Electrical and Electronic Measurements, Part 2

Lecture 7: Sensors and Transducers

Fluid Pressure and Temperature Sensors

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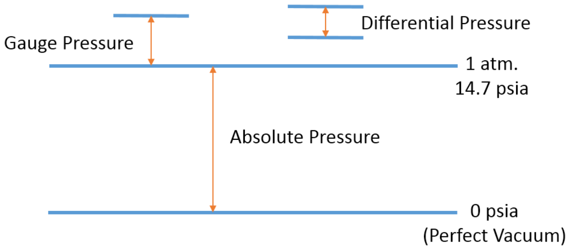
Fluid Pressure Sensors:

Basic Principle:

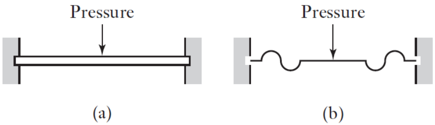
- Three types of pressure could be measured:
  1. **Absolute pressure**: the pressure is measured relative to zero pressure.
  2. **Gauge pressure**: the pressure is measured relative to the barometric pressure.
  3. **Differential pressure**: The pressure difference is measured.

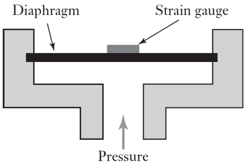


Fluid Pressure Sensors:

[1] Displacement-based Pressure Sensors:

- The basic principle to measure the fluid pressure is to **measure the elastic deformation caused by the fluid** on a flexible material.
- A **diaphragm** could be used as a pressure sensor, when there is a difference in pressure between the two sides, then the center of the diaphragm becomes displaced.
- To increase the sensitivity, **corrugations** could be made in the diaphragm.
- The sensor movement can be monitored by some form of **displacement** sensor, e.g. a strain gauge.

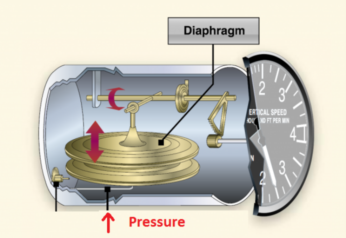


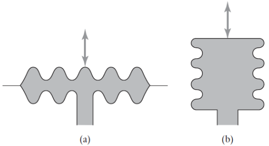


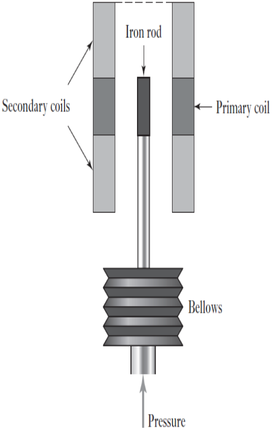
Fluid Pressure Sensors:

[1] Displacement-based Pressure Sensors:

- (a) **Capsules** are two or more corrugated diaphragms to give greater sensitivity.
- (b) A stack of capsules combine a **bellows** to give more sensitive.
- A bellows can be combined with an LVDT to give a pressure sensor with an electrical output.



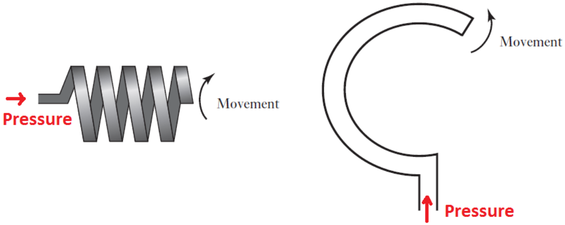




Fluid Pressure Sensors:

[1] Displacement-based Pressure Sensors:

- A different form of deformation is obtained using a tube with in the form of a C-shaped tube, the C opens up to some extent when the pressure in the tube increases.
- A helical form of such a tube gives a greater sensitivity.

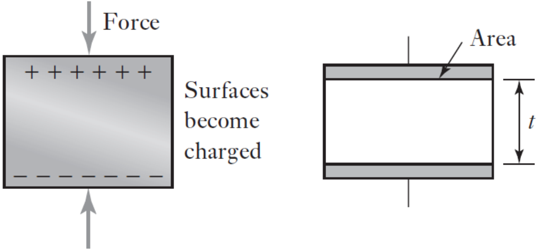


Fluid Pressure Sensors:

[2] Piezoelectric Pressure Sensors:

- Piezoelectric materials **when stretched or compressed generate electric charges**.
- The net charge q on a surface is proportional to the displacement x which is proportional to the applied force F:

$$q = kx = SF \qquad S: \text{ (sensitivity)}$$

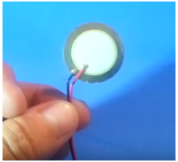


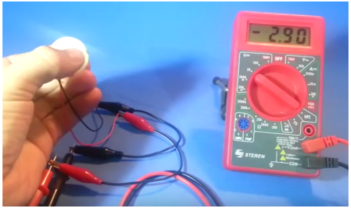
(a) (b)

- The voltage produces across the capacitance C:

$$V = \frac{q}{C} = \frac{St}{\epsilon_0 \epsilon_r A} F = S_v t P$$

S_v: Voltage sensitivity factor.
P: The pressure to be measured.

