Stress-Strain Measurement and Strain Gauge

Strain Measurement and Strain Gauges

Strain Measurement

o Strain is defined as the change in length of a line segment between two points divided by the original length of the segment.

o For the strain measurement it is the usual practice to make measurement over shortest possible gauge lengths.

Strain Gauges

o A strain gauges is a device which is used to measured dimensional change on the surface of the structural member under test.

o Strain gauges given indication of strain at only one point.

o Strain gauges are mostly used to measure strains on the free surface of a body. The state of strain at any point on the free surface of a body can be characterized in terms of three Cartesian strain components $\in_{xx}$, $\in_{yy}$ and γ_{xy} as

Strain Measurement and Strain Gauges

$$\in xx = \frac{\partial u}{\partial x}$$

$$\in yy = \frac{\partial v}{\partial y}$$

$$\gamma_{XY} = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}$$

Where *u* and *v* are the displacement components in *x* and *y* directions respectively. These equations suggest that if the two displacements *u* and *v* can be measured at all points on the surface of a body, strains at any point on the surface can be determined.

Requirement of Good Strain

o Cheaper, reliable and readily available.

o Negligible mass and extremely small size.

o High speed of response, negligible time lag.

o Capability to indicate static, transient and dynamic strain.

o Availability of gauge in variety of types and size suitable for a wide range of applications.

o Insensitiveness to ambient conditions (e.g., temperature , humidity, vibration etc.).

o Simple and easy attachment to the specimen under test.

o Non-interference with the stiffness and other characteristics of the member over which it is mounted.

Types of Strain Gauges

Strain gauges of all types are essentially devices that sense the change in length, magnify it and indicate it in some form. They can be classified into broadly three groups on the basis of the physical employed for the magnification of change in length.

o Mechanical Strain Gauges

o Optical Strain Gauges

o Electrical Strain Gauges

Mechanical Strain Gauges

- These mechanical devices are generally known as extensometers and are used to measure strain under static or gradually varying loading conditions.

- An extensometer is usually provided with two knife edges which are clamped firmly in contact with the test component at a specific distance or gauge length apart.

- When the test component is strained, the two knife edges undergo a small relative displacement.

- This is amplified through a mechanical linkage and the magnified displacement or strain is displayed on a calibrated scale.
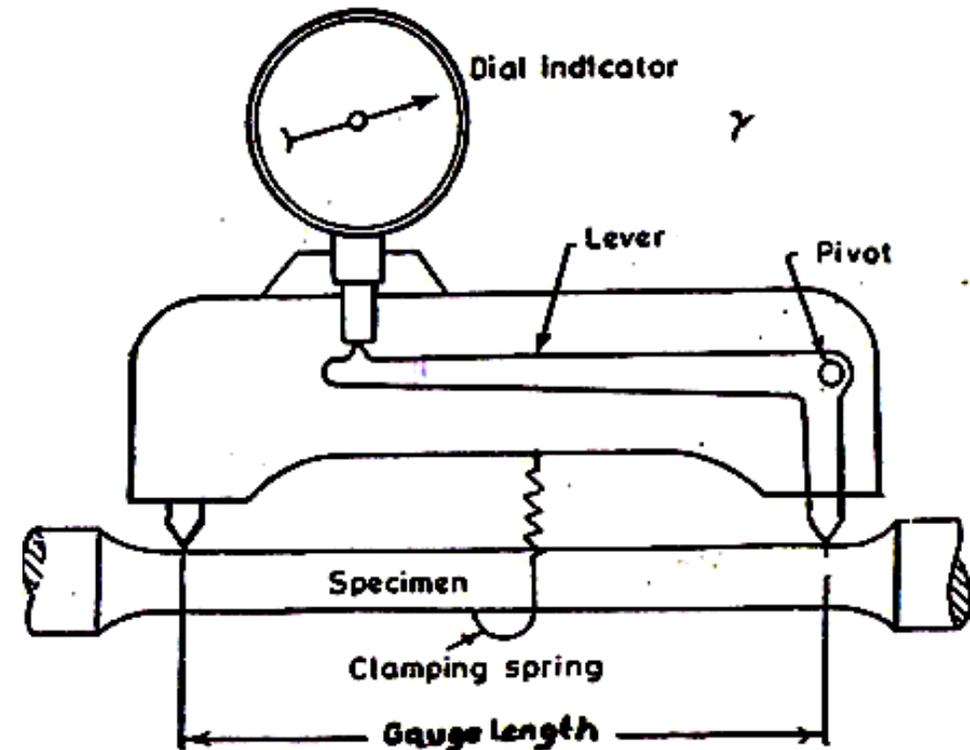
Advantage and disadvantage of Mechanical Strain Gauges

Advantage

o Self contained magnification system.

o No auxillary equipment required.

Disadvantage

o Owing to high inertia of the gauge, it is unsuitable for dynamic measurements and varying strain.

o Slow response (due to high inertia)

o Non-availability of adequate surface area on the test specimen and clearance above it to accommodate the gauge together with its mounting fixture.

Optical Strain Gauges

- Optical gauges a combination of mechanical and optical levers are used to amplify the relative displacement between the knife edges.

- So that it rotates while undergoing displacement. The principle of the signal mirror system is illustrated in Figure.

- The pivoting knife edge carries a mirror A. The reflection of an illuminated scale B in this mirror is viewed through the observing telescope.

