Smart
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Systems

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Strain Gages

Overview

The strain gage is a versatile measuring device that allows an engineer to not only measure the deformation of materials, but also measure vibration, thermal coefficients of expansion, and pressure. Unlike many temperature measurement devices, the strain gage is linear – making the calculations much easier to deal with. On the down side, strain involves measuring very small changes in the material. Therefore, the initial measurement is not as simple as measuring with other types of devices.

What is Strain?

Simply stated, strain is the measurement of the deformation of a material – the change in length of the material under stress divided by the total length, or $\Delta L/L$. This is commonly represented by the Greek letter ε. Then, using Hooke's Law, the stress in the material can be found:

$\sigma = \varepsilon E$,

σ = stress in the beam
ε = strain
E = Young's modulus (or modulus of elasticity – found in reference tables).

The Strain Gage

The strain gage consists of a material who's resistance, inductance, capacitance, or other property changes as the strain applied to it changes. We will limit our discussion to devices that have a change of resistance when strain is applied.

The strain gage is attached to the material to be tested with an adhesive, such as epoxy, allowing the material and gage to deform in unison. As the material bends with strain, so does the gage. However, with a strain gage, the resistance does not change in a 1 for 1 ratio. The change in resistance in a strain gage can be found by:

$\Delta R/R = \varepsilon * G_f$,

where G_f, = the gage factor (provided by the manufacturer of the strain gage)

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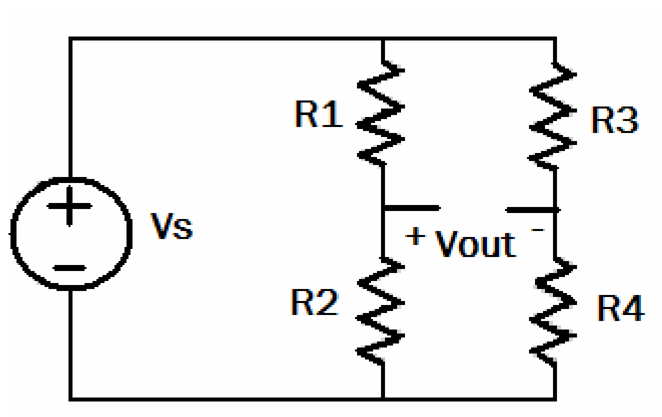
Any manufacturing errors or variations in G_f will result in a measurement error. In addition, if the adhesive contact is poor, this will be another source of measurement error. Temperature changes between measurements are another possible source of measurement error. That is, the resistance of the strain gage can change with temperature changes as well as strain. Somehow you must isolate the resistance change due to temperature from the strain measurement. This is typically done by using a full bridge measurement – having gages in both compression and tension. As long as the thermal coefficients of all the gages track each other, the errors due to thermal drifts can be minimized.

<u>The Bridge Circuit – Measuring Small Resistance Changes</u>

Because the resistance changes in the strain gages are so small, you would need a very accurate resolution meter to measure this directly. This would be expensive – and it still would not compensate for thermal drifts in the gages. Rather, a Wheatstone Bridge circuit is used to measure these small changes. This requires making a differential voltage measurement. Consider the following bridge circuit:



We can calculate Vout as Vs*(R2/(R1+R2) - R4/(R3+R4)).

Now if R1 and R4 are strain gages mounted in compression mode, and R2 and R3 are strain gages mounted in tension mode on the same piece of material, then we will have:

$R1=R4 = R-\Delta R$
$R2=R3 = R+\Delta R$

$Vout = Vs*((R+\Delta R)/2R - (R-\Delta R)/2R) = Vs * \Delta R/R = Vs*\varepsilon*G_f$
$strain = \varepsilon = Vout/(Vs * G_f)$

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The resolution of the Vout and Vs measurements will determine the resolution of the strain measurement.

Note that if two of the resistors, such as R1 and R2, are replaced by fixed resistors of equal value, then Vout will be 0.5* Vs * ΔR/R = 0.5*Vs*ε*G_f. In other words, you will have only half the resolution in strain measurement as you would with the full bridge. You will have a trade-off between the cost of the extra strain gages versus the loss of resolution. Further, if all but one of the strain gages are replaced with fixed resistors, then Vout will be 0.25* Vs * ΔR/R = 0.25*Vs*ε*G_f. Again there is a cost versus resolution trade-off. But in addition, this quarter-bridge configuration also suffers in that it does not compensate for thermal drifts in the gage factor resistance that has been previously discussed.

Thermal Coefficient of Expansion

The Thermal Coefficient of Expansion of a new material may be determined with strain gages by mounting gage R3 on a known material, and R4 on the new material. Then either make R1 and R2 fixed resistors or make them strain gages, but reverse the materials that they are mounted on. Using multiple strain gages in this manner will reduce errors caused by the thermal coefficients of the strain gage resistances. Since strain is just change in length per unit length, this set up will measure the difference in the thermal coefficient of expansion of the two materials. Be sure to multiply by the factor of 2 if the half-bridge configuration is used, and be careful of the sign in the measurements – that is, if the known material has a thermal coefficient of expansion of 100ppm, and you measure a difference of 25ppm – is the unknown material 125ppm or 75ppm? It depends upon how you mount the strain gages and which direction you connect your DAQ.

Pressure Transducers

You can measure pressure by mounting a strain gage on a disk that is exposed to a differential pressure. The strain on a disk whose outer edge is supported and has a uniform pressure over the entire area is:

$$\varepsilon = (39/80)(p*a^2/T^2)/E,$$

where: p = differential pressure, a = radius, T = thickness, E = Young's modulus

From this you can find the differential pressure on a quarter bridge strain measurement on a disk:

$$p = 0.25*Vout/(Vs * G_f)*(80/39)*E* T^2/a^2$$

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References:

Strain Gage Technical Data from Omega:
http://www.omega.com/techref/strain-gage.html

Interactive Guide to Strain Measurement and Technology from Vishay:
http://www.vishay.com/brands/measurements_group/guide/guide.htm

Omega SG-7/350-LY41 Strain Gages at http://www.omega.com/ and search by part number, or
http://www.omega.com/toc_asp/frameset.html?book=Pressure&file=STRAIN_GAGES