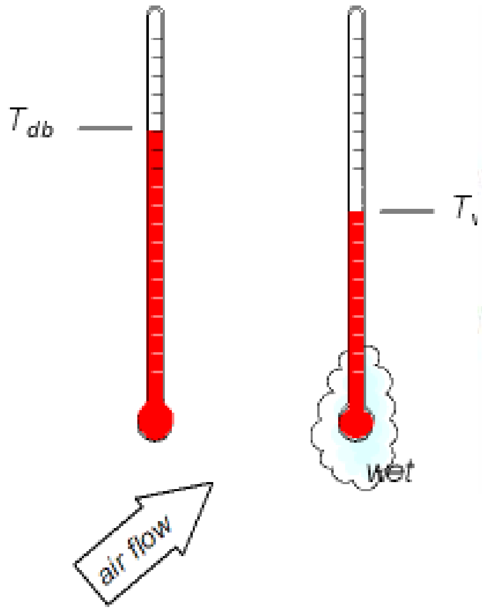
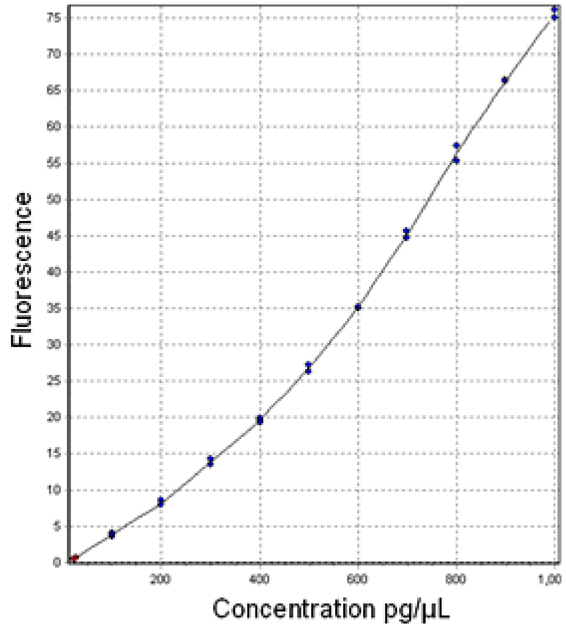




EMaSM

Principles
Of
Sensors
& transducers

[4]

PRINCIPLES OF SENSORS & TRANSDUCERS

- **Introduction:**
- At the heart of measurement of common physical parameters such as force and pressure are ***sensors and transducers***.
- These devices respond to the parameters by producing an output which is related to the value being measured or ***measurand***.
- Examples of these are strain gauges and Bourdon tubes. Details of some of these devices are given in Table next.

PRINCIPLES OF SENSORS & TRANSDUCERS

Sensor/transducer	**Measurand [value being measured]**	**Output [Change]**
Strain gauge	Strain	Resistance
Bourdon tube	Pressure	Scale display
Thermocouple	Temperature	Voltage
Tachogenerator	Velocity	Voltage
Thermistor	Temperature	Resistance change
Pitot tube	Flow	Pressure
Load cell	Force	Voltage
Manometer	Pressure	Displacement

PRINCIPLES OF SENSORS & TRANSDUCERS

- The previous table shows some examples of the types of sensor used in engineering systems.
- The final column shows what form the output takes.
- You will notice that many are electrical in nature and in fact this conversion into electrical energy is common in both the measurement of electrical and mechanical properties

PRINCIPLES OF SENSORS & TRANSDUCERS

- **Selection of sensors and transducers**

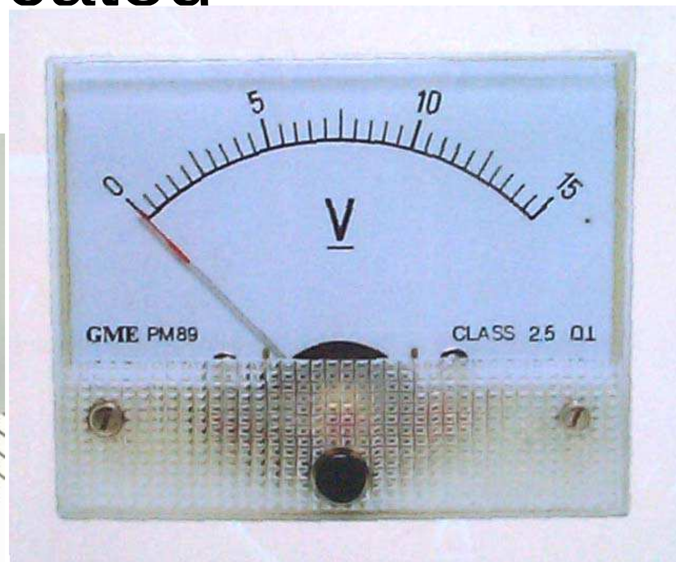
- Some of the factors affecting the accuracy and reliability of data were discussed in the previous section.
- Here we will look at other issues to be considered when selecting or specifying devices.

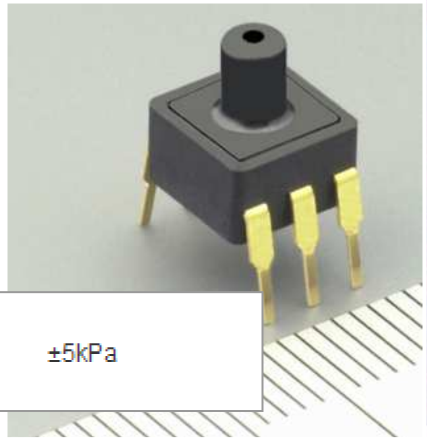
PRINCIPELS OF SENSORS & TRANSDUCERS

- **Range**

- The ***limits of measurement*** are indicated by the ***range*** of the device. This will be specified in terms of the indicated parameter, for example

  0–15V or .





Measurable pressure range	60kPa-110kPa (Altitude conversion capability: 4000m to-700m)	±5kPa

PRINCIPLES OF SENSORS & TRANSDUCERS

- **Size**
- It seems fairly obvious that the size of a sensor will be an influencing factor, but it is worth stating that any device which cannot be mounted, inserted, or otherwise fixed to the system will be unsuitable.
- Fixing methods will vary, for example strain gauges are often secured with adhesive, whereas a tachogenerator must be coupled onto a rotating shaft.

PRINCIPLES OF SENSORS & TRANSDUCERS

- **Signal conditioning**
- Most often associated with transducers which produce an electrical signal, signal conditioning requirements may be as straightforward as voltage amplification.
- For some systems mathematical tasks such as integration or differentiation may be needed.
- This signal conditioning may be carried out by electronic circuits or by computer programs.

PRINCIPLES OF SENSORS & TRANSDUCERS

- **Response time**
- For many engineering systems parameter changes take place over a distinct period of time.
- Where measurements are being used to help control the system, it is vital that these are made in a shorter timescale.
- A familiar example would be a heating system in which a mass of water has its temperature raised by an electric heater.

