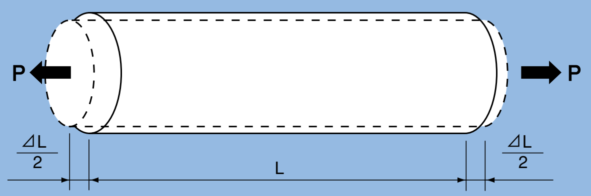
GENERAL DESCRIPTION

TML Strain Gauges are widely used for physical force measurement in mechanical, marine, aircraft and civil engineering as well as the fields of architecture, automobiles, and medical science.
Strain is measured; to determine a degree of deformation due to mechanical strain to determine forces such as stress or load and the degree of safety of a material or of a structural element that uses that material.
There are a number of ways of measuring strain mechanically and electrically, but the vast majority of stress measurement is carried out using strain gauges due to their superior measurement characteristics. Backed by our long experience and advanced technology, TML lines up a lot of strain gauges to meet with your needs.

What is STRAIN

When a material is streched (or compressed), the force used generates a corresponding stress inside. This stress in turn generates a proportional tensile strain (or compressive strain) which deforms the material by L+⊿L (or L−⊿L). Where L is the original length of the material. When this occurs, the ratio of ⊿L to L is called strain.



$$\varepsilon = \frac{\Delta L}{L}$$

ε : strain
L : Original length of material
⊿L : Increment due to force P

Example) when a material of 100mm length deforms by 0.1mm length, it generates strain as follows.

$$\varepsilon = \frac{\Delta L}{L} = \frac{0.1}{100} = 0.001 = 1000 \times 10^{-6}$$

What is STRAIN GAUGE

External force applied to a ferritic material generates physical deformation and electrical resistance change of the material. In case that such material is sticked onto test specimen via electrical insulation, the material produces a change of electrical resistance corresponding to the deformation. Strain gauges consist of electrical resistance material and measure proportional strains to the resistance changes.

STRAIN GAUGE PRINCIPLES

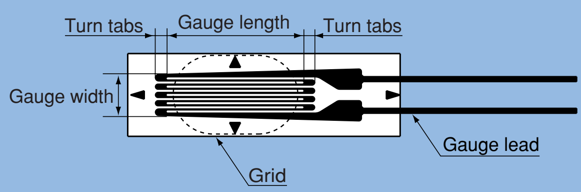
When strain is generated in a test specimen and a strain gauge is attached, the strain is relayed via the gauge base(electrical insulation) to the resistance wire or foil in the gauge. As a result, the fine wire or foil experiences a variation in electrical resistance. This variation is exactly proportional to the strain.

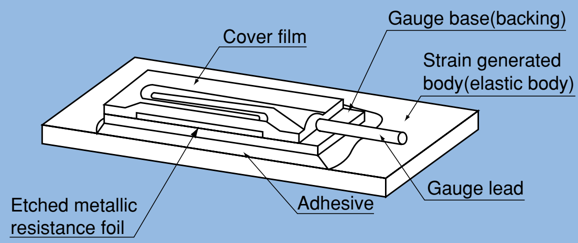
$$\varepsilon = \frac{\Delta L}{L} = \frac{\Delta R / R}{K}$$

ε : strain measured
R : Gauge resistance
⊿R : Resistance change due to strain
K : Gauge Factor as shown on package

STRAIN GAUGE CONFIGURATION

A strain gauge is constructed by bonding a fine electric resistance wire or photographically etched metallic resistance foil to an electrical insulation base using an appropriate bonding materials, and attaching gauge leads.





SELECTING STRAIN GAUGES

Strain gauges are provided with many convenient features, but they also have limitations. Each strain gauge has its limitations in terms of temperature, fatigue, the amount of strain, and the measurement environment. These limitations must be examined before a strain gauge is used.

●Strain Gauge Featuring
- Simple construction with a small mass and volume so as not to interfere with the stresses on the specimen.
- Short distance between measuring points for localized evaluation.
- Good frequency response for tracking rapid fluctuations in stress.
- Simultaneous measurement of multiple points and remote measurement.
- Electrical output for easy data processing.

TECHNICAL TERMS

GAUGE LENGTH

This dimension represents the actual grid length in the sensitive direction.

GAUGE RESISTANCE

Gauge resistance in ohms (Ω) expresses electrical resistance under free conditions at room temperature, unbonded as supplied.

GAUGE FACTOR

The amount shown in the following equation is called the gauge factor. In this equation, ε indicates the strain generated due to uniaxial stress in the direction of the strain gauge axis. $\Delta R/R$ shows the ratio of resistance change due to strain ε. This is generally indicated by specifying the Poissson's ratio of the test specimen used.