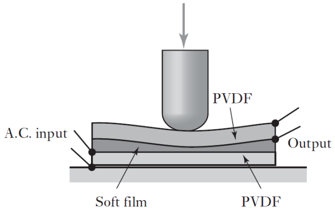




Fluid Pressure Sensors:

[3] Tactile Pressure Sensors:

- A tactile sensor is a particular form of pressure sensor. Such a sensor is used on the 'fingertips' of robotic 'hands' to determine when a 'hand' has come into contact with an object.
- It consists of **two layers of a piezoelectric films** separated by a soft film which transmits vibrations.
- The lower film has an alternating voltage applied to it and this results in mechanical oscillations of the film (Reverse Piezoelectric).
- The intermediate film transmits these vibrations to the upper film and an alternating voltage is produced across the upper film.
- When pressure is applied to the upper film **its vibrations are affected** and the output alternating voltage is changed.



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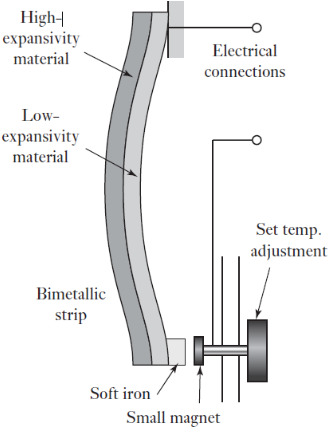
Temperature Sensors:

[1] Bimetallic strips:

- A bimetallic strip is used to convert a temperature change into mechanical displacement.
- It consists of two different metal strips with different coefficients of expansion bonded together.
- When the temperature changes, the composite strip bends into a curved strip, with the higher coefficient metal on the outside of the curve.
- This deformation may be used as a temperature controlled switch.
- The small magnet enables the sensor to change the temperature at which the switch close.



Temperature Sensors:

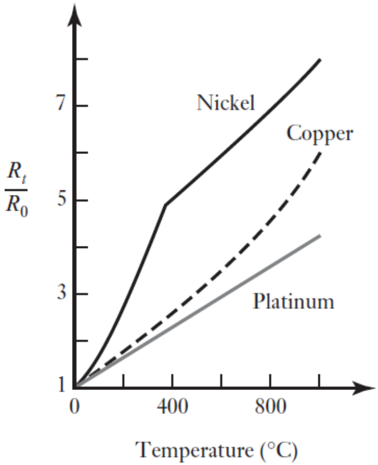
[2] Resistance Temperature Detectors (RTDs):

- The resistance of most metals changes with the change in the temperature as follows:

$$R_t = R_0(1 + \alpha t)$$

R_t: Resistance at temperature t.
R_0: Resistance at temperature $0^o C$
α: Temperature coefficient.

- RTDs are highly stable and give reproducible responses over long periods of time.
- They tend to have response times of the order of 0.5 to 5 seconds or more.



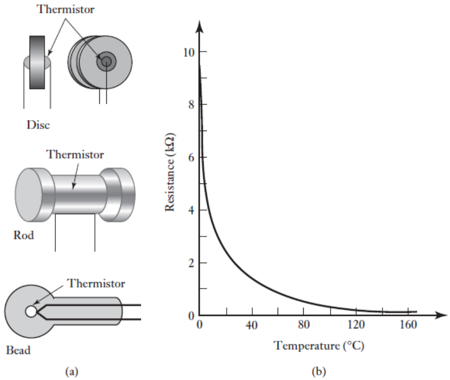
Temperature Sensors:

[3] Thermistors:

- Thermistors are small pieces of material made from a mixture of semiconductor oxides.
- The thermistor material is formed into various forms of element, such as beads, discs and rods.
- The resistance of conventional metal-oxide thermistors decreases in a very non-linear manner with an increase in temperature.

$$R_t = K e^{\frac{\beta}{t}}$$

- They can be very small and responding very rapidly to changes in temperature.
- Their main disadvantage is their non-linearity.