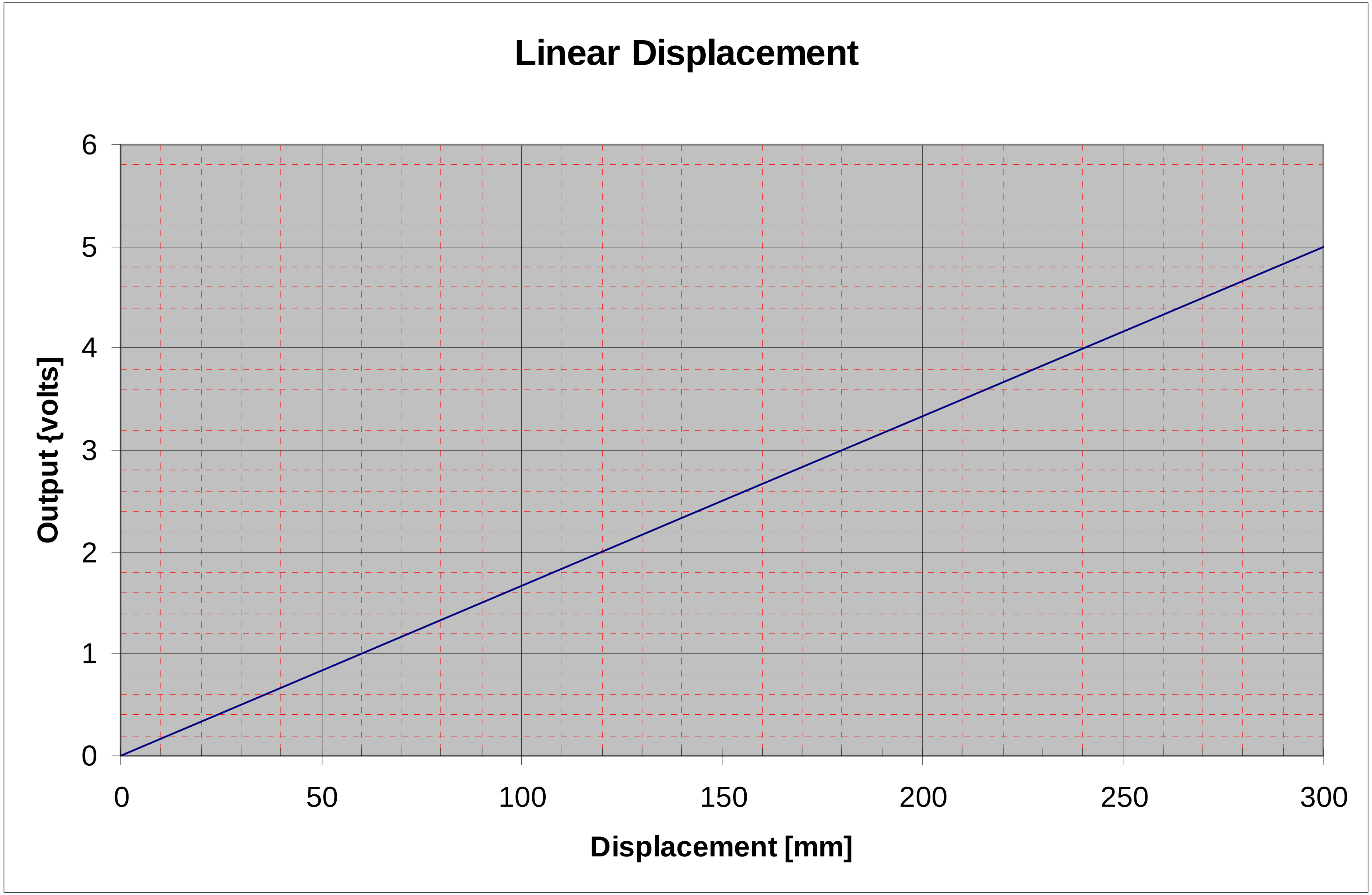
PRINCIPLES OF SENSORS & TRANSDUCERS

- As the ***input energy increases the temperature***, the ***sensor must*** be able to ***identify the target temperature*** and ***deliver*** this ***information in time*** for the heater ***to turn off before an excess of energy is delivered***, otherwise there is a risk of an ***over temperature condition***.

PRINCIPLES OF SENSORS & TRANSDUCERS

- **Linearity**
- The relationship between output and input is a key parameter for sensors and transducers.
- Ideally there should be a straight line relationship so that equivalent changes in input produce the same order of change in output no matter where within the sensor’s range these occur.

PRINCIPLES OF SENSORS & TRANSDUCERS



PRINCIPLES OF SENSORS & TRANSDUCERS

- **Cost**
- It is unrealistic to expect that transducer or sensor selection will not be subject to the cost constraints of other parts of the systems.
- When taking cost into account, system designers and operators should be aware not only of the initial price but also cost of ownership factors such as service costs, availability of spares, reliability and maintenance.

PRINCIPLES OF SENSORS & TRANSDUCERS

- **Calibration**
- We calibrate an instrument or sensor to establish the accuracy of the measurements it produces.
- Ideal devices will give an exact value for the measurand in all circumstances.
- Practical instruments and sensors will not, of course, be able to do this, however it is possible for us to take into account inaccuracies due to ageing, etc.