- Any deformation of the structure to which this gauge is fixed, rotates the mirror A and thereby brings different portion of the scale into view.
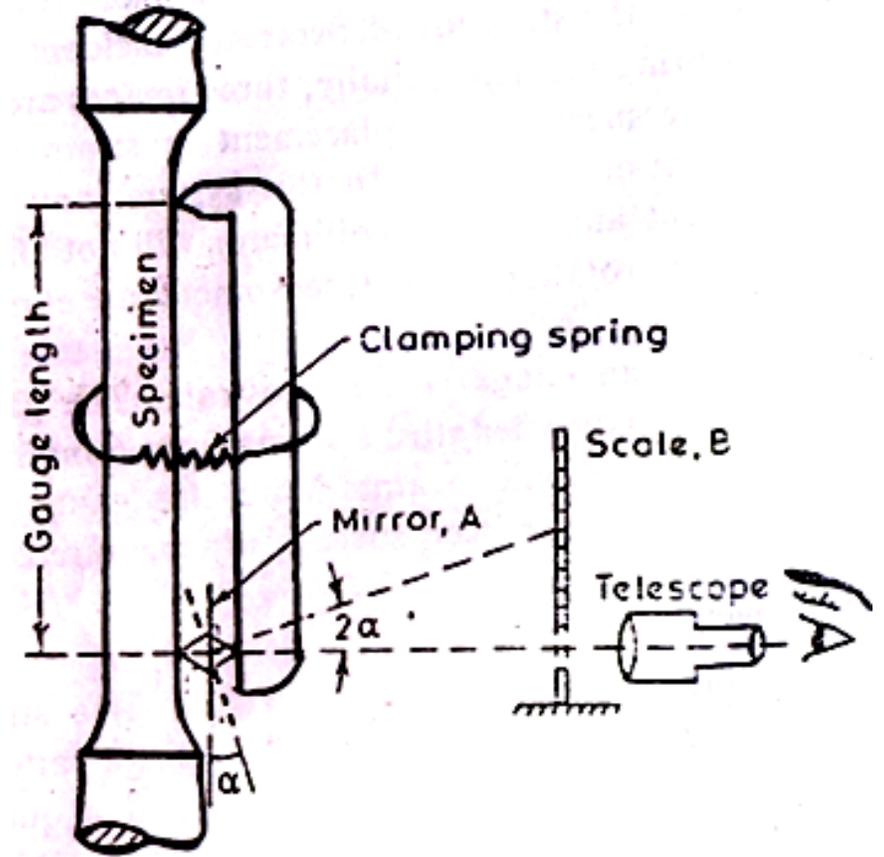
**Figure: Martens optical gauge**

Optical Strain Gauges

- A schematic diagram of the Tuckerman optical gauge and the autocollimator used with it is given in Figure.

- The autocollimator carries both the source of a parallel beam of light to measure the deflection of the reflected ray.

- The sensitivity of the Tuckerman gauge is 2 micro strain. The gauge is available with a wide range of gauge lengths, starting from 6 mm. It can reliably measure both static and dynamic strains.
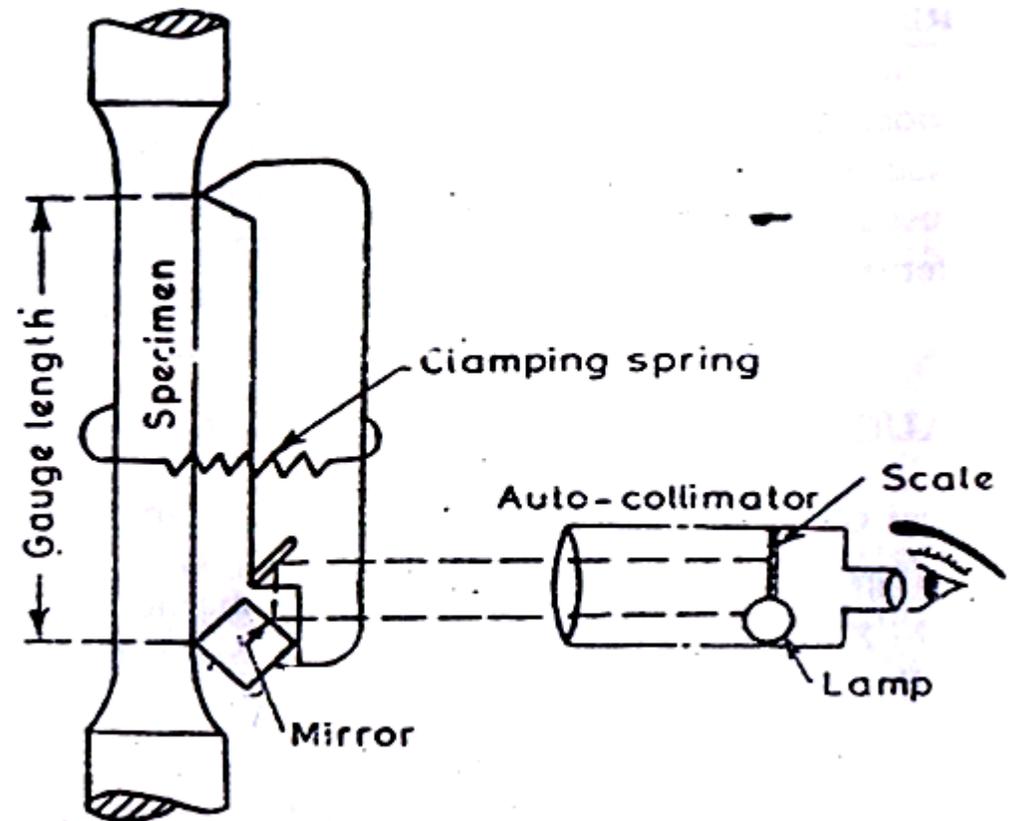

Tuckerman optical gauge

Electrical Resistance Strain Gauge

o Strain Gauge is a passive transducer that converts a mechanical elongation or displacement produced due to a force into its corresponding change in resistance (R) or electrical signal.

o A strain gauge is basically used to measure the strain in a work piece.

o If a metal piece is subjected to a tensile stress, the metal length will increase and thus will increase the electrical resistance of the material. Similarly, if the metal is subjected to compressive stress, the length will decrease, but the width will increase.
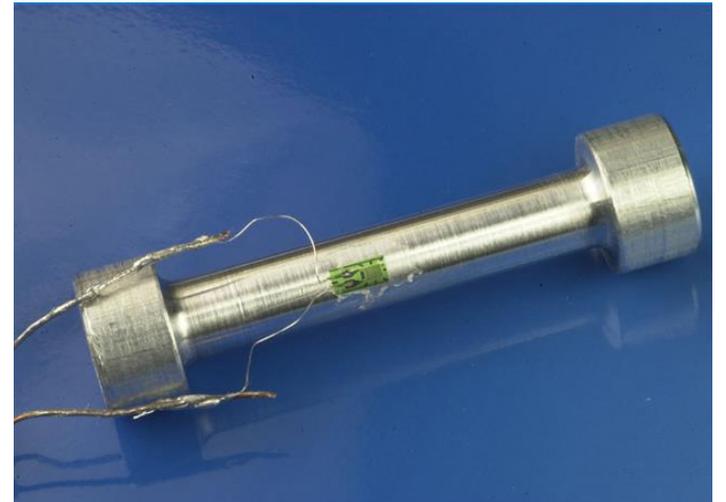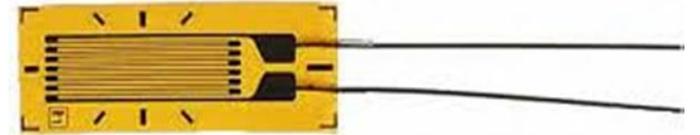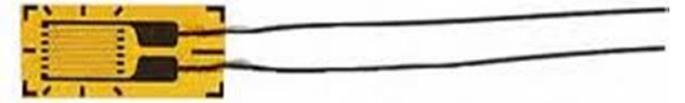
Structure of Strain Gauge

o The majority of strain gauges are of foil type available in different shape and size.

