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The use of strain gauges in the Kenyan industry for measurement

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Abstract

The rapid development of micro-electronics has produced an increasing demand for small sensors offering high quality performance. Strain gauges are an important aid in all areas of experimental stress analysis, for determining the strain on the surface of components. In addition, the uses of strain gauges in the manufacture of transducers for measuring mechanical quantities has proven to be extremely reliable technology, giving excellent results.

Key words: Strain Measurement, Strain Analysis and Wheatstone bridge.

Introduction

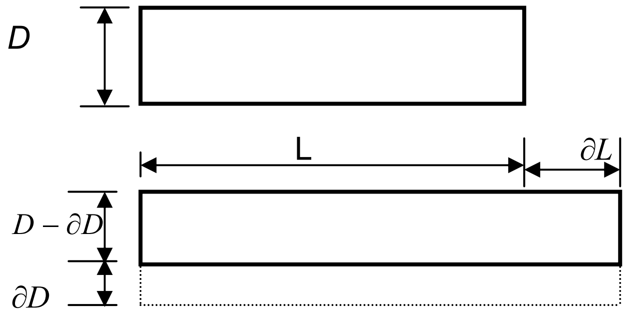
Strain gauges are used in large number for the manufacture of many different types of transducers. Both standard and customized gauges for transducer manufacturers and complete transducers for measuring the physical quantities of force, weight, torque and pressure etc.

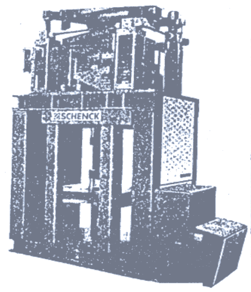
Strain Measurement

A strain gauge is one transducer that undertakes this measurement. If a metal conductor is stretched or compressed, it's resistance will change on the account that it's length and diameter changes. Also, a change in resistivity occurs when it's strained. This attribute is known as Piezo-resistant effect and therefore resistance strain gauges are also known as resistive gauges.

Other detectors and transducers notably Load cells, Torque meters, Accelerometers and flow meters employing strain gauges may be partly explained by normal dimensional behaviour of an elastic material.

If a strip of elastic material is tensioned by positive strain it's longitudinal dimension increases while lateral dimension will decrease. As shown below





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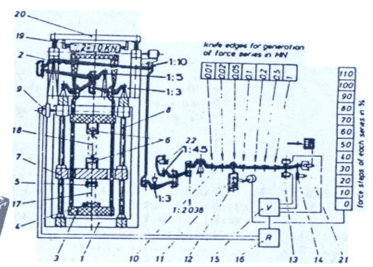

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Since the resistance R of a conductor is directly proportional to it's length and inversely proportional to it's cross-sectional area, the resistance of the gauge will increase with positive strain.

$$R \alpha \frac{L}{A} \tag{1}$$

A change in value of the resistance of the strained conductor is more than that which can be accounted for an increase in resistance due to dimensions changes. The extra change is attributed to a change in resistivity of the conductor when strained. This property is known as piezo-resistance effect.

1.1 Strain Analysis

Consider a strain gauge made of a circular wire with the following dimensions

Length ⟶ L
Area ⟶ A
Diameter ⟶ D

All these are considered under no strain of the wire of resistivity ρ. Therefore, under no strain.

$$R = \rho \frac{L}{A} \tag{2}$$

Let a tensile strain S be applied. This produces a positive strain causing L to increase and A to decrease. Thus we have the following.

$$\partial L = \text{change in } L$$
$$\partial A = \text{change in } A$$
$$\partial D = \text{change in } D$$
$$\partial R = \text{change in } R$$

In order to find ∂R depends upon the material physical quantity, R is differentiated with respect to S

$$\frac{\partial R}{\partial S} = \frac{\partial}{\partial S}\left[\rho \frac{L}{A}\right] \Rightarrow L\frac{\partial}{\partial S}\frac{\rho}{A} + \frac{\rho}{A}\frac{\partial L}{\partial S}$$

but
$$L\frac{\partial}{\partial S}\left(\frac{\rho}{A}\right) \Rightarrow L\left[\frac{\left(A.\frac{\partial \rho}{\partial S} - \rho\frac{\partial A}{\partial S}\right)}{A^2}\right]$$