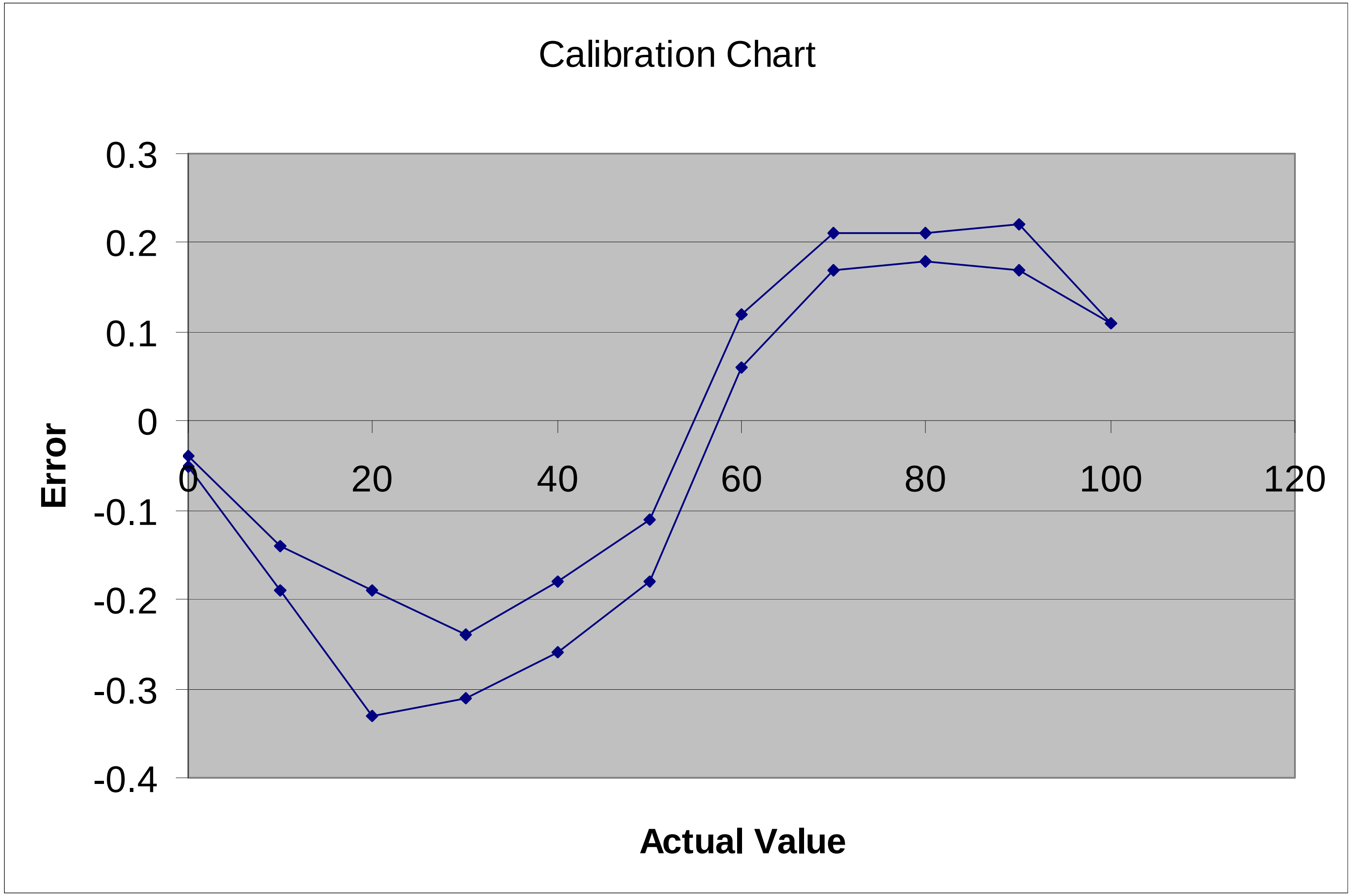
PRINCIPLES OF SENSORS & TRANSDUCERS

- This process often generates a calibration table or calibration graph.
- An example of each is shown [next slide]. These allow us to identify the worst case accuracy of the device.
- The largest error (0.4%) is shown in the third measurement column at the value 30 and it is this which will be used to classify the accuracy of the device.

PRINCIPLES OF SENSORS & TRANSDUCERS

value	1st measure	2nd measure	3rd measure	Avg	error
0	-0.06	-0.05	-0.04	-0.05	-0.05
10	9.8	9.81	9.83	9.81	-0.19
20	19.7	19.7	19.6	19.67	-0.33
30	29.7	29.68	29.69	29.69	-0.31
40	39.8	39.7	39.72	39.74	-0.26
50	49.8	49.82	49.83	49.82	-0.18
60	60.01	60.02	60.15	60.06	0.06
70	70.15	70.15	70.2	70.17	0.17
80	80.2	80.22	80.12	80.18	0.18
90	90.2	90.17	90.15	90.17	0.17
100	100.1	100.12	100.11	100.11	0.11
90	90.25	90.2	90.22	90.22	0.22
80	80.2	80.21	80.21	80.21	0.21
70	70.23	70.2	70.2	70.21	0.21
60	60.14	60.1	60.12	60.12	0.12
50	49.9	49.88	49.89	49.89	-0.11
40	39.8	39.82	39.84	39.82	-0.18
30	29.75	29.78	29.76	29.76	-0.24
20	19.8	19.82	19.81	19.81	-0.19
10	9.85	9.87	9.87	9.86	-0.14
0	-0.05	-0.04	-0.04	-0.04	-0.04

