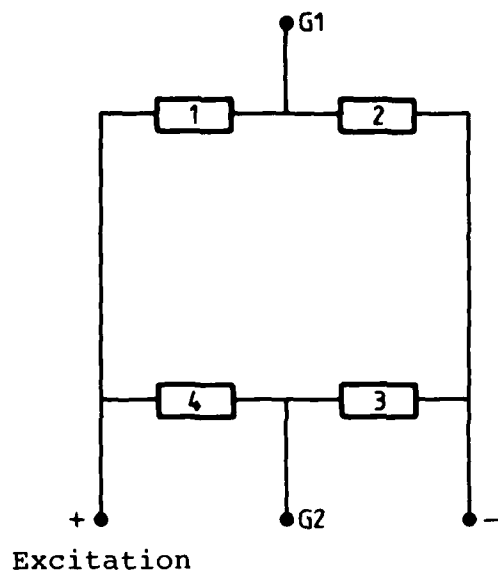ON STAINLESS STEEL

FIG. 4. METHOD OF USING TERMINALS

•G1

1   2

G2 is + output, for tension
in Guage 1.

One, two, or four gauges may
be attached to the test piece.
The other gauges may be on
dummy plates or built into
the measuring equipment.

4   3

+ •   •G2   • −

Excitation

FIG. 5.   GAUGES CONNECTED IN WHEATSTONE BRIDGE CIRCUIT.

Third wire for
temperature
compensation
of leads.

1

G1 •   2

Tension Compression
Measurement.

B = Bridge Factor = 1.00

4   3

+ •   G2•   • −

Excitation
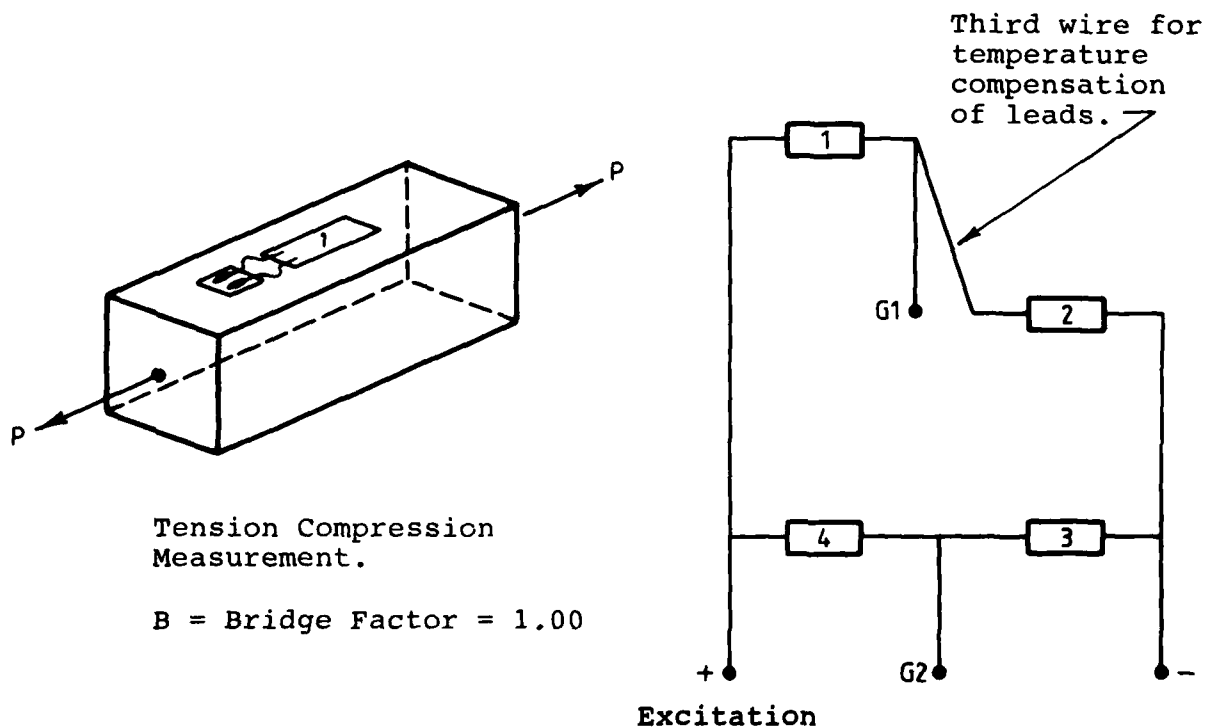
FIG. 6.   SINGLE GAUGE - 3 WIRE CONNECTION