Combining the two sections

$$\frac{\partial R}{\partial S} = \frac{\rho}{A}.\frac{\partial R}{\partial S} + L\left[\frac{\left(A.\frac{\partial \rho}{\partial S} - \rho\frac{\partial A}{\partial S}\right)}{A^2}\right]$$

$$\frac{\partial R}{\partial S} = \frac{\rho}{A}.\frac{\partial L}{\partial S} + \frac{LA}{A^2}\frac{\partial \rho}{\partial S} - \frac{\rho L}{A^2}.\frac{\partial A}{\partial S}$$

$$= \frac{\rho}{A}.\frac{\partial L}{\partial S} + \frac{L}{A}.\frac{\partial \rho}{\partial S} - \frac{\rho L}{A^2}.\frac{\partial A}{\partial S} \qquad (3)$$

Dividing thro' by $R = \rho\frac{L}{A}$

$$\frac{\partial R}{\partial S}.\frac{1}{R} = \frac{\rho}{A}.\frac{A}{\rho L}.\frac{\partial L}{\partial S} + \frac{L}{A}.\frac{A}{\rho L}.\frac{\partial \rho}{\partial S} - \frac{\rho L}{A^2}.\frac{A}{A^2}.\frac{A}{\rho L}.\frac{\partial A}{\partial s}$$

$$\frac{\partial R}{\partial S}.\frac{1}{R} = \frac{1}{L}.\frac{\partial L}{\partial S} + \frac{1}{\rho}.\frac{\partial \rho}{\partial S} - \frac{\rho L}{A^2}.\frac{1}{A}.\frac{\partial A}{\partial s}$$

$$\frac{\partial R}{\partial S}.\frac{1}{R} = \frac{\partial L}{L}.\frac{1}{\partial S} + \frac{\partial \rho}{\rho}.\frac{1}{\partial S} - \frac{\partial A}{A}.\frac{1}{\partial s} \qquad (4)$$

From this expression, it's clear that per Unit change in R is due to the following:-

$$\text{Per unit change in } \rho; \text{ i.e } \frac{\partial \rho}{\rho}.$$

$$\text{Per unit change in } A; \text{ i.e } \frac{\partial A}{A}.$$

$$\text{Per unit change in } L; \text{ i.e } \frac{\partial L}{L}.$$

$$\text{Area } A = \prod r^2 \quad ; \quad \text{since } r = \frac{1}{2}D$$

$$A = \Pi\left(\frac{D}{2}\right)^2 = \frac{\prod D^2}{4}$$

$$\frac{\partial A}{\partial S} = \text{implicit functions}.$$

$$\frac{\partial A}{\partial S} = \frac{\partial}{\partial S}\left[\frac{\prod D^2}{4}\right].\frac{\partial D}{\partial S} \Rightarrow \frac{2\prod D}{4}.\frac{\partial D}{\partial S} \qquad (5)$$

$$A \rightarrow \frac{\prod D^2}{4}; \frac{\partial A}{\partial S} \rightarrow \frac{2\prod D}{4}.\frac{\partial D}{\partial S}$$

$$Substitute \quad in \quad \frac{1}{A}.\frac{\partial A}{\partial S} \rightarrow \frac{1}{\frac{\Pi D^2}{4}}.\frac{2 \Pi D}{4}.\frac{\partial D}{\partial S}$$

$$= \frac{1}{D}.2.\frac{\partial D}{\partial S} \qquad (6)$$

$$\frac{1}{R}.\frac{\partial R}{\partial S} = \frac{1}{L}.\frac{\partial L}{\partial S} - \frac{2}{D}.\frac{\partial D}{\partial S} + \frac{1}{\rho}.\frac{\partial \rho}{\partial S} \qquad (7)$$

From this, one important parameter pertaining to strain is known as the poisons Ratio.

This is defined as;

Poisons Ratio $\upsilon = \left(\frac{lateral}{longitudin \quad al}\right) strain$

Lateral strain $= \frac{\partial D}{D}$ and Longitudinal strain $= \frac{\partial L}{L}$

$$\upsilon = \frac{\partial D}{D} \div \frac{\partial L}{L} \Rightarrow \frac{\frac{\partial D}{D}}{\frac{\partial L}{L}} = \upsilon \qquad (8)$$

or

$$\frac{\partial D}{D} = \upsilon \frac{\partial L}{L}$$

$$\frac{1}{R}.\frac{\partial R}{\partial S} = \frac{\partial L}{\partial S}.\frac{1}{L} - 2\upsilon.\frac{\partial L}{L}.\frac{1}{\partial S} + \frac{1}{\rho}.\frac{\partial \rho}{\partial S} \quad (9)$$