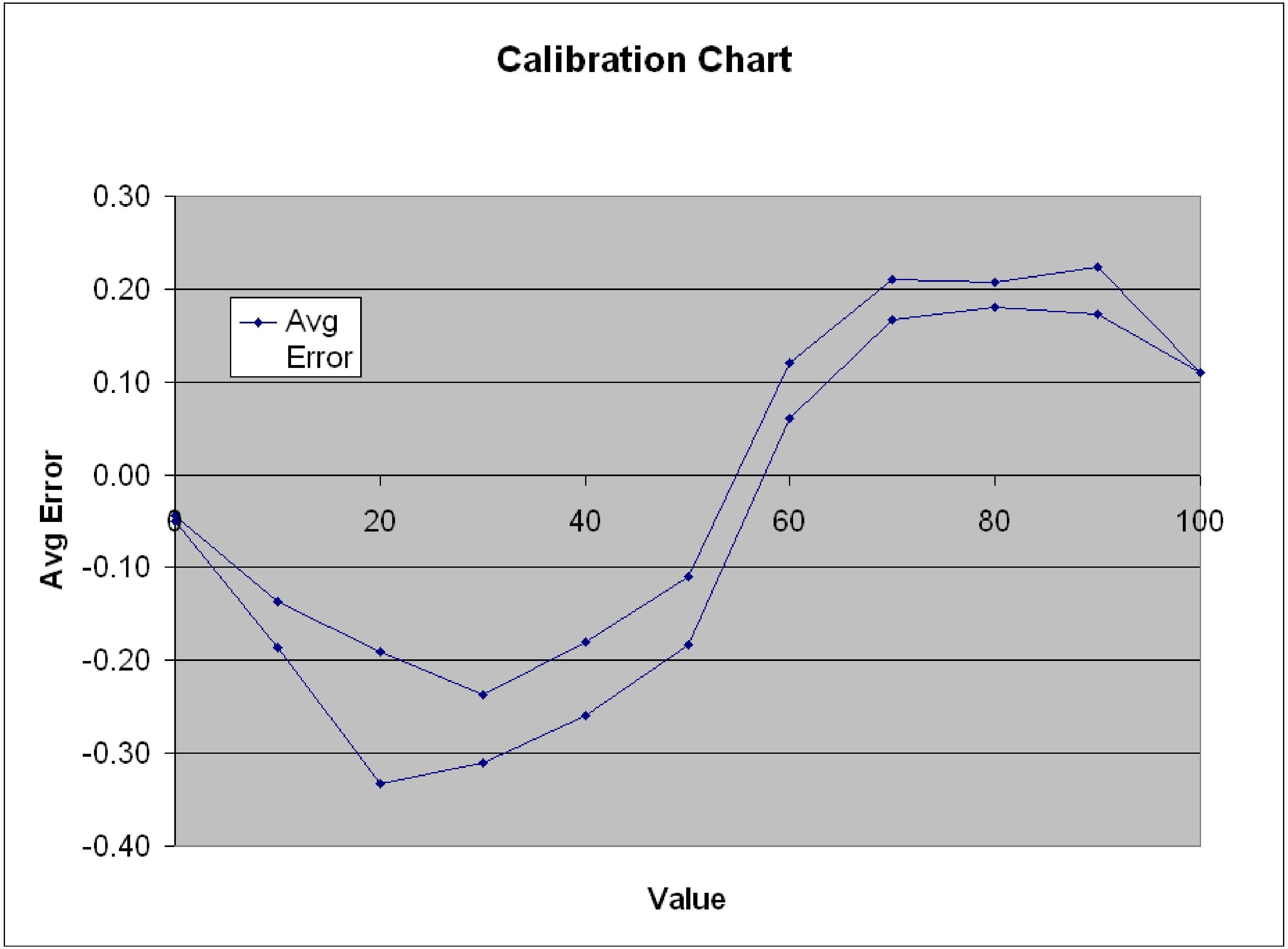
PRINCIPLES OF SENSORS & TRANSDUCERS



PRINCIPLES OF SENSORS & TRANSDUCERS

Value	1st Measurement	1st Error	2nd Measurement	2nd Error	3rd Measurement	3rd Error	Average	Avg Error
0	-0.06	-0.06	-0.05	-0.05	-0.04	-0.04	-0.05	-0.05
10	9.80	-0.20	9.81	-0.19	9.83	-0.17	9.81	-0.19
20	19.70	-0.30	19.70	-0.30	19.60	**-0.40**	19.67	-0.33
30	29.70	-0.30	29.68	-0.32	29.69	-0.31	29.69	-0.31
40	39.80	-0.20	39.70	-0.30	39.72	-0.28	39.74	-0.26
50	49.80	-0.20	49.82	-0.18	49.83	-0.17	49.82	-0.18
60	60.01	0.01	60.02	0.02	60.15	0.15	60.06	0.06
70	70.15	0.15	70.15	0.15	70.20	0.20	70.17	0.17
80	80.20	0.20	80.22	0.22	80.12	0.12	80.18	0.18
90	90.20	0.20	90.17	0.17	90.15	0.15	90.17	0.17
100	100.10	0.10	100.12	0.12	100.11	0.11	100.11	0.11
90	90.25	0.25	90.20	0.20	90.22	0.22	90.22	0.22
80	80.20	0.20	80.21	0.21	80.21	0.21	80.21	0.21
70	70.23	0.23	70.20	0.20	70.20	0.20	70.21	0.21
60	60.14	0.14	60.10	0.10	60.12	0.12	60.12	0.12
50	49.90	-0.10	49.88	-0.12	49.89	-0.11	49.89	-0.11
40	39.80	-0.20	39.82	-0.18	39.84	-0.16	39.82	-0.18
30	29.75	-0.25	29.78	-0.22	29.76	-0.24	29.76	-0.24
20	19.80	-0.20	19.82	-0.18	19.81	-0.19	19.81	-0.19
10	9.85	-0.15	9.87	-0.13	9.87	-0.13	9.86	-0.14
0	-0.05	-0.05	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04

PRINCIPLES OF SENSORS & TRANSDUCERS



PRINCIPLES OF SENSORS & TRANSDUCERS

- **Electrical sensors and transducers**

- Electrical transducers may have mechanical, thermal, chemical, mass, or electromagnetism as their measurand.
- These may change resistive, capacitive, or inductive properties of the transducer, or in fact may directly produce a voltage.

PRINCIPLES OF SENSORS & TRANSDUCERS

- **LVDT**
- Linear variable differential transformers are used to measure movement or displacement.
- These operate by producing a.c. voltages from a pair of secondary windings as a sensing rod fixed to the magnetic core moves linearly between the windings.

PRINCIPLES OF SENSORS & TRANSDUCERS

- The primary winding of the transformer is supplied from a stable source.
- As the core moves, the difference in the voltages produced by the two secondary windings is proportional to its displacement.

PRINCIPLES OF SENSORS & TRANSDUCERS

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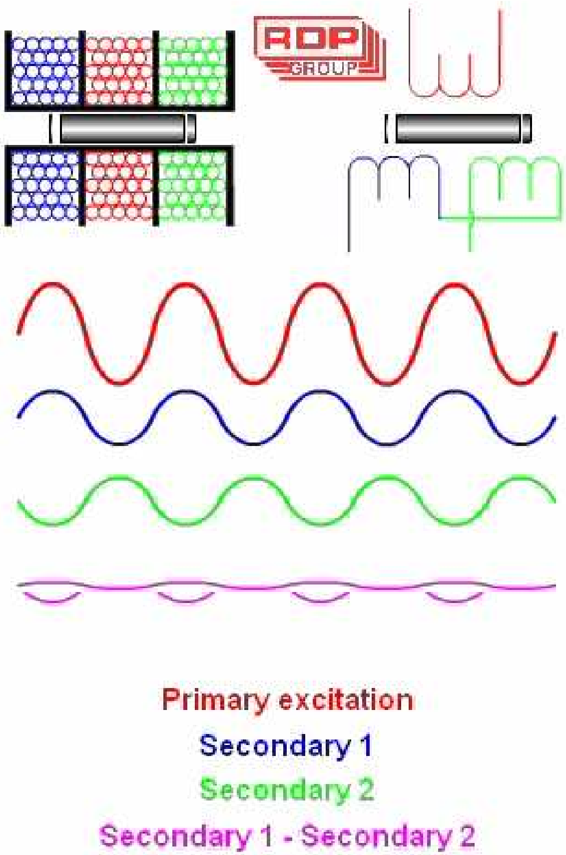

An LVDT Displacement Transducer comprises 3 coils; a primary and two secondaries.

The transfer of current between the primary and the secondaries of the LVDT displacement transducer is controlled by the position of a magnetic core called an armature.

On our position measurement LVDTs, the two transducer secondaries are connected in opposition.

At the centre of the position measurement stroke, the two secondary voltages of the displacement transducer are equal but because they are connected in opposition the resulting output from the sensor is zero.

As the LVDTs armature moves away from centre, the result is an increase in one of the position sensor secondaries and a decrease in the other. This results in an output from the measurement sensor.

With LVDTs, the phase of the output (compared with the excitation phase) enables the electronics to know which half of the coil the armature is in.

The strength of the LVDT sensor's principle is that there is no electrical contact across the transducer position sensing element which for the user of the sensor means clean data, infinite resolution and a very long life.

Our range of signal conditioning electronics for LVDTs handles all of the above so that you get an output of voltage, current or serial data proportional to the measurement position of the displacement transducer.

http://www.rdpe.com/displacement

PRINCIPLES OF SENSORS & TRANSDUCERS

- **Strain gauge**

- The strain gauge can be considered as an electromechanical transducer used for measuring strain in a structure.
- The principle of operation of bonded gauges is as follows.
- A thin piece of conductive material is formed into a pattern so as to create a resistance.
- This is secured, typically through adhesive bonding, onto the surface of the structure such as a bridge support or a generator shaft.

PRINCIPLES OF SENSORS & TRANSDUCERS

- Forces applied to this structure will cause the gauge to change length and diameter, and hence its resistance.
- This change in resistance is used to indicate the deformation of the structure.
- Strain gauges will typically form part of a bridge circuit designed to produce a voltage output which is directly related to this change in resistance.

