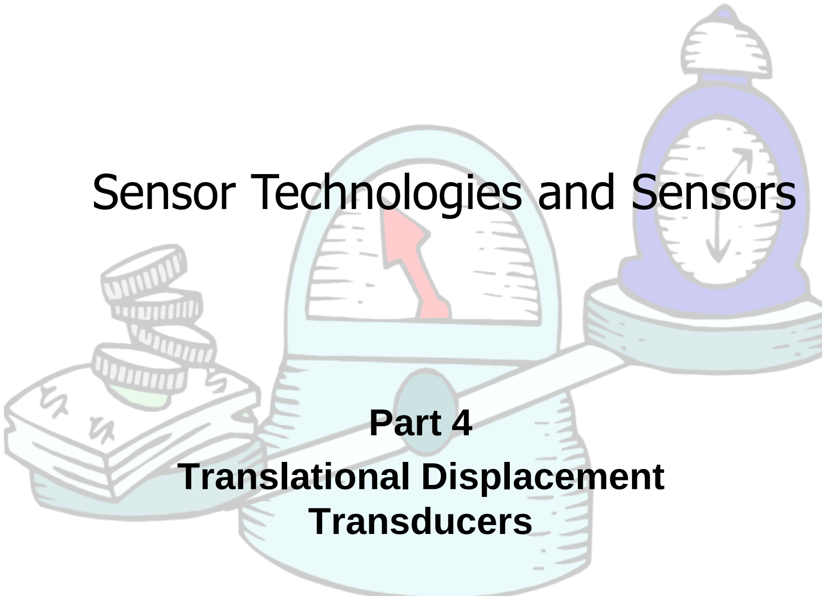


Sensor Technologies and Sensors

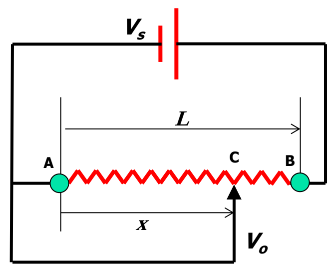
Part 4
Translational Displacement Transducers

Introduction

- Translational displacement transducers are instruments that measure the motion of a body in a straight line between two points.
- A part from their use as a primary transducer measuring the motion of a body, translational displacement transducers are also widely used as a secondary component in measurement systems, where some other physical quantity such as pressure, force, acceleration or temperature is translated into a translational motion by the primary measurement transducer.

The resistive potentiometer

- The resistive potentiometer is perhaps the best-known displacement-measuring device. It consists of a resistance element with a movable contact. A voltage V_s is applied across the two ends A and B of the resistance element and an output voltage V_o is measured between the point of contact C of the sliding element and the end of the resistance element A.

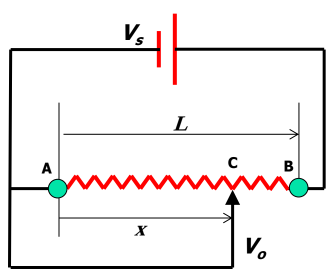


- A linear relationship exists between the output voltage V_o and the distance *x*

$$V_o = R_{AC} I = R_{AC}\left(V_s / R_{AB}\right) = \frac{x}{L} V_s$$

The resistive potentiometer

- The body whose motion is being measured is connected to the sliding element of the potentiometer, so that translational motion of the body causes a motion of equal magnitude of the slider along the resistance element and a corresponding change in the output voltage V0.



$$V_o = R_{AC} I = R_{AC}\left(V_s / R_{AB}\right) = \frac{x}{L} V_s$$

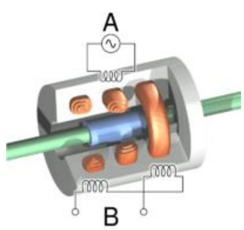
- Three different types of potentiometer are availabe, wire-wound, carbon-film and plastic-film.

The resistive potentiometer problems

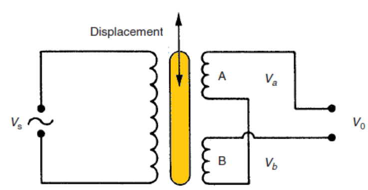
- Operational problems of potentiometers all occur at the point of contact between the sliding element and the resistance track. The most common problem is dirt under the slider, which increases the resistance and thereby gives a false output voltage reading, or in the worst case causes a total loss of output.
- High-speed motion of the slider can also cause the contact to bounce, giving an intermittent output. Friction between the slider and the track can also be a problem in some measurement systems where the body whose motion is being measured is moved by only a small force of a similar magnitude to these friction forces.