Temperature Sensors:

[4] Thermodiodes and transistors:

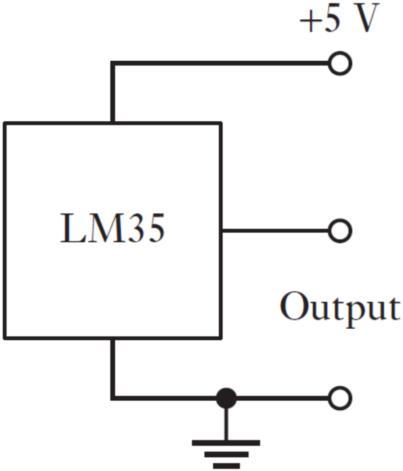
- When the temperature of doped semiconductors changes, the mobility of their charge carriers changes giving a current I through the junction that is a function of the temperature T and the applied voltage V:

$$I = I_0(e^{eV/kT} - 1)$$

By taking logarithms we can write the equation in terms of the voltage as:

$$V = \frac{kT}{e} ln(\frac{I}{I_0} + 1)$$

if I is a constant current source, the voltage across the thermo-diode is proportional to the temperature.



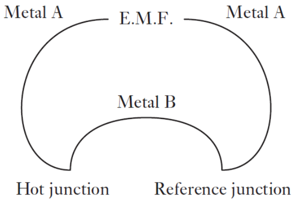
Temperature Sensors:

[5] Thermocouples:

- If two different metals are joined together, a **potential difference occurs** across the junction depending on the metal and the temperature.
- Usually, a thermocouple involves **two metal junctions** one as a reference junction.
- If the reference junction holds at $0^o C$, there is an e.m.f. E as follows:

$$E = at + bt^2 \qquad \text{a,b are constants}$$

- Commonly used thermocouples are shown in the table with different given reference letters



Ref.	Materials	Range (°C)	(μV/°C)
B	Platinum 30% rhodium/platinum 6% rhodium	0 to 1800	3
E	Chromel/constantan	−200 to 1000	63
J	Iron/constantan	−200 to 900	53
K	Chromel/alumel	−200 to 1300	41
N	Nirosil/nisil	−200 to 1300	28
R	Platinum/platinum 13% rhodium	0 to 1400	6
S	Platinum/platinum 10% rhodium	0 to 1400	6
T	Copper/constantan	−200 to 400	43

Temperature Sensors:

[5] Thermocouples:

- A thermocouple can be used with the reference junction at a temperature other than $0^o C$.
- A correction has to be applied to the standard tables to find the new e.m.f. value when using the new reference temperature:

$$E_{t,0} = E_{t,I} + E_{I,0} \quad \text{intermediate temperature law}$$

$E_{t,0}$ e.m.f at temperature t when the cold junction is at 0.
$E_{t,I}$ e.m.f at temperature t when the cold junction is at $I^o C$.
$E_{I,0}$ e.m.f at temperature I when the cold junction is at 0.

Example: This reference table is given when the cold junction is at $0^o C$.

Temp. (°C)	0	20	200
E.M.F. (mV)	0	1.192	13.419

If the cold junction is at $20^o C$ what will be the e.m.f. at $200^o C$?

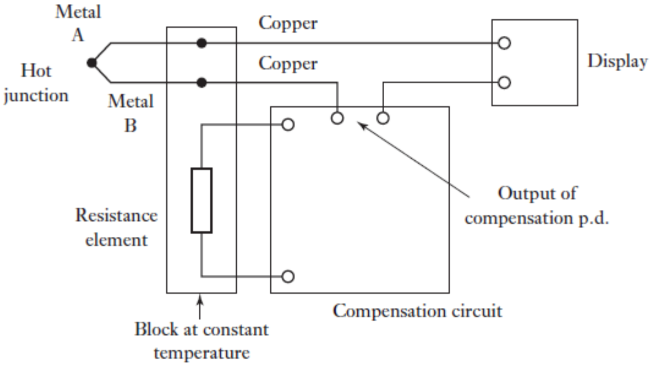
$$E_{200,0} = \boxed{E_{200,20}} + E_{20,0}$$

$$\boxed{E_{200,20}} = 12.227 mV$$

Temperature Sensors:

[5] Thermocouples:

- It is often not convenient to maintain the reference junction of a thermocouple at 0.
- A compensation circuit can, however, be used to provide an e.m.f. which is added to the junction e.m.f in such a way that simulate the cold junction.



End of Lecture

Best Wishes