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

, where K : Gauge Factor
ε : Mechanical strain
R : Gauge Resistance
ΔR : Resistance variation

TRANSVERSE SENSITIVITY (Kt)

The gauge also exhibits sensitivity in the direction perpendicular to the axial diretion. The amount shown in the following equation due to the uniaxial strain (ε t) in the direction perpendicular to the gauge axis, and the resistance variation generated thereby, is called transverse sensitivity (Kt).

$$K_t = \frac{\Delta R / R}{\varepsilon_t} \times 100$$

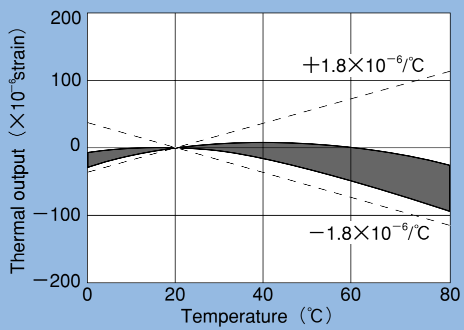
, where K_t : Transverse sensitivity
ε_t : uniaxial strain

TEMPERATURE COMPENSATION RANGE

This refers to a temperature range in which the thermal output of a self-temperature compensated gauge conforms to the requirement. Compensation is accurate within approximately $\pm 1.8 \times 10^{-6}$ strain/℃. For greater accuracy, corrections can be made using the curves for apparent strain vs. temeprature which are supplied with each package of gauge.

SELF-TEMPERATURE COMPENSATED GAUGES

The ambient temperature change may cause a variation of strain gauge resistance. The amount of variation is subject to the thermal expansion of both the strain gauge material and the specimen, together with the thermal coefficient of resistance of the gauge material. Self-temprature compensated gauges are commonly used to minimize the gauge thermal output when bonded to test specimens having a specific linear thermal expansion coefficient in the specified temeprature range. The following graph shows an example of thermal output.



OPERATIONAL TEMPERATURE RANGE

The temperature range listed in the Normal column of the selection is for stable static measurement. The Short-Term or Special column indicates the range for dynamic measurement, short term measurement or measurement without temperature change.

STRAIN LIMIT

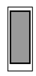
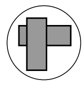
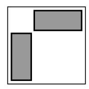
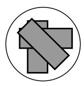
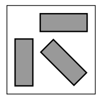
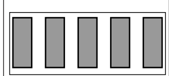
The strain limit or allowable elongation percent depends on the properties of the wire, foil material, backing, and adhesive used. In general, the strain limit for a gauge with a short gauge length is slightly lower than that for one with a longer gauge length in the same series.

FATIGUE LIFE

When strain is repeatedly applied to the gauge, it causes increased resistance under zero strain, peeling-off of the gauge, or disconnection, resulting in failure. The number of repeated cycles that the gauge can endure is called its fatigue life. It is generally indicated by the repetition number under the specified conditions of strain amount and repetition speed as apparent strain drifts to 100×10^{-6} strain from the beginning. The fatigue life of TML gauges depends mainlly on the properties of the backing material and adhesive used. This varies somewhat with the size and configuration of the grid. In general, larger gauges exhibit better fatigue performance. It is advisable to use foil gauges where maximum resistance to fatigue is required.

STRAIN GAUGE SHAPE

TML also supplies strain gauges in different patterns for a range of applications. Select the appropriate gauge patterns for your application.

Qty. of elements	1	2	2
Gauge pattern			
Nomenclature	Single element	2-element Cross	2-element Cross
Grid layout	—	Stacked type	Plane type
Qty. of elements	3	3	5
Gauge pattern			
Nomenclature	3-element Rosette	3-element Rosette	5-element Single-axis
Grid layout	Stacked type	Plane type	—

GAUGE LENGTH SELECTION

Different gauge length should be selected depending on the specimen. Gauges with short gauge lengths are used to measure localized strain, while gauges with long lengths can be used to measure averaged stress over a larger area. For a heterogeneous material, a gauge length is required that can average out the irregular stresses in the material. For example, because concrete is composed of cement and an aggregate (gravel or sand, etc.), the length of the gauge used is three times the diameter of the gravel pieces so as to give an averaged evaluation of the concrete.

Gauge length	Gauge applications
0.2～1 mm	For stress concentration measurement
2～6 mm	For metal and general use
10～20 mm	For mortar, wood, FRP, etc.
30～120 mm	For concrete

FREQUENCY RESPONSE

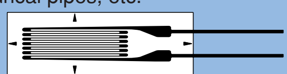
The frequency response of a strain gauge is determined by the gauge length and the longitudinal elastic wave speed of the test specimen.

Gauge length (mm)	0.2	1	3	5	10	30	60
Steel [kHz]	660	530	360	270	170	—	—
Concrete [kHz]	—	—	—	—	120	50	20

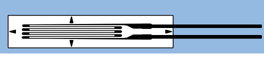
GAUGE WIDTH

Strain gauges with the same gauge length are also available in a narrower width (FLK-type). Select narrow strain gauges for thin specimens such as cylindrical pipes, etc.

FLA type



FLK type



STRAIN GAUGES ANALYSIS

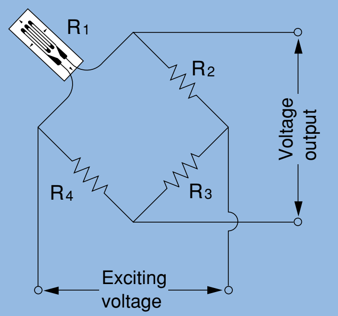
STRAIN GAUGE MEASUREMENT

When strain is generated in a test specimen and a strain gauge is attached, the strain is relayed via the gauge base(electrical insulation) to the resistance wire or foil in the gauge. As a result, the fine wire or foil experiences a variation in electrical resistance. This variation is exactly proportional to the strain.