PRINCIPLES OF SENSORS & TRANSDUCERS

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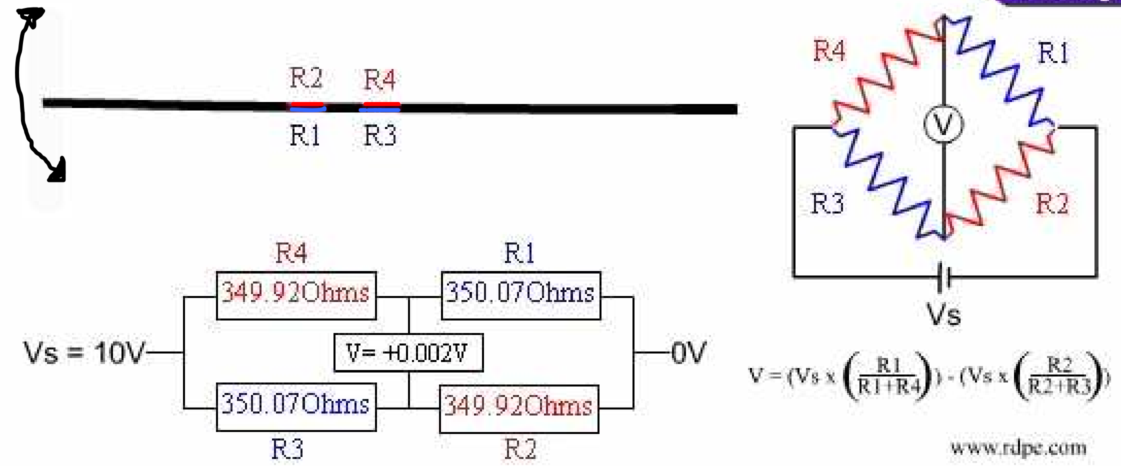
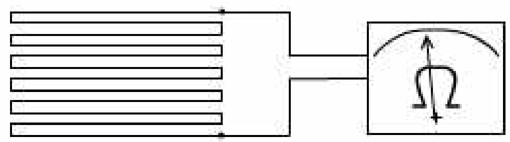


A strain gauge is a long length of conductor arranged in a zigzag pattern on a membrane.



When it is stretched, its resistance increases.

Strain gauges are mounted in the same direction as the strain and often in fours to form a full 'Wheatstone Bridge'.

The diagram above represents what might happen if a strip of metal were fitted with four gauges.

An downward bend stretches the gauges on the top and compresses those on the bottom.

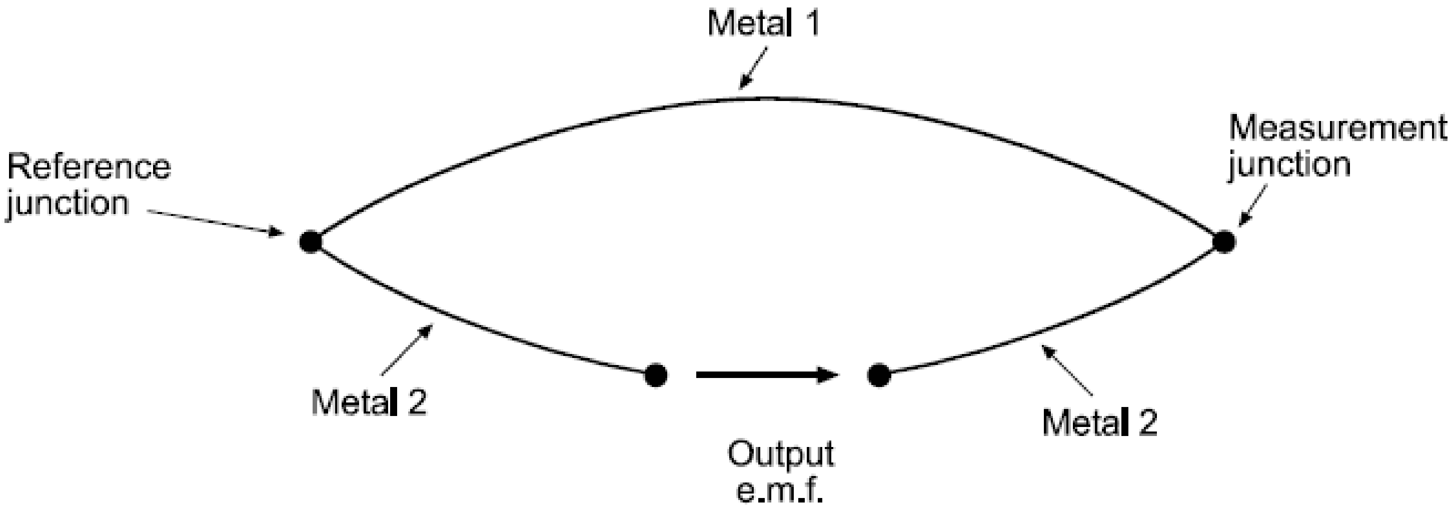
A pressure transducer contains a diaphragm which is deformed by the pressure which can be measured by a strain gauged element.

http://www.rdpe.com/displacement

PRINCIPLES OF SENSORS & TRANSDUCERS

- **Thermocouples**
- The operation of thermocouples relies on the electric current which flows in the junction of two dissimilar metals when a pair of their junctions are at different temperatures, one of these being used as a reference.
- This is due to the Seebeck effect.
- The resulting electromotive force (e.m.f.) can be readily calibrated to measure temperature at the location of the measurement junction.