Translational Motion Transducers

- Translational displacement is movement in a straight line between two points
- Translational Displacement transducers can be used as primary or secondary transducers
- Simple type as resistive potentiometer
- LVDT: linear variable differential transformer



Cutaway view of an LVDT. Current is driven through the primary coil at *A*, causing an induction current to be generated through the secondary coils at *B*.



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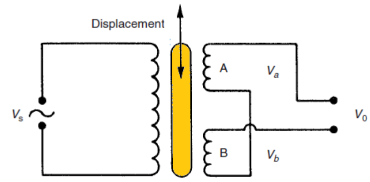
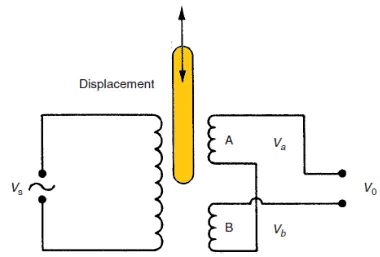
Linear Variable Differential Transformer

- The linear variable differential transformer, (LVDT), consists of a transformer with a single primary winding and two secondary windings connected in the series in opposing manner.
- The object whose translational displacement is to be measured is physically attached to the central iron core of the transformer, so that all motions of the body are transferred to the core.
- For an excitation voltage Vs given by $V_s = V_p \sin(\omega t)$, the e.m.f.s induced in the secondary windings V_a and V_b are given by:

$$V_a = K_a \sin(\omega t - \varphi), V_b = K_b \sin(\omega t - \varphi)$$



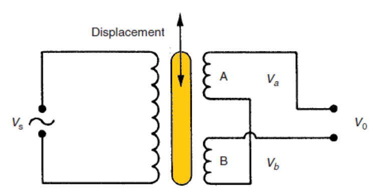


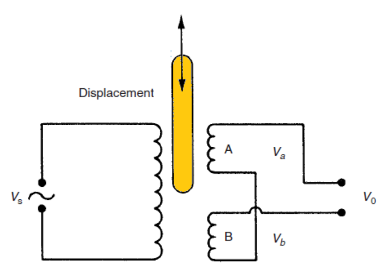
Linear Variable Differential Transformer

- The parameters K_a and K_b depend on the amount of coupling between the respective secondary and primary windings and hence on the position of the iron core.
- Because of the series opposition mode of connection of the secondary windings, the output voltage, V_0 is the difference between V_a and V_b,

$$V_o = V_a - V_b = (K_a - K_b)\sin(\omega t - \varphi)$$

- With the core in the central position, $K_a = K_b$, and $V_0 = 0$. The relationship between the magnitude of V_0 and the core position is approximately linear over a reasonable range of movement of the core on either side of the null position.

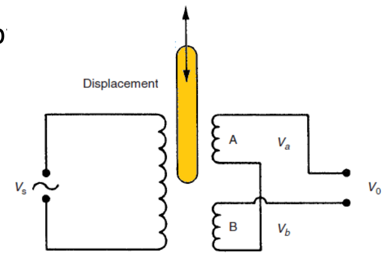




Linear Variable Differential Transformer

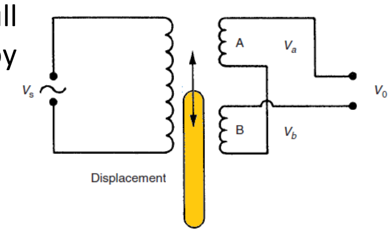
- Suppose that the core is displaced upwards (i.e. towards winding A) b a distance *x*. then K_a increases to become K_L and K_b decreases to become K_S. We thus have:

$$V_o = V_a - V_b = (K_L - K_S)\sin(\omega t - \varphi)$$



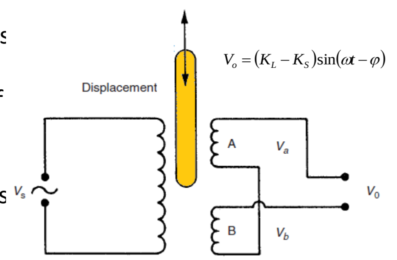
- If, alternatively, the core were displaced downwards from the null position (i.e. towards winding B) by a distance *x*, then K_a decreases to become K_S and K_b increases to become K_L, and we would have:

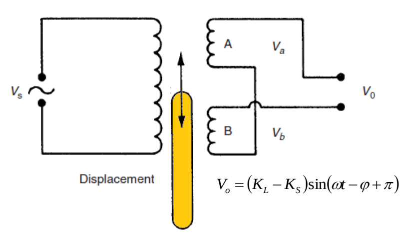
$$V_o = V_a - V_b = (K_S - K_L)\sin(\omega t - \varphi)$$
$$V_o = V_a - V_b = (K_L - K_S)\sin(\omega t - \varphi + \pi)$$



Linear Variable Differential Transformer

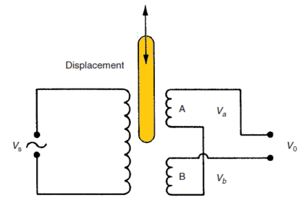
- Thus for equal magnitude displacement +*x* and -*x* of the core away from the central (null) position, the magnitude of the output voltage V_0 is the same in both cases. The only information about the direction of movement of the core is contained in the phase of the output voltage, which differs between the two cases by 180°.
- If, therefore, measurements of core position on both sides of the null position are required, it is necessary to measure the phase as well as the magnitude of the output voltage.





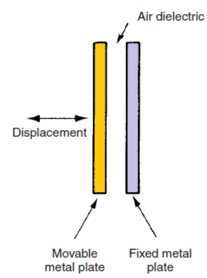
Linear Variable Differential Transformer

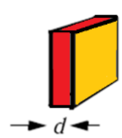
- Some problems that affect the accuracy of the LVDT are the presence of harmonics in the excitation voltage and stray capacitances, both of which cause a non-zero output of low magnitude when the core is in the null position.
- It is also impossible in practice to produce two identical secondary windings, and the small asymmetry that invariably exists between the secondary windings adds to this non-zero null output. The magnitude of this is always less than 1% of the full-scale output and in many measurement situations is of little consequence.
- Where necessary, the magnitude of these effects can be measured by applying known displacements to the instrument. Following this, appropriate compensation can be applied to subsequent measurements.



Variable Capacitance Transducers

- The principle of variable capacitance is used in displacement measuring transducers in various ways.
- The two plates variable capacitance transducer consists of two flat, parallel, metal plates, one of which is fixed and one of which is movable.
- Displacements to be measured are applied to the movable plate, and the capacitance changes as this moves. Air serves as the dielectric medium between the plates.

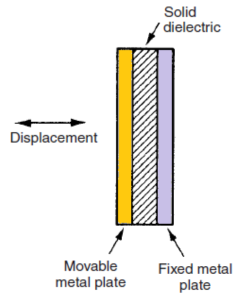


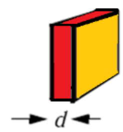


$$C = \varepsilon_o \varepsilon_r \frac{A}{d}$$

Variable Capacitance Transducers

- In an alternative form, a sheet of solid dielectric material between can be placed between the two parallel plates instead of the air layer.
- The displacement to be measured causes a capacitance change by moving the dielectric sheet.

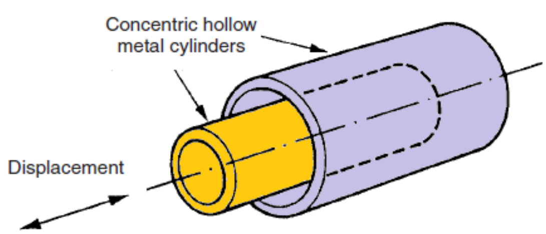




$$C = \varepsilon_o \varepsilon_r \frac{A}{d}$$

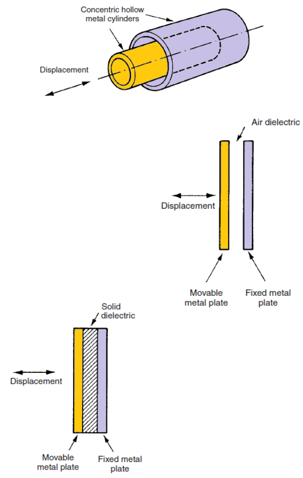
Variable Capacitance Transducers

- In the concentric cylinders variable capacitance transducer, capacitance plates are formed by two concentric, hollow, metal cylinders.
- The displacement to be measured is applied to the inner cylinder, which alters the capacitance