o They consist of a pattern of resistive foil which is mounted on a backing material.

o They operate on the principle that as the foil is subjected to stress, the resistance of the foil changes in a defined way.
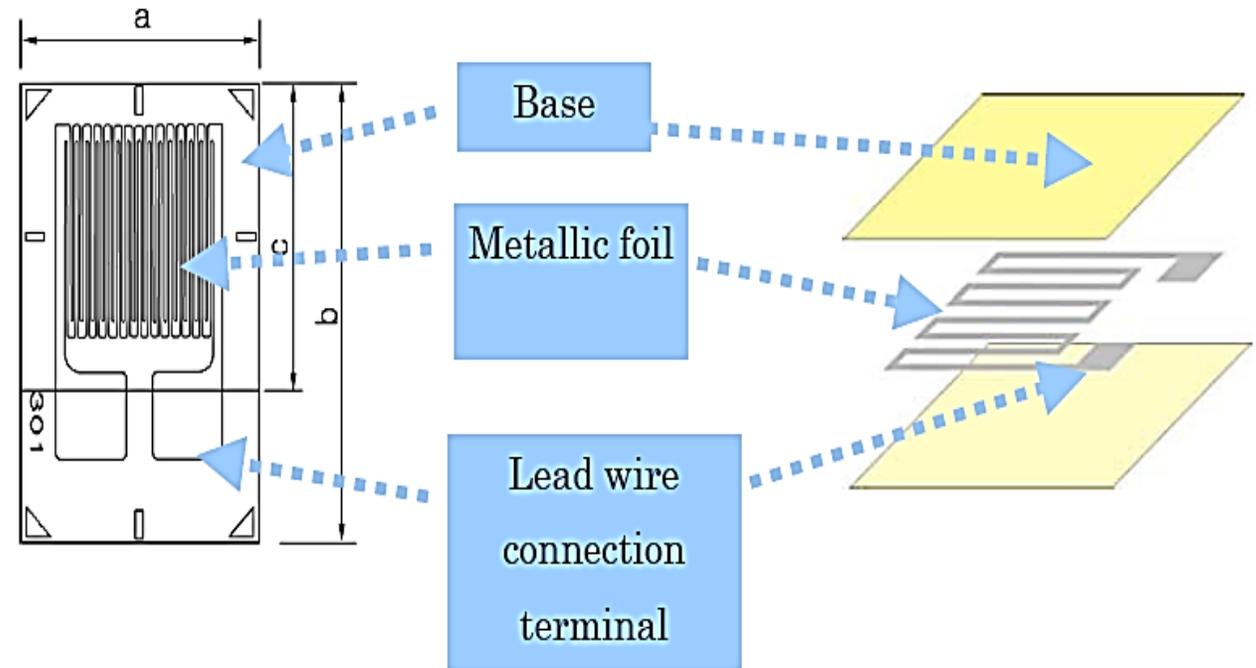
Structure of Strain Gauge
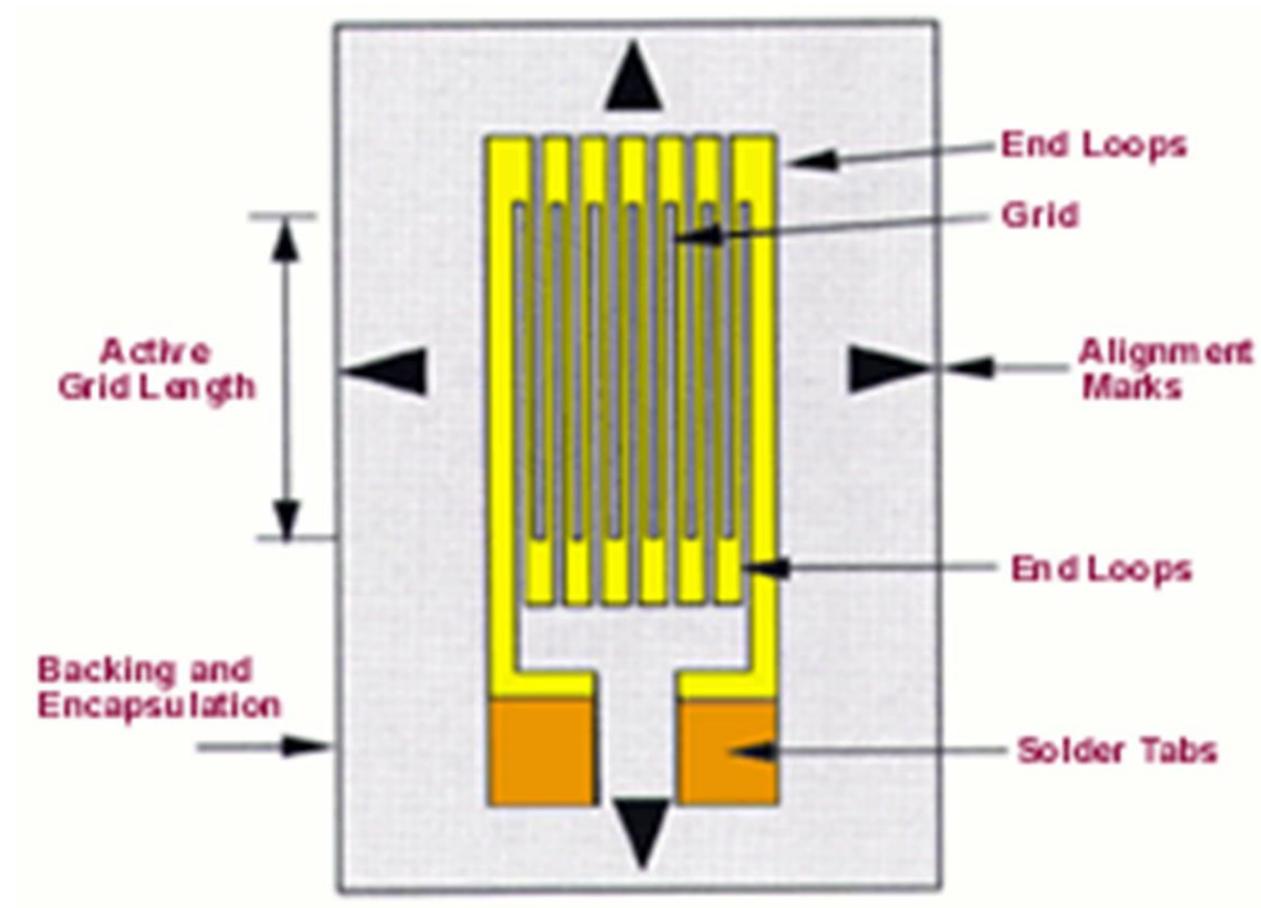
Working of Strain Gauge

