ELECTRONIC SENSORS

PREAMBLE

This note gives a brief introduction to sensors. The focus is on sensor mechanisms. It describes in general terms how sensors work. It covers strain gage sensors in detail.

MAIN SENSOR CHARACTERISTICS

Only the main sensor characteristics are considered herein. These are: sensitivity, range, resolution, speed of response and drift. Sensitivity is the ratio of output over input and is basically the gain of the sensor. Range is the minimum to maximum coverage of a sensor. Resolution is the smallest change in a physical quantity that a sensor can read. It is determined mainly by the physical makeup of the sensor. However, electronic noise and dac quantization error can also influence it. Speed of response is how fast a sensor can respond to a change in physical quantity. Again, this is determined mainly by the physical makeup of the sensor. For example, if a sensor has a large scale motion internally, inertia will make sensing action slow. When motion within the sensor is insignificant, sensing action is usually fast. Drift refers to how a sensor signal changes over time even when the physical quantity being measured does not change. Devices which generate charge often drift because charge tends to leak away to ground.

SIGNAL CONDITIONING

Some sensors generate very small voltages or currents when the physical quantity being measured changes. So, often the signals require amplification before they can be recorded. Also, some signals have electronic noise superimposed on them. In this case, the signals must be passed through filters. Usually, these are low pass which means low frequencies signals are allowed to pass through them but high frequency noise is filtered away. When sensor signals are high frequency, the low frequencies are filtered away. Sometimes everything outside a band of frequencies is filtered away. Today, filtering is usually done in software not in hardware. Finally, some signals are very strong. When this is the case, isolation circuits, must be used to protect equipment like computers. These circuits are usually optical.

RESISTANCE DEVICES

Strain gages make use of the resistance change which occurs when a wire is strained. Strain creates more resistive paths for electrons. Gages are attached to members that are strained by the process under investigation. They can be used to measure load or pressure or acceleration. Because a resistor is a static device, it requires only DC power. A fluids analogy of a resistor is a valve.

CAPACITANCE DEVICES

The process under investigation would change the capacitance between the plates of a capacitor. It could change the spacing between the plates or the degree of overlap. Capacitance devices can be used to measure load or pressure or acceleration. Because a capacitor is a dynamic device, it generally makes use of AC power. A capacitor is a charge storage device. A fluids analogy of a capacitor is fluid compressibility which allows for mass storage.

INDUCTANCE DEVICES

The Linear Variable Differential Transformer or LVDT displacement transducer makes use of inductance phenomenon. An iron core which is moved by the surroundings influences the electromagnetic connection between two coils of wire. Because an inductor is a dynamic device, LVDTs generally makes use of AC power. A fluids analogy of an electrical inductor is fluid inertia or inertance.

PIEZOELECTRIC DEVICES

When certain materials, such as quartz crystals, are put under stress, dipoles within them align which creates a voltage and this moves charge. The charge collects on the surface of the crystal. Some texts say it is like squeezing water from a sponge. Piezoelectric devices can be used to measure load or pressure or acceleration. They respond extremely fast. A fluids analogy of the piezoelectric phenomenon is the flow in an inclined pipe.

JUNCTION DEVICES

Energy can be added to or subtracted from electrons when they pass through certain junctions. A fluids analogy is energy addition or subtraction by turbomachines. A thermocouple is an example of a junction device. It consists of 2 wires of different materials. The energy gain or loss at a junction depends on its temperature.

PHOTON DEVICES

Light shining on certain materials can change the resistance of the material. The light gives electrons more energy which allows them to move more freely. Photo resistive devices use this phenomenon. A fluids analogy is turbulence. Light shining on certain materials can generate emf or voltage. Photo electric devices use this phenomenon. A thermo/fluids analogy is pressure generation by heat.

PYRO DEVICES

Pyro resistive devices are similar to photo resistive devices. Pyro electric devices are similar to photo electric devices. Heat is used instead of light

MAGNETIC DEVICES

A simple magnetic sensor is the Reed Switch. In it, a magnet is used to open or close the switch. Some float switches make use of this phenomenon. Another magnetic device is the Hall Effect sensor. The presence of a magnet allows electrons to flow through the side of the device. Some proximity sensors make use of this phenomenon.