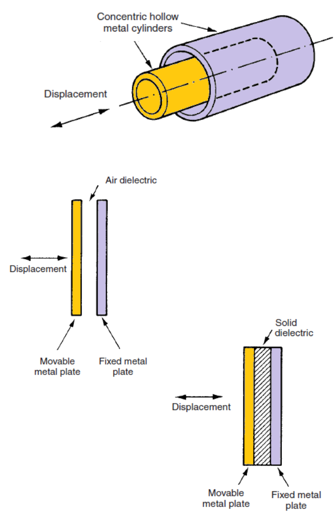
Variable Capacitance Transducers

- Inaccuracies as low as ±0.01% are possible with these instruments, with measurement resolutions of 1 micron. Individual devices can be selected from manufacturers' ranges that measure displacements as small as 10-11 m or as large as 1m.
- The fact that such instruments consist only of two simple conducting plates means that it is possible to fabricate devices that are tolerant to a wide range of environmental hazards such as extreme temperatures, radiation and corrosive atmospheres.
- As there are no contacting moving parts, there is no friction or wear in operation and the life expectancy quoted is 200 years.



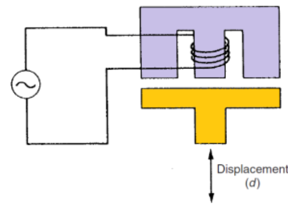
Variable Capacitance Transducers

- The major problem with variable capacitance transducers is their high impedance. This makes them very susceptible to noise and means that the length and position of connecting cables need to be chosen very carefully.
- In addition, very high impedance instruments need to be used to measure the value of the capacitance.
- Because of these difficulties, use of these devices tends to be limited to those few applications where the high accuracy and measurement resolution of the instrument are required.



Variable Inductance Transducers

- One simple type of variable inductance transducer was described earlier. Movements of the plate alter the flux paths and hence cause a change in the current flowing in the winding.
- This has a typical measurement range of 0–10 mm.



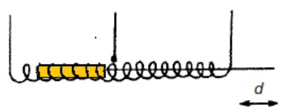
$$v = L\frac{di}{dt},$$

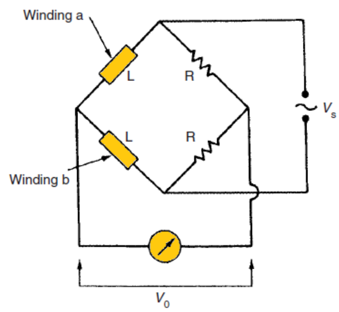
$$i = \frac{1}{L}\int v\,dt = \frac{V}{L}\int \cos\omega t\,dt = \frac{V}{\omega L}\sin\omega t$$

$$I = \frac{V}{\omega L}$$

Variable Inductance Transducers

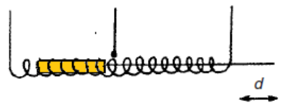
- An alternative form has a very similar size and physical appearance to the LVDT, but has a centre-tapped single winding. The two halves of the winding are connected to form two arms of a bridge circuit that is excited with an alternating voltage.
- With the core in the central position, the output from the bridge is zero. Displacements of the core either side of the null position cause a net output voltage that is approximately proportional to the displacement for small movements of the core.

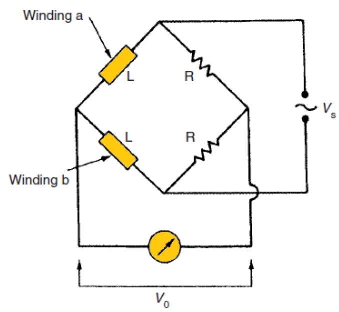




Variable Inductance Transducers

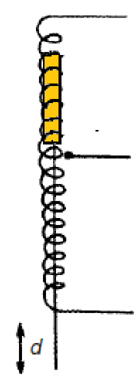
- Instruments in this form are available to cover a wide span of displacement measurements. At the lower end of this span, instruments with a range of 0–2mm are available, whilst at the top end, instruments with a range of 0–5m can be obtained.