PRINCIPLES OF SENSORS & TRANSDUCERS



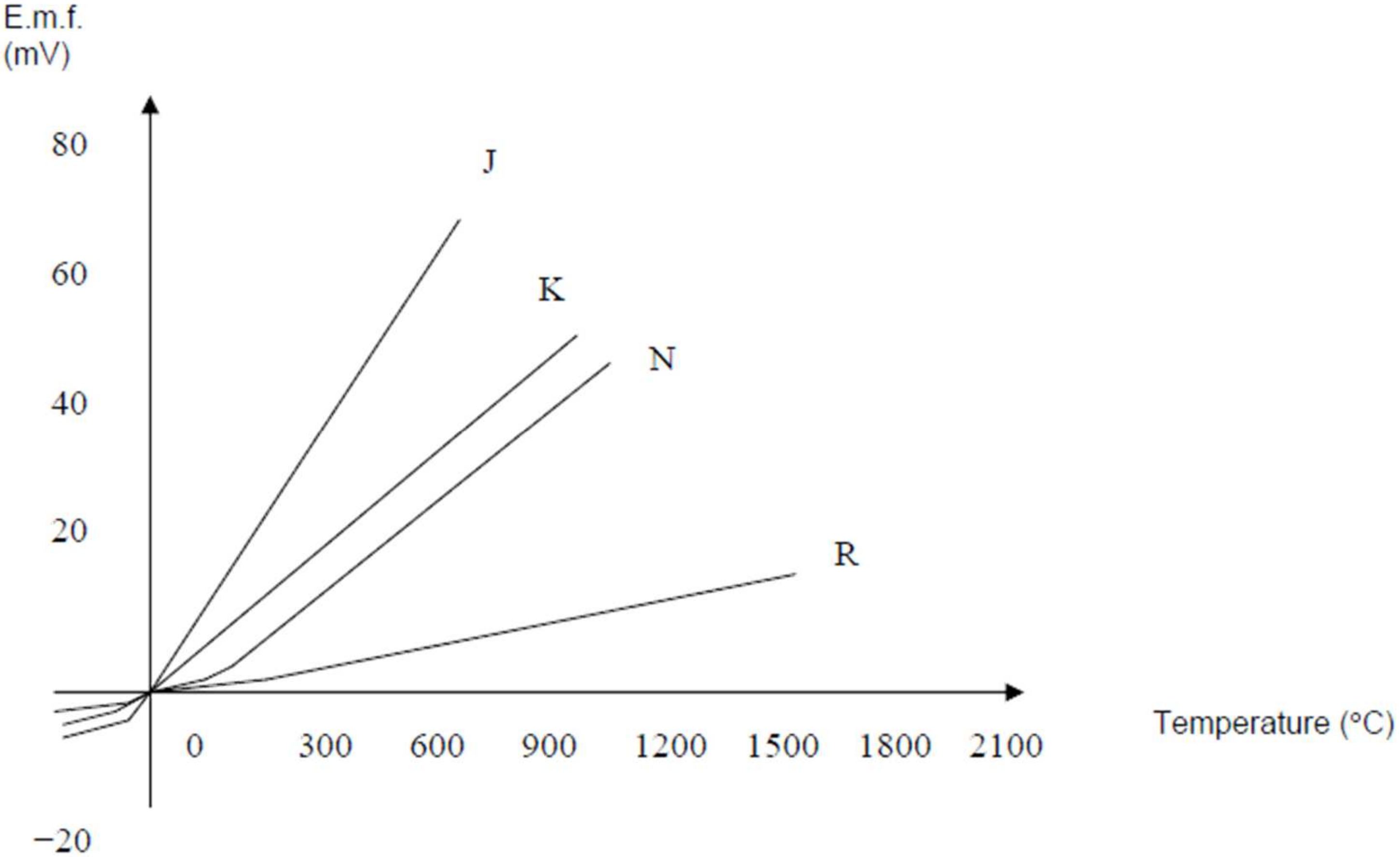
- Thermocouples are available in different materials and classifications to suit the wide range of temperatures which we may require to measure.
- The following table and graph give information about some of the types available and their temperature/e.m.f. relationship.

PRINCIPLES OF SENSORS & TRANSDUCERS

Type	Metal/alloy 1	Metal/alloy 2	Characteristics
J	Iron	Copper–nickel	Cheap and common High e.m.f. output
K	Nickel–chromium	Nickel–aluminium	Wider temperature range than type J
N	Nickel–chromium–silicon	Nickel–silicon	Reliable at high temperatures
R	Platinum–rhodium	Platinum	Relatively expensive High temperature applications

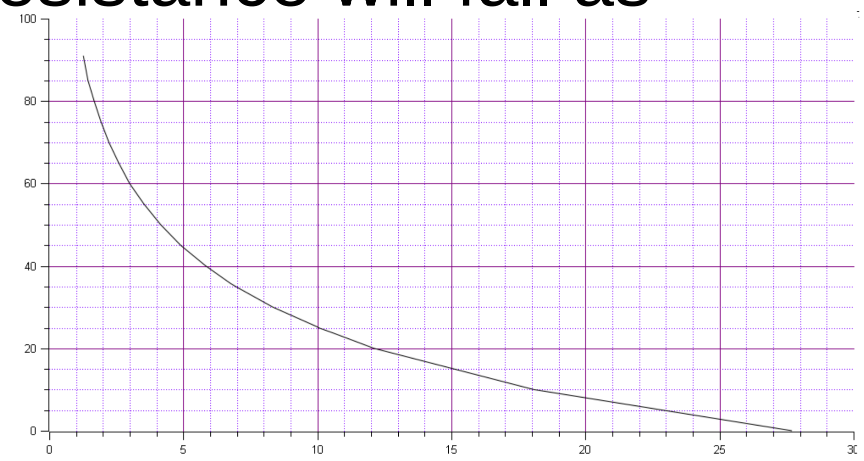
PRINCIPLES OF SENSORS & TRANSDUCERS

- The graph below gives an indication of the ranges of e.m.f. and temperature over which these devices operate.
- Note the linearity of the responses over most of the range.



PRINCIPLES OF SENSORS & TRANSDUCERS

- **Thermistors**
- These transducers are constructed with materials which produce a large change in resistance for a relatively small change in temperature.
- Most have a negative temperature coefficient (ntc); this means that the resistance will fall as temperature increases.



PRINCIPLES OF SENSORS & TRANSDUCERS

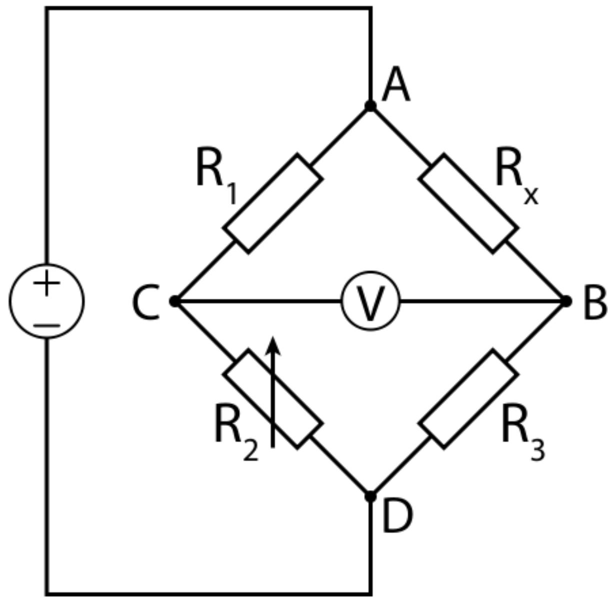
- Resistance changes exponentially:

$$R = Ae^{\frac{B}{T}}$$

- where *A* and *B* are constants for the material from which the thermistor is made.
- The change in resistance is normally converted into a voltage.
- The fact that we must pass current through the thermistor to do this means that we have introduced a source of error as the I^2R power will raise the temperature of the thermistor and so alter its resistance.