The strain gauge is connected into a Wheatstone Bridge circuit. The change in resistance is proportional to applied strain and is measured with Wheatstone bridge.
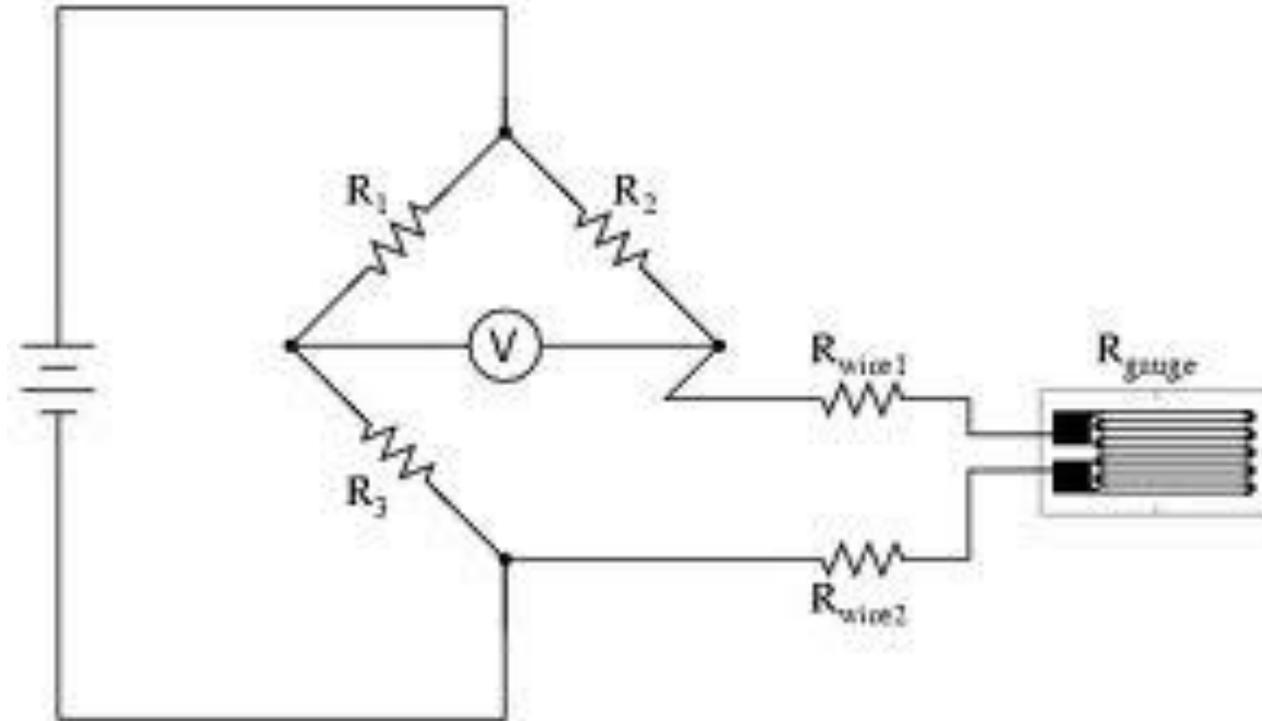
Working of Strain Gauge

The sensitivity of a strain gauge is described in terms of a characteristic called the gauge factor, defined as unit change in resistance per unit change in length.

$$K = \frac{\Delta R/R}{\Delta l/l}$$

- K = the gauge factor
- R = the initial resistance in ohms (without strain)
- ΔR = the change in initial resistance in ohms
- L = the initial length in meters (without strain)
- ΔL = the change in initial length in meters

$$R = \rho\, L/A$$

- o ρ = the resistivity of the material (Ohms*m)
- o L = the length of the conductor (m)
- o A = the cross-sectional area of the conductor (m^2)

Tension

Compression

$l \downarrow$ $l \uparrow$

$R \downarrow$ $R \uparrow$
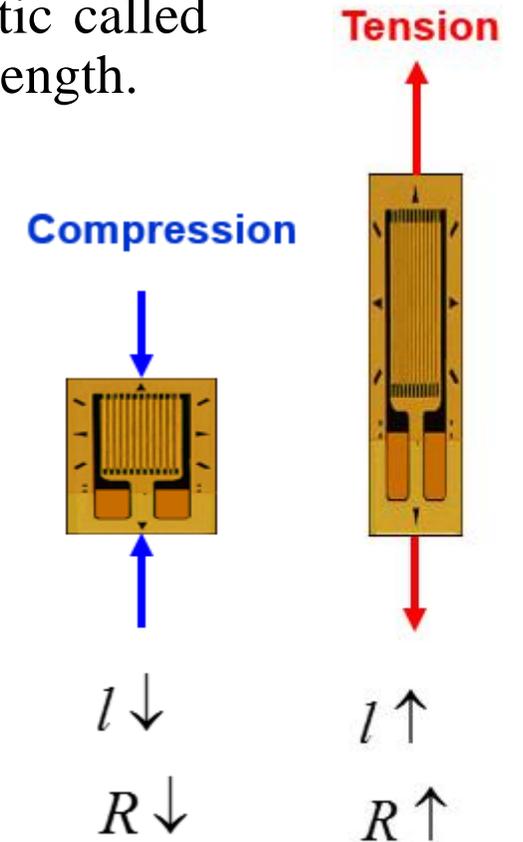
What's the Wheatstone Bridge?

- Wheatstone bridge is an electric circuit suitable for detection of minute resistance changes, therefore used to measure resistance changes of a strain gage

- The bridge is configured by combining four resistors as shown in Figure.