NB

For small strain variations $\partial S \rightarrow 1 \quad or \quad less$

From equation (vii)

$$\frac{\partial R}{R} = \frac{\partial L}{L} - 2\upsilon.\frac{\partial L}{L} + \frac{\partial \rho}{\rho} \qquad (10)$$

Another important parameter of a strain gauge is the gauge factor. It is defined as the ratio of per unit change in resistance to the per unit change in length.

i. e. $\quad G.F = \frac{\partial R}{R} \div \frac{\partial L}{L} \quad \rightarrow \quad Strain = \varepsilon$

$$\frac{\partial R}{R} = G.F \frac{\partial L}{L} \quad = \quad G.F.\varepsilon \ Strain$$

$$Since \frac{\partial R}{R} = \frac{\partial L}{L} - 2\upsilon.\frac{\partial L}{L} + \frac{\partial \rho}{\rho} \ and \ G.F = \frac{\partial R}{R} \div \frac{\partial L}{L} \ then$$

$$\frac{\partial R}{R} \div \frac{\partial L}{L} = \frac{\partial L}{L}.\frac{L}{\partial L} - 2\upsilon.\frac{\partial L}{L}.\frac{\partial L}{\partial L} + \frac{\partial \rho}{\rho}.\frac{L}{\partial L}$$

$$G.F = 1 - 2\upsilon + \frac{\frac{\partial \rho}{\rho}}{\frac{\partial L}{L}} \rightarrow \varepsilon$$

Since this is positive strain the (-ve) sign changes to (+ve)

$$G.F = 1 + 2\upsilon + \frac{\partial \rho}{\rho} \div \varepsilon$$

If the change in resistivity is neglected, then G.F. 1+ 2υ.
Poisons Ratio for all metals typically range from 0-5

Example

A resistance wire gauge with G.F = 2 is bonded to a steel structural member under a stress of 100MN/m^2. The Young's Modulus of the material is 200GN/m^2. Find the % change in resistance due to stress $\rightarrow \varepsilon$

$$Strain = \frac{Stress}{Young's\ Modulus} = \frac{S}{E}$$

S= 100×10^6N/m^2
E= 200×10^9N/m^2

$$\varepsilon = \frac{100 \times 10^6}{200 \times 10^9} = \frac{1}{2}.10^{-3} = 0.5 \times 10^{-3} = 500 \ \upsilon Strain$$

$$G.F.\,\varepsilon = \frac{\partial R}{R} \qquad and \qquad G.F. = 2$$

$$\%\ Change = \frac{\partial R}{R}.100 = 2 \times 500 \times 10^{-6} \times 100\% = 0.1\%$$

1.2 Strain Gauge Load Cells

The most common type of force transducer, and one which is clear example of an elastic device, which consists of an element on which a number of resistance strain gauges are bonded. The force acts on the elastic element producing a strain field whose amplitude is related to the force through the modulus of elasticity and geometric shape of the elastic material of all force measurement systems and have also been used with high resolution digital indicators as high accuracy force transfer standards for the international inter-comparison of force standard machines.

In electrical terms, all strain gauges may be considered as a length of a conducting material, such as a wire. When a length of a wire is subjected to a tension within its elastic limit, its length increases with corresponding decrease in diameter and change of its electrical resistance. If the wire is bonded to an elastic element under strain then the change in resistance may be measured and used to calculate the force from the calibration of the device. The most common materials used for the manufacture of strain gauges are copper-nickel, nickel-chromium-molybdenum and platinum-tungstein alloys and these are generally referred to by their trade names.

Wheatstone Bridge

The resistance change is detected by connecting the stain gauges in a wheatstone bridge configuration and measuring the differential voltage across the bridge. A wheatstone bridge is normally formed by four strain gauges although it is not uncommon to use two strain gauges for half bridge or more than four on complex shaped load bearing elements. Half the total number of the strain gauges, normally two, forming the network are subjected to compressive strain and other half to tensile strains. The voltage output from the bridge when resistance change of the strain gauge and is therefore a function of the force applied to the element. It can be shown that the output voltage is the mathematical product of the strain and the excitation voltage.

A strain gauge load cell has two distinct temperature coefficients (TC) as shown in Fig. 1 below. One on zero load output and one on full scale output. The mismatch between the expansion coefficient of the gauge and the spring element to which it is bonded and the out of balance condition in the bridge wiring. The effect on full scale output is mainly caused by the temperature dependence of the modulus of elasticity.