PRINCIPLES OF SENSORS & TRANSDUCERS

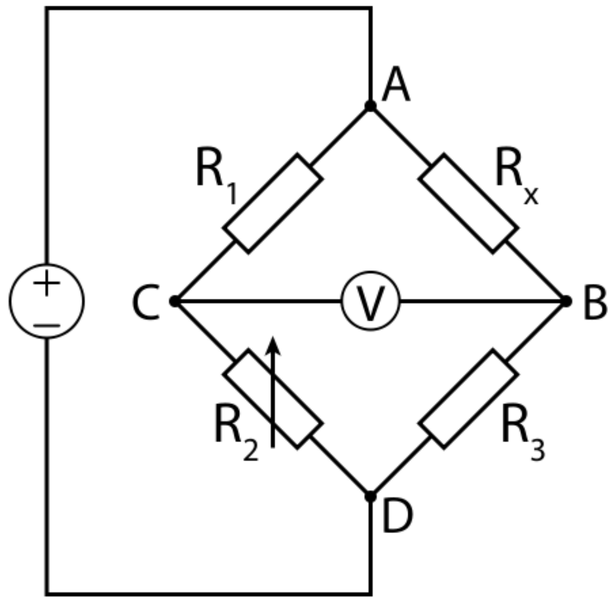
- **Bridge circuits**
- Transducers and sensors which produce a change in resistance are typically used in a bridge circuit.
- This consists of an arrangement of resistances supplied from a stable voltage source.



PRINCIPLES OF SENSORS & TRANSDUCERS

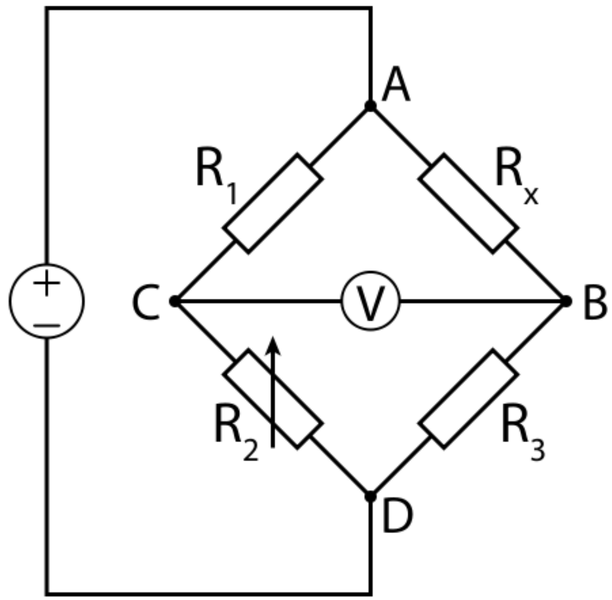
- For the bridge to be balanced, the ratio of resistances in each branch must be balanced.

- Any change in resistance will produce a potential difference between the two junctions C and B.



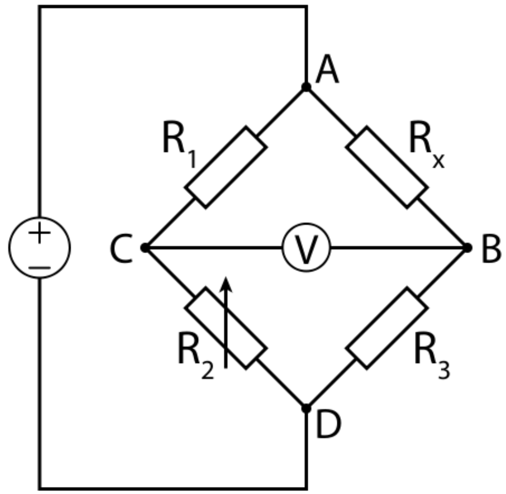
PRINCIPLES OF SENSORS & TRANSDUCERS

- The values of resistance are designed so that the small changes in resistance from the sensor will result in an improvement in resolution of the measurement.



PRINCIPLES OF SENSORS & TRANSDUCERS

- A **bridge circuit** is a type of electrical circuit in which two circuit branches
- (usually in parallel with each other) are "bridged" by a third branch connected between the first two branches at some intermediate point along them.

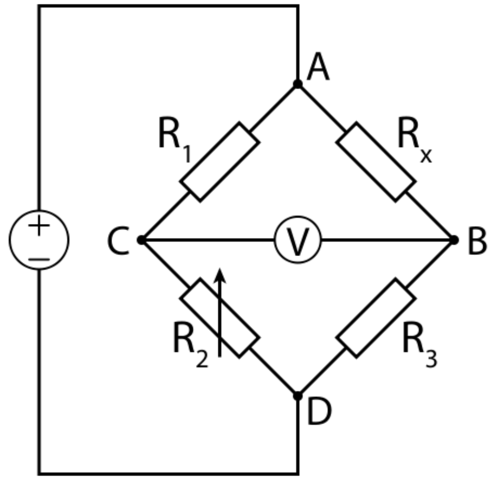


PRINCIPLES OF SENSORS & TRANSDUCERS

- The bridge was originally developed for laboratory measurement purposes and one of the intermediate bridging points is often adjustable when so used.
- Bridge circuits now find many applications, both linear and non-linear, including in instrumentation, filtering and power conversion.

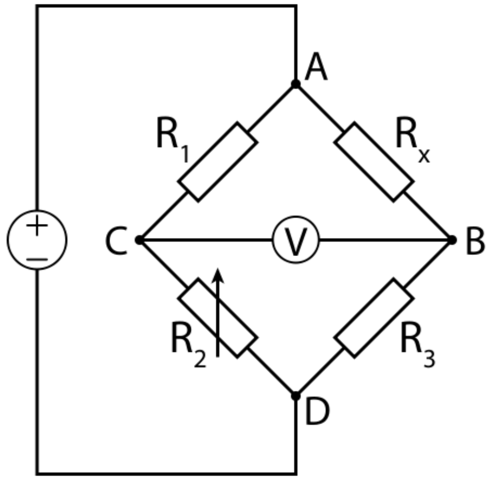
PRINCIPLES OF SENSORS & TRANSDUCERS

- It is constructed from four resistors, one of which has an unknown value (R_x), one of which is variable (R_2), and two of which are fixed and equal (R_1 and R_3), connected as the sides of a square.



PRINCIPLES OF SENSORS & TRANSDUCERS

- Two opposite corners of the square are connected to a source of electric current, such as a battery.
- A galvanometer [sensitive voltmeter] is connected across the other two opposite corners.
- The variable resistor is adjusted so the galvanometer reads zero.

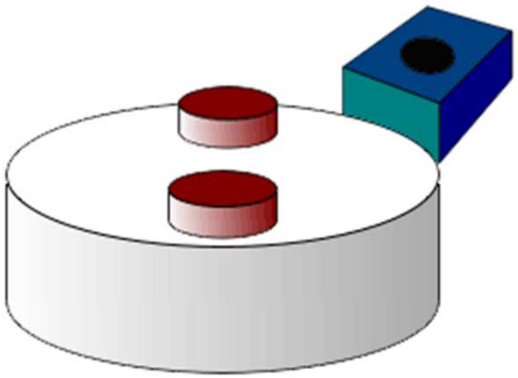


PRINCIPLES OF SENSORS & TRANSDUCERS

- It is then known that the ratio between the variable resistor and its neighbour is equal to the ratio between the unknown resistor and its neighbour, and this enables the value of the unknown resistor to be calculated.