- Initially R1=R2=R3=R4, in this condition no output voltage is there, **e=0**

- When one of the Resistances is replaced by strain Gauge attached to the object whose strain is to be measured and load is applied, then there is small change in the resistance of gauge, hence some output voltage is there which can be related to strain as $e = \dfrac{1}{4} \cdot \dfrac{\Delta R}{R} \cdot E$

- From this, strain can be easily determined using the relation

$$e = \dfrac{1}{4} \cdot K \cdot \varepsilon \cdot E$$
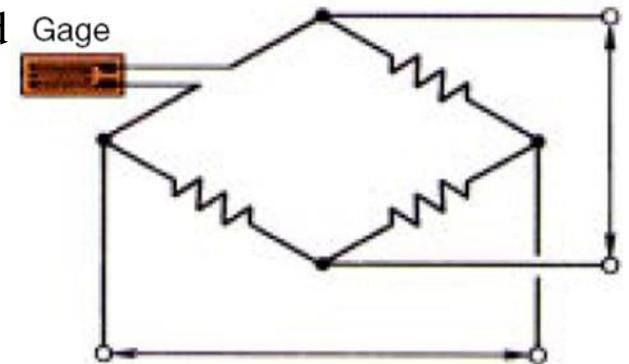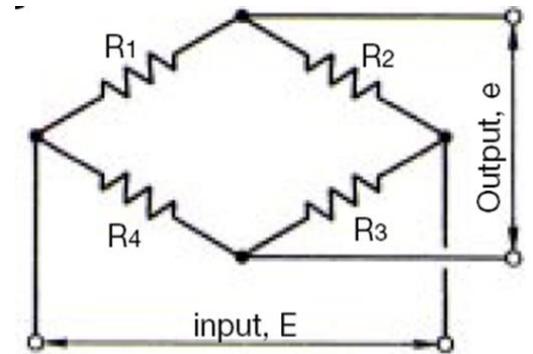
Half Bridge Configuration

To increase the sensitivity of measurement, two strain gauges are connected in the bridge, this type of configuration is called as Half bridge as shown in figure and the output voltage and strain can be related as

$$e = \frac{1}{4} K (\varepsilon_1 - \varepsilon_2) E$$

When gauges are connected to adjacent arms and

$$e = \frac{1}{4} K (\varepsilon_1 + \varepsilon_3) E$$

When gauges are connected to opposite arms
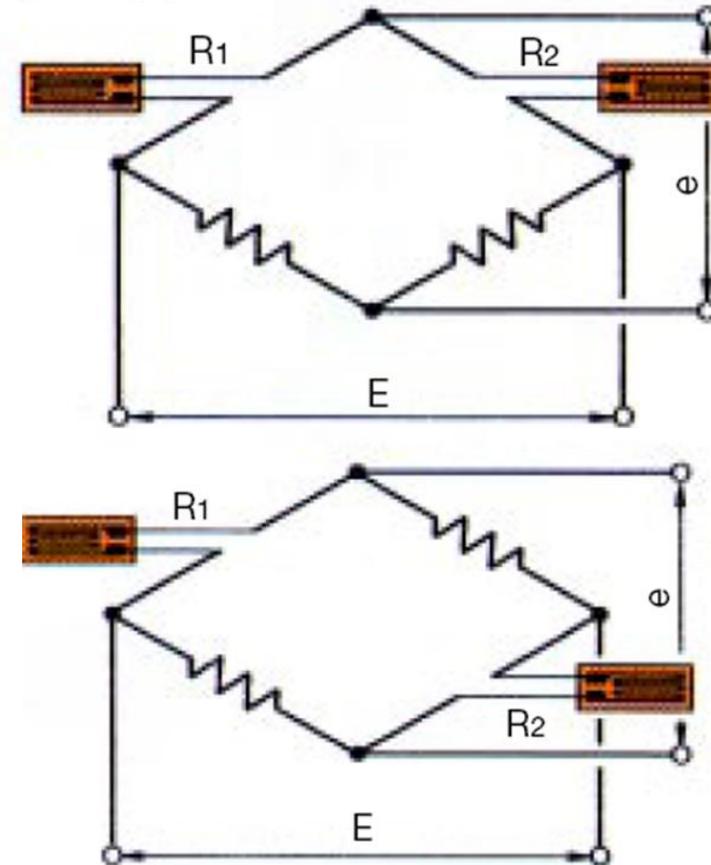
Full Bridge Configuration

To further enhance the sensitivity, all 4 resistances are replaced by strain gauges. While this system is rarely used for strain measurement, it is frequently applied to strain-gage transducers. When the gages at the four sides have their resistance changed to R1 + ΔR1, R2 + ΔR2, R3 + ΔR3 and R4 + ΔR4, respectively, the bridge output voltage, e, is

$$e = \frac{1}{4}\left(\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} - \frac{\Delta R_4}{R_4}\right) E$$

Or

$$e = \frac{1}{4} \cdot K\,(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4)\, E$$

Where K is the Gauge Factor.
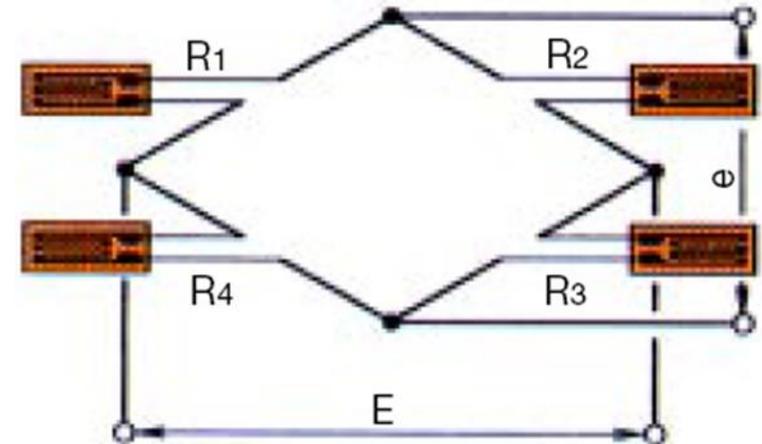
Selection of a Strain Gauge