Gauges

Dummy Plate

Poissons Ratio
Half Bridge

Bridge Factor B = 1.33

Dummy Plate
Half Bridge

B = 2.00

Poissons Ratio
Full Bridge

B = 2.66

Dummy Plate
Full Bridge
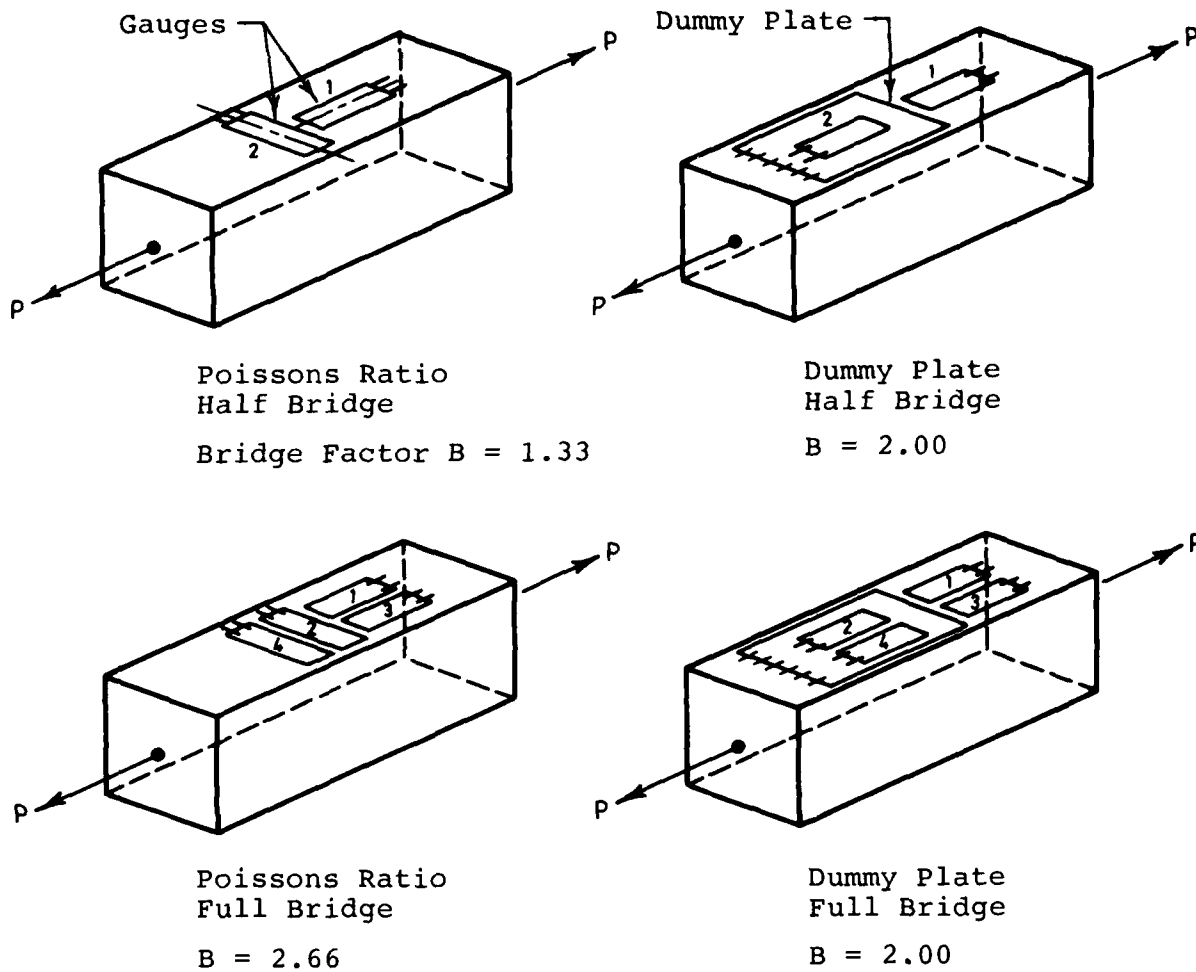