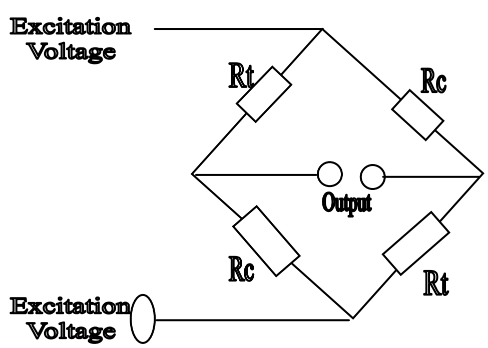

Fig. 1

Rt – Tension Strain Gauges
Rc – Compression Strain Gauges

The load cell is part of a measurement chain and it requires an excitation voltage to be supplied and amplification and conditioning of the output signal before it can be meaningfully displayed or used in a control system as shown in Fig. 2 below. Normally a DC system excites the load cell with a direct current (DC) voltage and amplifies the output through an instrumentation amplifier. This chain features a wide frequency bandwidth, high stability and relatively low cost. In many industrial applications the distance between the load cell and the measuring instrument is considerable. The voltage drop along the connecting cable and its temperature dependence can significantly contribute to the system error. This additional error can be remedied by a six wire excitations technique.

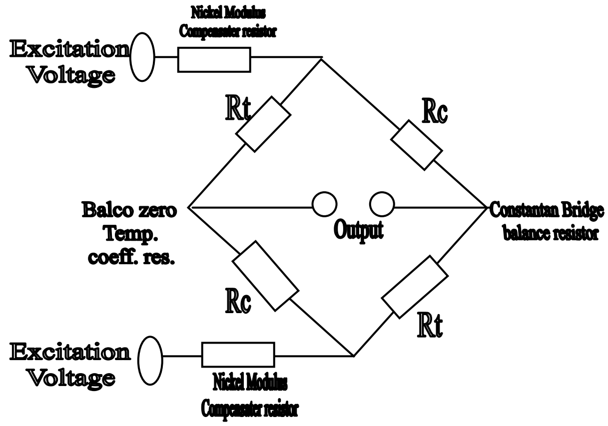

Fig. 2

Rt – Tension Strain Gauges
Rc – Compression Strain Gauges

An alternative to DC excitation is the AC system, which excites the load cell with an AC signal sine wave, square wave or other periodically varying input as shown in Fig. 3 below. The output is processed through an AC amplifier, a synchronous demodulator, filter and DC amplifier. A high level DC signal is obtained suitable for analogue display or for conversion to a digital with the use of an analogue-to-digital converter AC/DC. Such a system features immunity from thermal effects in load cells, high noise rejection, good zero force output stability and ease of achieving isolation between the signal output and the load cell. However in view of the relatively complex measuring chain, these system tend to be costly.

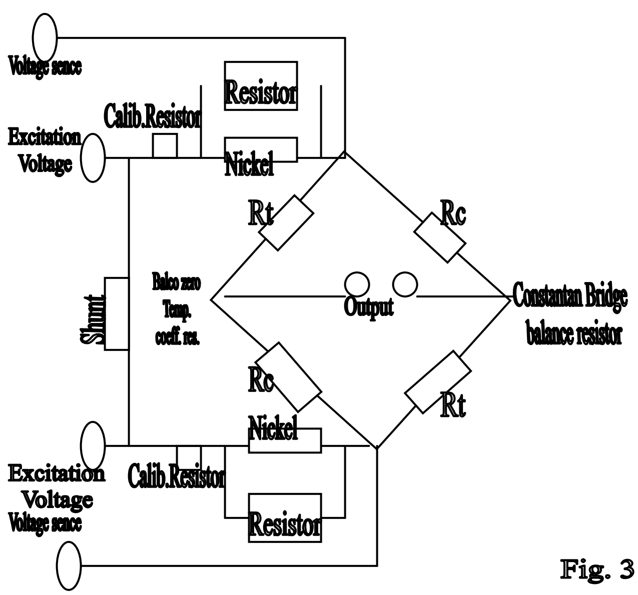

Fig. 3

Rt – Tension Strain Gauges
Rc – Compression Strain Gauges

Conclusions

The use of strain gauges has force sensors e. g. in load cells and micro-electronics is of great importance in the calibration of material testing machines (Tensile/ Compression/Universal). promotes the development of Industries and Research Institutions in any country in the world and also the use of strain gauges.

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