o Nature of the strain to be detected

o Gauge Length

o Number of Gauges in Gauge Pattern

o Arrangement of Gauges in Gauge Pattern

o Grid Resistance

o Temperature sensitivity

o Carrier Material

o Gauge Width

o Availability

o low cost

Electrical Resistance Type Strain Gauge

Based on mounting :
- Bonded strain gauge
- Un-bonded strain gauge

Based on construction :
- Foil strain gauge
- Semiconductor strain gauge

Bonded Strain Gauge

A bonded strain-gage element, consisting of a metallic wire, etched foil, vacuum-deposited film, is cemented to the strained surface.
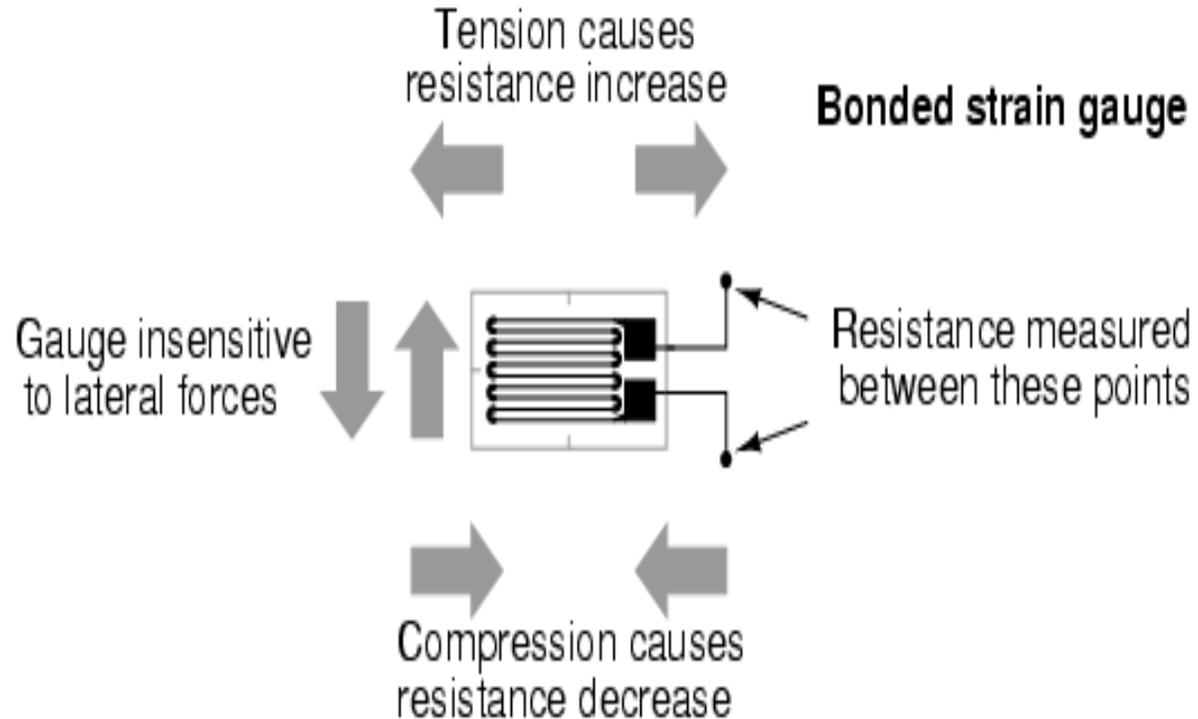
Un-bonded Strain Gauge

The unbonded strain gage consists of a wire stretched between two points in an insulating medium such as air. One end of the wire is fixed and the other end is attached to a movable element.

Unbonded Strain Gauge
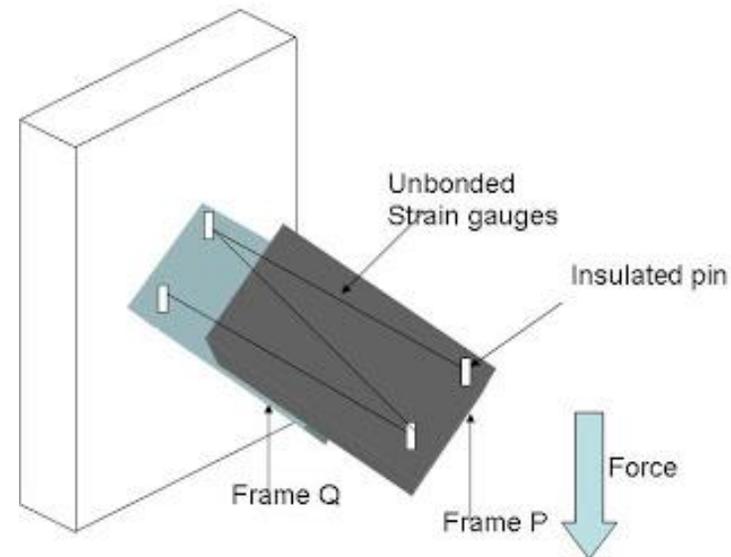
Foil Strain Gauge

The foil strain gage has metal foil photo-etched in a grid pattern on the electric insulator of the thin resin and gage leads attached.
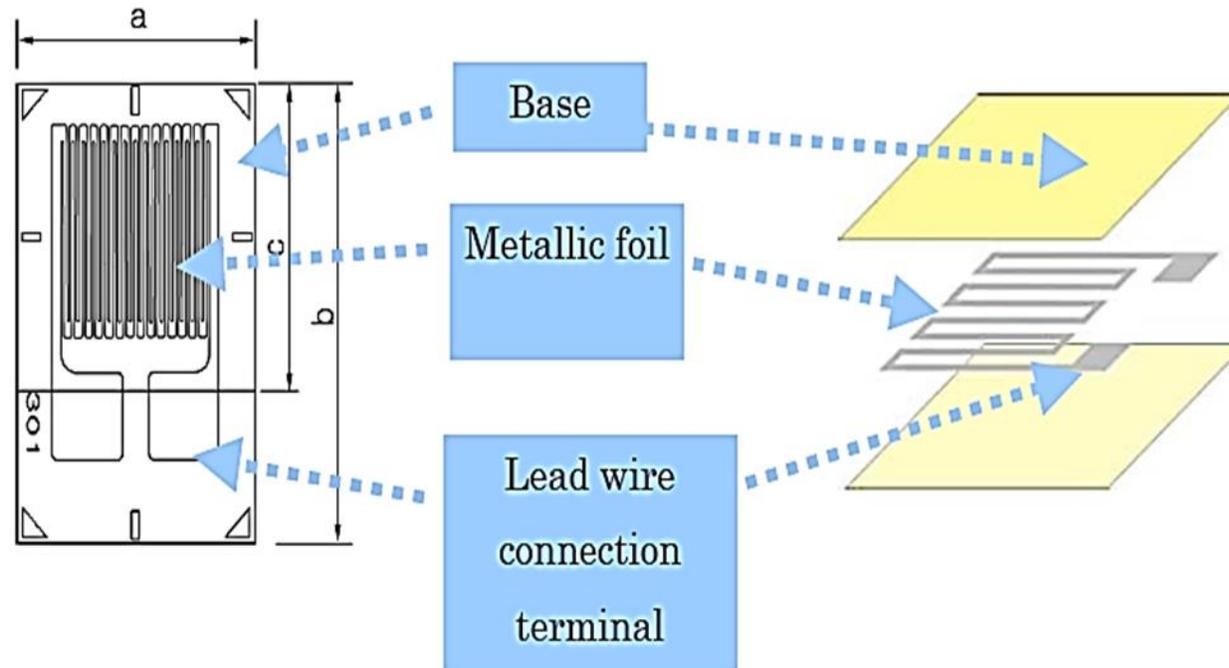
Semiconductor Strain Gauge