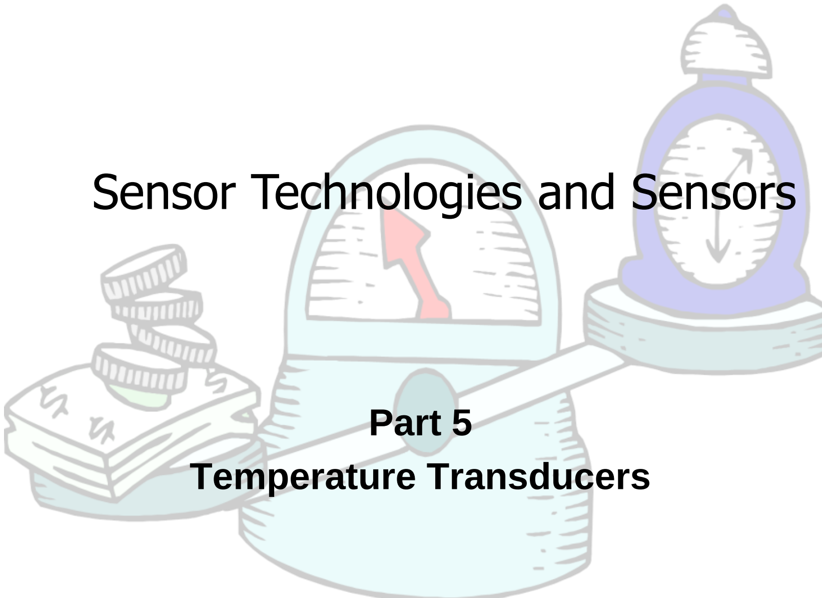




Variable Inductance Transducers

- An alternative form has a very similar size and physical appearance to the LVDT, but has a centre-tapped single winding. The two halves of the winding are connected to form two arms of a bridge circuit that is excited with an alternating voltage.
- With the core in the central position, the output from the bridge is zero. Displacements of the core either side of the null position cause a net output voltage that is approximately proportional to the displacement for small movements of the core. Instruments in this second form are available to cover a wide span of displacement measurements.
- At the lower end of this span, instruments with a range of 0–2mm are available, whilst at the top end, instruments with a range of 0–5m can be obtained.





Sensor Technologies and Sensors

Part 5

Temperature Transducers

Temperature Measurement

- Instruments to measure temperature can be divided into separate classes according to the physical principle on which they operate. The main principles used are:
- The thermoelectric effect ➔ Thermocouples
- Resistance change ➔ RTD's and Thermistors

Other Principles (FYI)

- Sensitivity of semiconductor device
- Radiative heat emission
- Thermography
- Thermal expansion
- Resonant frequency change
- Sensitivity of fibre optic devices
- Acoustic thermometry
- Colour change
- Change of state of material.

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Thermocouples- important

- Consist of a pair of dissimilar metal wires joined together at one end (sensing, hot junction) and terminated at the other end (reference, cold junction) which is kept at known constant temperature.
- emf (voltage) is produced when there is a difference in temperature between the two junctions, this is called the **thermocouple effect or Seebeck effect**.
- $$e = a_1 T + a_2 T^2 + a_3 T^3 + \cdots + a_n T^n$$ ← FYI

  Which can be approximated for certain pairs of metals by

  $$e \approx a_1 T$$
- Thermal emf magnitude depends on the materials used and on temperature difference .
- Remember how to convert from degrees C to degrees F
- Many types of thermocouples exist which differ in the metals used to construct them,
- among these are type E,J,K and S which differ in the combination of the used materials and their temperature range and application

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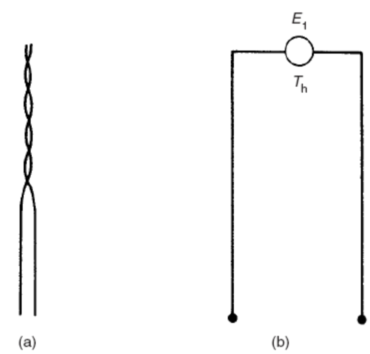

Fig. 14.2 (a) Thermocouple; (b) equivalent circuit.