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

ε : strain measured
R : Gauge resistance
ΔR : Resistance change due to strain
K : Gauge Factor as shown on package

Normally, this resistance change is very small and requires a Wheatstone bridge circuit to convert it to voltage output.



The voltage output of a bridge circuit is given as follows.

$$e = \frac{R_1R_3 - R_2R_4}{(R_1+R_2)(R_3+R_4)}E$$

e : Voltage output
E : Exciting voltage
R_1 : Gauge resistance
$R_2 \sim R_4$: Fixed resistance

Assuming the value R such that $R = R_1 = R_2 = R_3 = R_4$, the active gauge resistance varies to $R+\Delta R$ due to strain. Thus, the output voltage Δe(variation) due to the strain is given as follows.

$$\Delta e = \frac{\Delta R}{4R + 2\Delta R}E$$

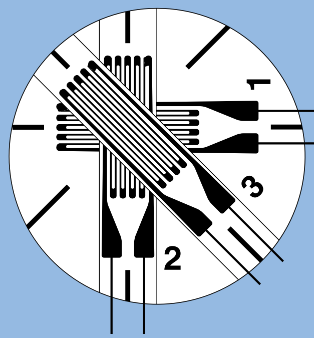
When $\Delta R \ll R$,

$$\Delta e = \frac{\Delta R}{4R}E = \frac{E}{4}K\varepsilon$$

The strain gauge is connected to a strainmeter, which provides the Wheatstone bridge circuit and exciting input voltage. The strain (ε) is measured on a digital or analog display.

CALCULATION FOR 3-ELEMENT ROSETTE ANALYSIS

The principal strain and its direction are calculated with a 45°/90° 3-element strain gauge, as described below.



Maximum principal strain

$$\varepsilon_{max} = \frac{1}{2}\left[\varepsilon_1 + \varepsilon_2 + \sqrt{2\{(\varepsilon_1-\varepsilon_3)^2 + (\varepsilon_2-\varepsilon_3)^2\}}\right]$$

Minimum principal strain

$$\varepsilon_{min} = \frac{1}{2}\left[\varepsilon_1 + \varepsilon_2 - \sqrt{2\{(\varepsilon_1-\varepsilon_3)^2 + (\varepsilon_2-\varepsilon_3)^2\}}\right]$$

Maximum shearing strain

$$\gamma_{max} = \sqrt{2\{(\varepsilon_1-\varepsilon_3)^2 + (\varepsilon_2-\varepsilon_3)^2\}}$$

Angle from ε_1 gauge to direction of principal strain

$$\phi_P = \frac{1}{2}\tan^{-1}\left\{\frac{2\varepsilon_3 - (\varepsilon_1+\varepsilon_2)}{\varepsilon_1 - \varepsilon_2}\right\}$$

If $\varepsilon_1 > \varepsilon_2$, the angle to the maximum principal strain is rotated by Φ_P clockwise from the 1st axis, and the minimum principal strain is located at $\Phi_P + 90°$. If $\varepsilon_1 < \varepsilon_2$, the angle to the maximum principal strain is rotated by $\Phi_P + 90°$ clockwise from the 1st axis, and the minimum principal strain is located at Φ_P.

Maximum principal stress

$$\sigma_{max} = \frac{E}{1-\nu^2}(\varepsilon_{max} + \nu\varepsilon_{min})$$
$$= \frac{E}{2}\left[\frac{\varepsilon_1+\varepsilon_2}{1-\nu} + \frac{1}{1+\nu}\sqrt{2\{(\varepsilon_1-\varepsilon_3)^2 + (\varepsilon_2-\varepsilon_3)^2\}}\right]$$

Minimum principal stress

$$\sigma_{min} = \frac{E}{1-\nu^2}(\varepsilon_{min} + \nu\varepsilon_{max})$$
$$= \frac{E}{2}\left[\frac{\varepsilon_1+\varepsilon_2}{1-\nu} - \frac{1}{1+\nu}\sqrt{2\{(\varepsilon_1-\varepsilon_3)^2 + (\varepsilon_2-\varepsilon_3)^2\}}\right]$$

Maximum shearing stress

$$\tau_{max} = \frac{E}{2(1+\nu)}\gamma_{max}$$
$$= \frac{E}{2(1+\nu)}\sqrt{2\{(\varepsilon_1-\varepsilon_3)^2 + (\varepsilon_2-\varepsilon_3)^2\}}$$

,where E: Elastic modulus (Young's modulus)
ν : Poisson's ratio

NOTE

The above rosette analysis equations are based on the 3-element strain gauge shown in the diagram. When the order of the axis numbers is different or when the gauge is not a 90° rosette gauge, different equations must be used. Check the axis numbers of the applicable strain gauge before performing rosette analysis calculations.