For measurements of small strain, semiconductor strain gauges, so called piezoresistors, are often preferred over foil gauges. Semiconductor strain gauges depend on the piezoresistive effects and measure the change in resistance with stress as opposed to strain.
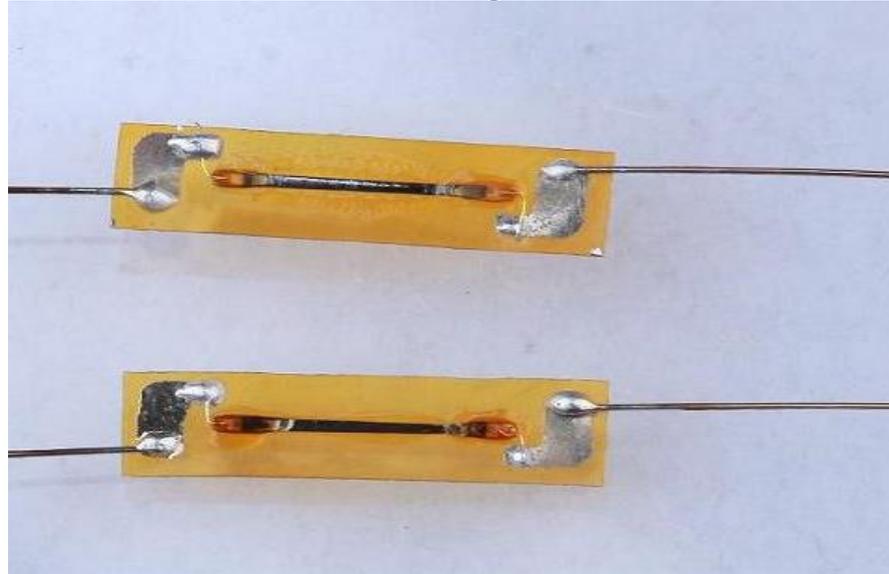
The piezoresistive effect is a change in the electrical resistivity of a semiconductor or metal when mechanical strain is applied. In contrast to the piezoelectric effect, the piezoresistive effect causes a change in electrical resistance.

Bending Beam
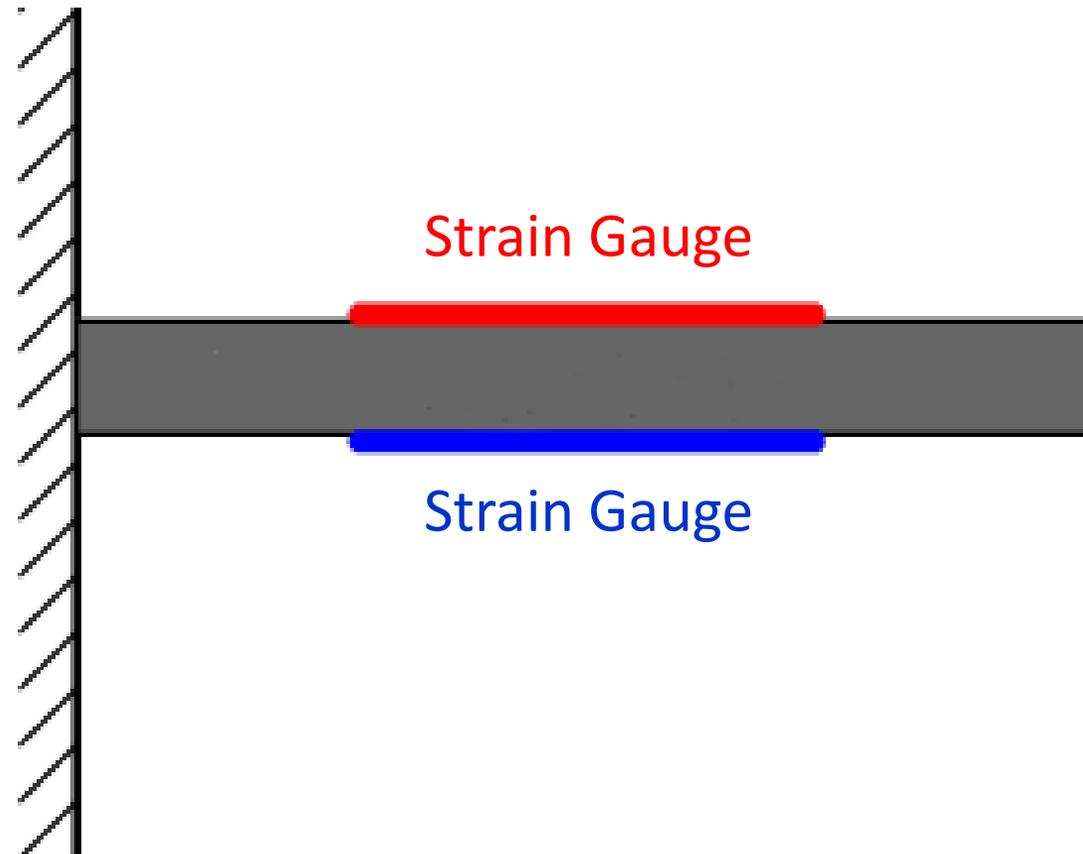
# Bending Beam
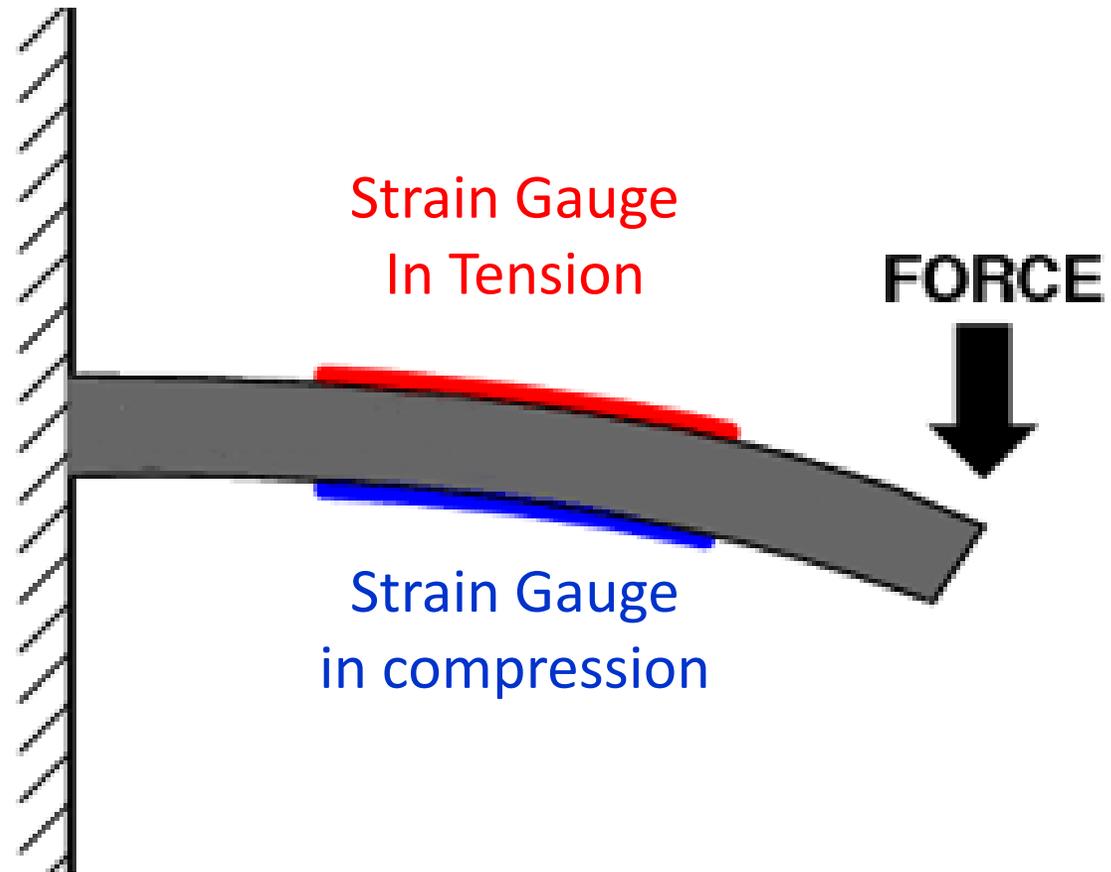
Advantages & Disadvantages