B = 2.00

FIG. 7.   TENSION - COMPRESSION STRAIN
(not compensated for bending)

Poissons Ratio
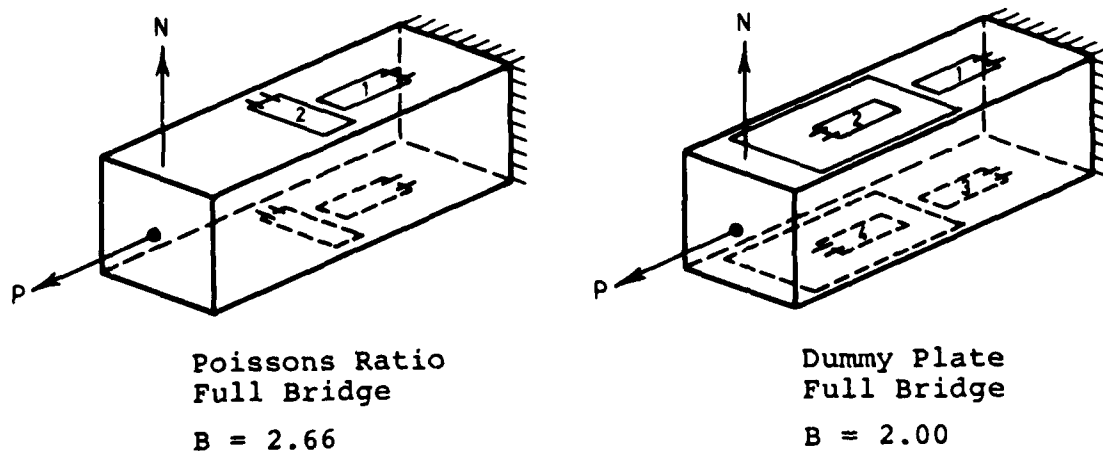Full Bridge
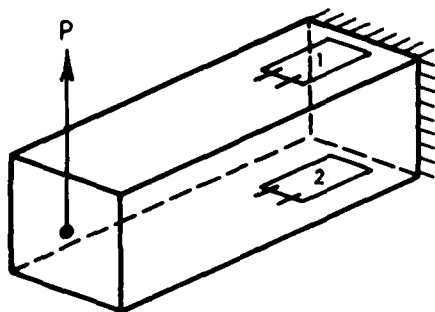
B = 2.66