DIGITAL DEVICES

In a way, most devices these days are digital in that a computer is used to sample signals from sensors step by step in time. However, some devices, like bar code readers and encoders, are inherently digital, in that the output is a pattern of lows and highs or zeros and ones.

STRAIN GAGES

Strain gages make use of the resistance change which occurs when a wire is strained. The resistance of a wire is:

$$R = L/A\ \sigma$$

where L is the length of the wire, A is its cross sectional area and σ is the piezoresistance of the wire material. Substitution into the resistance equation gives

$$R + \Delta R = [L + \Delta L] / [A + \Delta A]\ \ [\sigma + \Delta\sigma]$$

Manipulation gives

$$\Delta R = \sigma/A\ \Delta L - L\sigma/A^2\ \Delta A + L/A\ \Delta\sigma$$

For wire strain gages the geometry change terms dominate: for metallic strain gages the piezoresistance term dominates. For wire gages, subjected lengthwise to strain, the area change is due mainly to Poissons Ratio. For a circular wire:

$$A + \Delta A = \pi/4\ [D + \Delta D]^2$$

Manipulation gives

$$\Delta A / A = 2\ \Delta D / D$$

The change in D is related to the change in L as follows:

$$\Delta D / D = - \upsilon \, \Delta L / L$$

Substitution into the resistance equation gives

$$\Delta R = \sigma/A \, \Delta L - L\sigma/A^2 \, \Delta A + L/A \, \Delta\sigma$$

$$\Delta R = R \, \Delta L/L - R \, \Delta A/A + R \, \Delta\sigma/\sigma$$

$$\Delta R/R = [1+2\upsilon] \, \Delta L/L + \Delta\sigma/\sigma$$

The strain gage resistor can be made part of a two resistor circuit known as a ballast circuit. The two resistors are in series and have a known voltage imposed on them. The voltage between them is the sensor signal:

$$V \, [R + \Delta R] / 2R$$

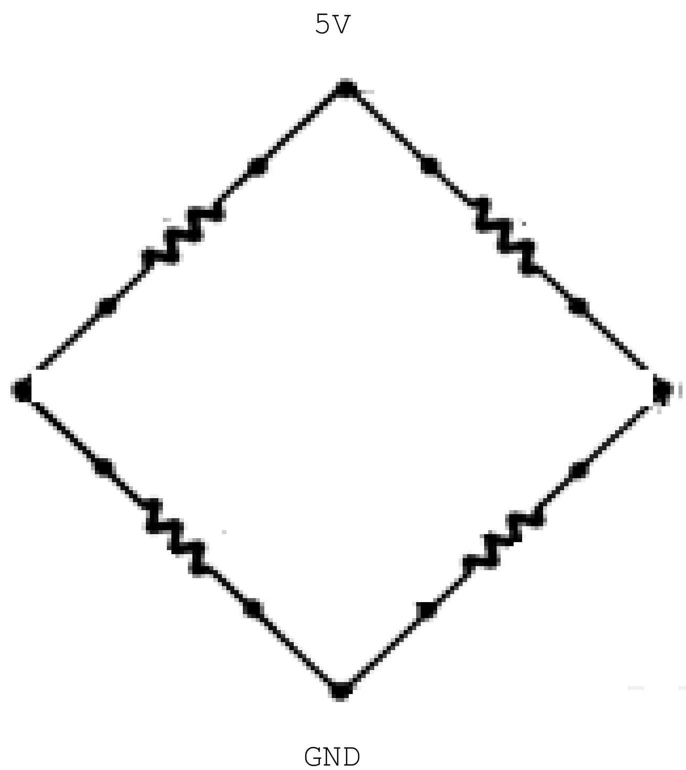
The standard practice is to make the strain gage resistor part of a four resistor circuit known as a bridge. The voltage at the middle of each leg is:

$$V \, R/[2R] \qquad\qquad V \, [R + \Delta R] / [2R + \Delta R]$$

The difference is the sensor signal:

$$V \, \Delta R / [4R]$$

BALLAST CIRCUIT



BRIDGE CIRCUIT