Advantages

o It has high accuracy and good stability.

o Easy to fabricate and install.

o Input is directly proportional to output.

o They can withstand high temperature.

o It consume very less power.

o Good repeatability.

o Rugged construction.

o Its output is very high.

Disadvantages

o It is non-linear.

o It needs to be calibrated.

Applications

o Residual stress

o Vibration measurement

o Torque measurement

o Bending and deflection measurement

o Compression and tension measurement

o Strain measurement

Bonding Procedure

- **Select Strain Gauge**

The two primary criteria for selecting the right type of strain gauge are sensitivity and precision. So Select the strain gauge model and gage length which meet the requirements of the measuring object and purpose
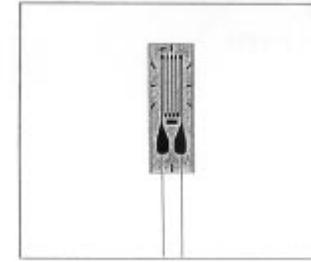

- **Remove Dust and Paint**

Using a sand cloth polish the strain-gage bonding site over a wider area than the strain-gage size. Wipe off paint, rust and plating, if any, with a grinder or sand blast before polishing
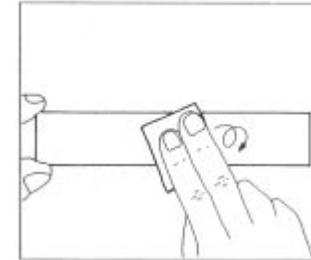

- **Decide Bonding Position**

Using a pencil or a marking-off pin, mark the measuring site in the strain direction. When using a marking off pin, take care not to deeply scratch the strain-gage bonding surface
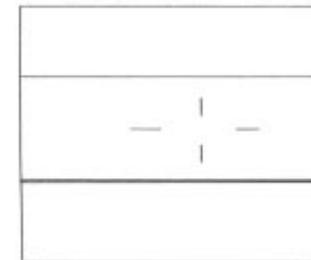
Bonding Procedure

- **Remove grease from bonding surface and clean**

Using an industrial tissue paper (SILBON paper) dipped in acetone, clean the strain-gage bonding site. Strongly wipe the surface in a single direction to collect dust and then remove by wiping in the same direction. Reciprocal wiping causes dust to move back and forth and does not ensure cleaning
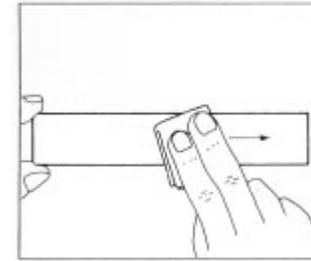

- **Apply adhesive**

Ascertain the back and front of the strain gage. Apply a drop of adhesive to the back of the strain gage. Do not spread the adhesive. If spreading occurs, curing is adversely accelerated, thereby lowering the adhesive strength
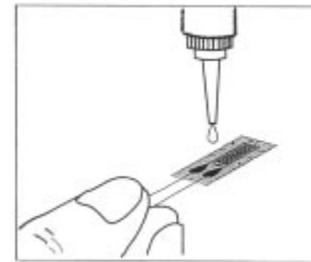
Bonding Procedure

- **Bond strain gage to measuring site**

After applying a drop of the adhesive, put the strain gage on the measuring site while lining up the center marks with the marking off lines
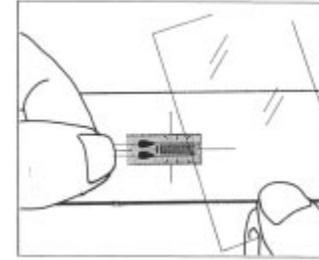
- **Press strain gauge**

Cover the strain gage with the accessory polyethylene sheet and press it over the sheet with a thumb. Once the strain gage is placed on the bonding site, do not lift it to adjust the position
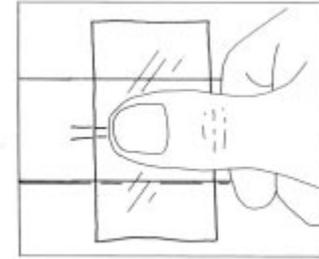
- **Complete bonding work**

After pressing the strain gage with a thumb for one minute or so, remove the polyethylene sheet and make sure the strain gage is securely bonded. The above steps complete the bonding work. However, good measurement results are available after 60 minutes of complete curing of the adhesive
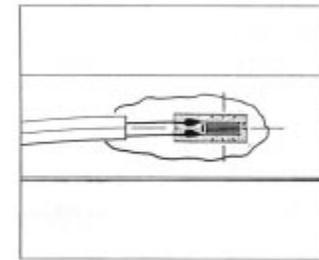
Measuring Strain with a Strain-Indicator

o First install a strain gauge

o Connect the wires from the strain gauge to the strain indicator.

o Apply loading conditions

o Read strain from strain indicator

– Note that the indicator always displays 4 digits and reads in microstrain!

– Thus, 0017 means 17 micro-inches / inch of strain.