Dummy Plate
Full Bridge

B = 2.00

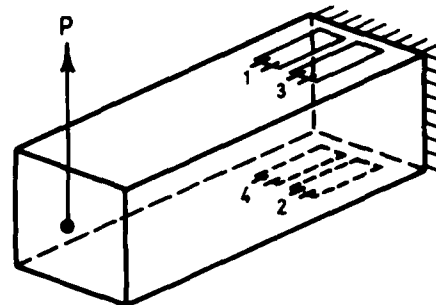FIG. 8.   TENSION - COMPRESSION STRAIN.
(compensated for bending)
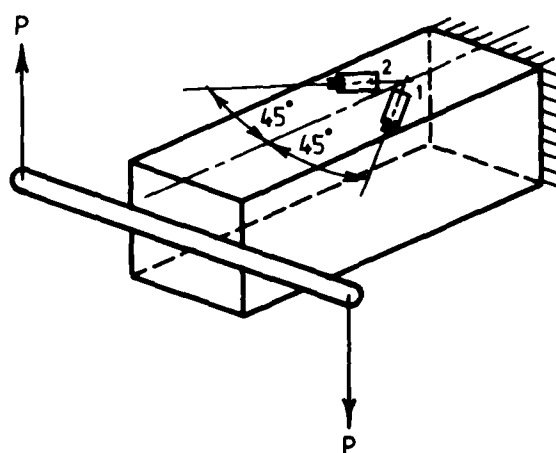
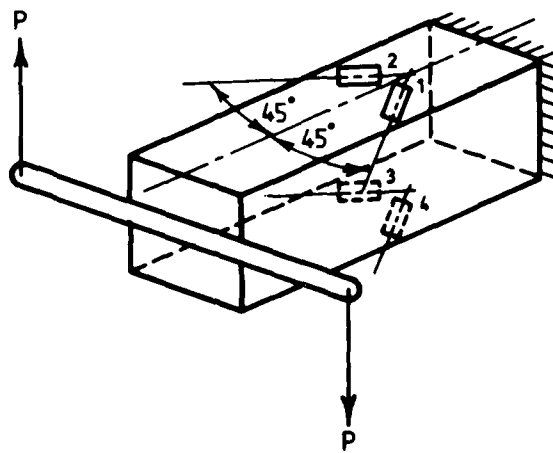Half Bridge. B = 2.00   Full Bridge. B = 4.00

FIG. 9.   BENDING STRAIN
          (compensated for tension, compression)

Half Bridge. B = 1.00   Full Bridge. B = 2.00

FIG. 10.   TORSION - SHEAR STRAIN
           (compensated for tension, compression)
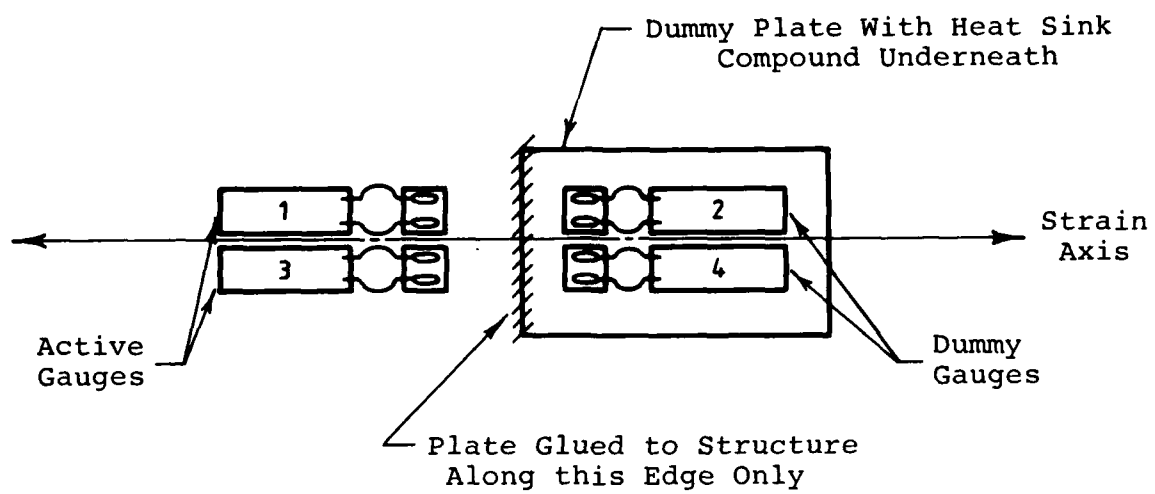
FIG. 11. STRAIN GAUGE BRIDGE WITH DUMMY GAUGES.
(wiring omitted for clarity)

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16. Abstract

        The electrical resistance strain gauge is a very reliable sensor, much used in structural and mechanical testing. This document has been prepared to assist the inexperienced technician in selecting and using these gauges. General recommendations are made regarding gauge types, adhesives, proofing materials and gauge techniques for a variety of environmental conditions. Oriﾠ ﾠ

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