- The emf generated at the hot junction is presented by E1 and temperature is known as Th
- E1 is measured at the open ends of the thermocouple (known as reference junction)

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Thermocouple Types

- Type E ➔ Chromel-Constantan
- Type J ➔ Iron-Constantan
- Type K ➔ Chromel-Alumel
- Type S ➔ Platinum-Platinum/Rhodium

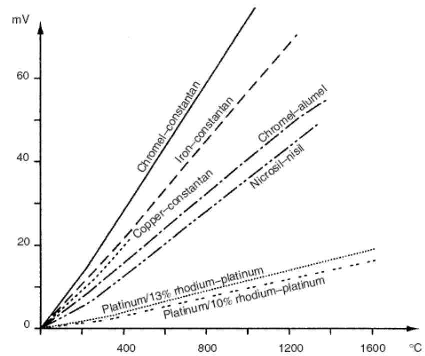

Fig. 14.1 E.m.f. temperature characteristics for some standard thermocouple materials.

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Thermistors / Important

- A **thermistor** is a type of resistor with resistance varying according to its temperature. The word is a combination of *thermal* and *resistor*.
- Thermistors are widely used as inrush current limiters, temperature sensors, self-resetting overcurrent protectors, and self-regulating heating elements.
- Assuming, as a first-order approximation, that the relationship between resistance and temperature is linear, then:

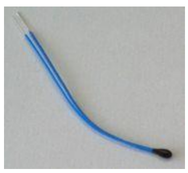
$$\Delta R = k \Delta T$$

where

ΔR = change in resistance

ΔT = change in temperature

k = first-order temperature coefficient of resistance



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Thermistors / Important

- Thermistors can be classified into two types depending on the sign of *k*. If *k* is positive, the resistance increases with increasing temperature, and the device is called a positive temperature coefficient (**PTC**) thermistor, or **posistor**.
- If *k* is negative, the resistance decreases with increasing temperature, and the device is called a negative temperature coefficient (**NTC**) thermistor.
- Resistors that are not thermistors are designed to have the smallest possible *k*, so that their resistance remains nearly constant over a wide temperature range
- Thermistors differ from resistance temperature detectors (RTD) in that the material used in a thermistor is generally a ceramic or polymer, while RTDs use pure metals. The temperature response is also different; RTDs are useful over larger temperature ranges.

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RTD's / Important

Resistance thermometers, which are alternatively known as *resistance temperature devices* (or RTDs), rely on the principle that the resistance of a metal varies with temperature according to the relationship:

➔ FYI $$R = R_0 \left(1 + a_1 T + a_2 T^2 + a_3 T^3 + \cdots + a_n T^n\right) \qquad (14.7)$$

This equation is non-linear and so is inconvenient for measurement purposes. The equation becomes linear if all the terms in $a_2 T^2$ and higher powers of T are negligible such that the resistance and temperature are related according to:

$$R \approx R_0 \left(1 + a_1 T\right)$$

This equation is approximately true over a limited temperature range for some metals, notably platinum, copper and nickel, whose characteristics are summarized in Figure 14.8. Platinum has the most linear resistance–temperature characteristic, and it also has good chemical inertness, making it the preferred type of resistance thermometer

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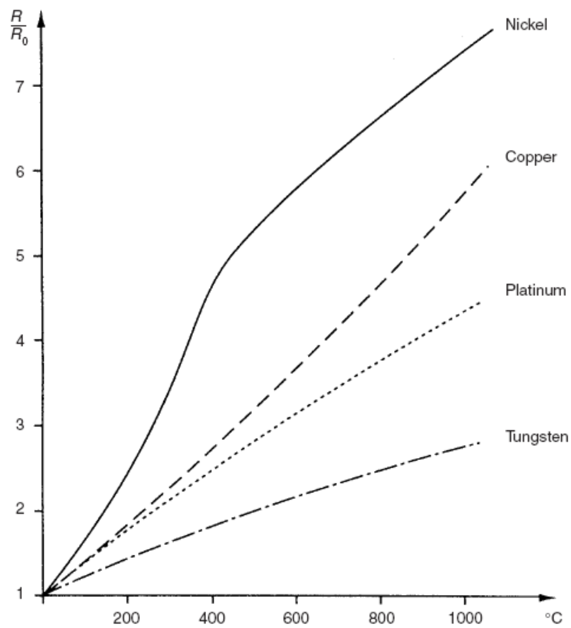

Typical resistance–temperature characteristics of metals.

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