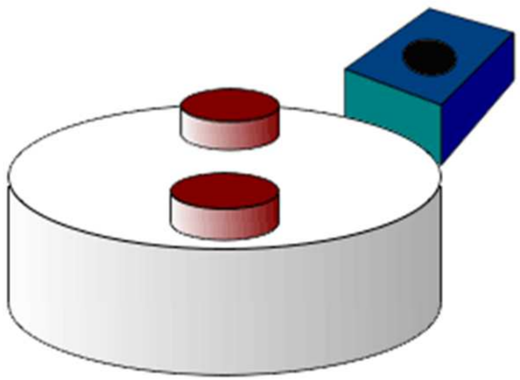
PRINCIPLES OF SENSORS & TRANSDUCERS

- **Hall effect sensors**
- These semiconductor-based devices work on the principle that a current flowing in a magnetic field will generate a voltage.
- In this type of sensor a constant current flows in the device and the voltage developed is proportional to the external magnetic field.



PRINCIPLES OF SENSORS & TRANSDUCERS

- Hall effect sensors are commonly used as proximity detectors, sensing the presence of a piece of magnetic material as it changes the magnetic field strength.
- They have the advantage of being immune to the contact bounce of mechanical switches and can be sealed to allow use in contaminated locations.



PRINCIPLES OF SENSORS & TRANSDUCERS

- **Mechanical sensors and transducers**
- The range of mechanical parameters is wide, as indicated previously.
- There have been a great number of developments within this area and the range of devices is also wide.

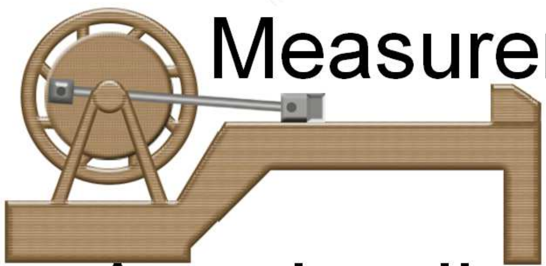
PRINCIPLES OF SENSORS & TRANSDUCERS

- If we refer back to the physical features which we require to measure, we see that in many cases the method of measurement and devices selected will be influenced by factors such as environment and time as well as accuracy and repeatability.

PRINCIPLES OF SENSORS & TRANSDUCERS

- Spring
- Diaphragm
- Bourdon gauge
- Venturi tube
- Mass flowmeters

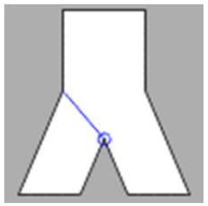
Rotational or Angular Displacement.

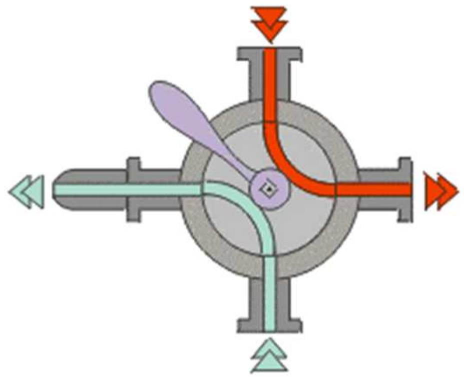


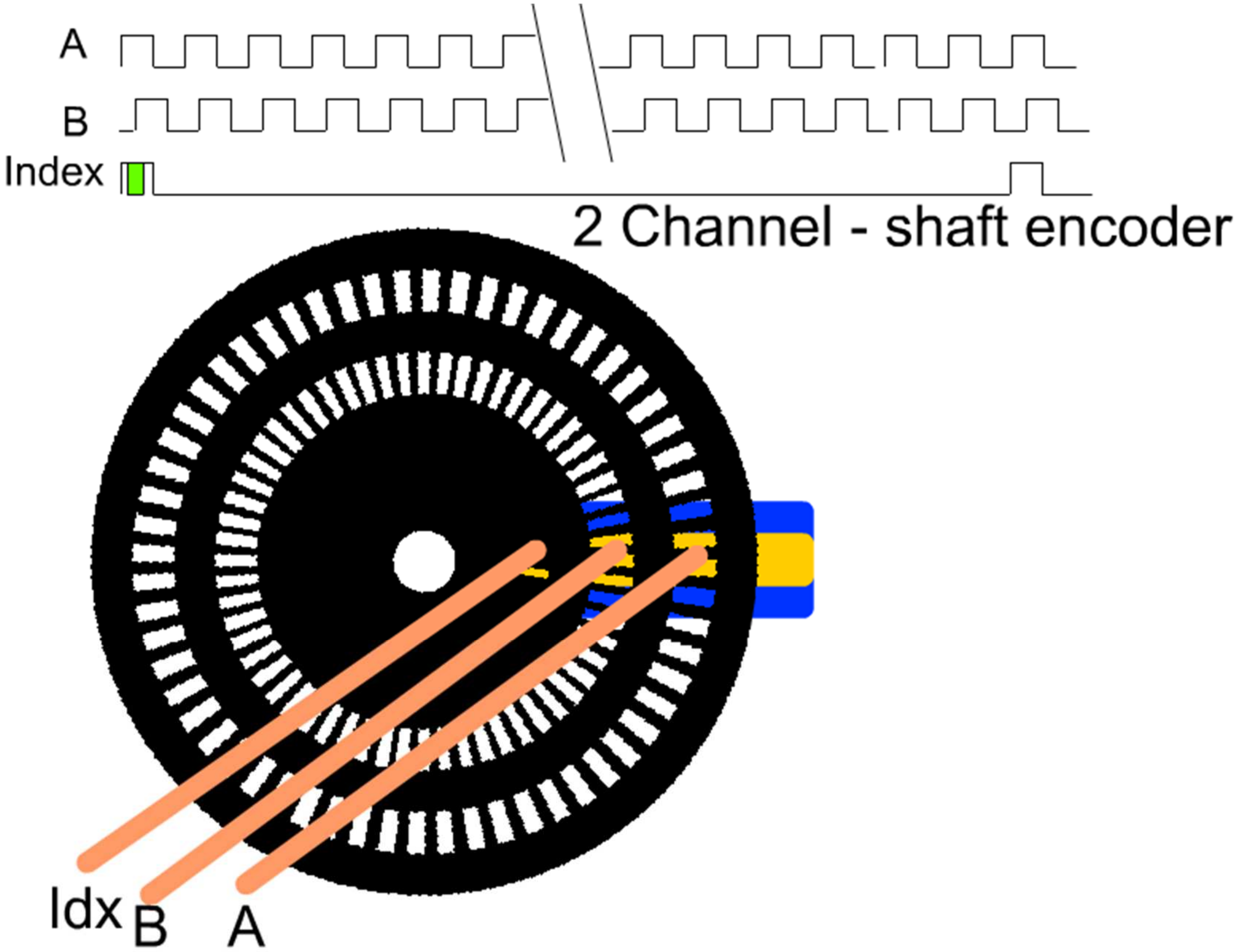
Measurement of angular movement.

Angular displacement is the angle that a rotating body moves through.

Why would we need to measure Angular displacement.

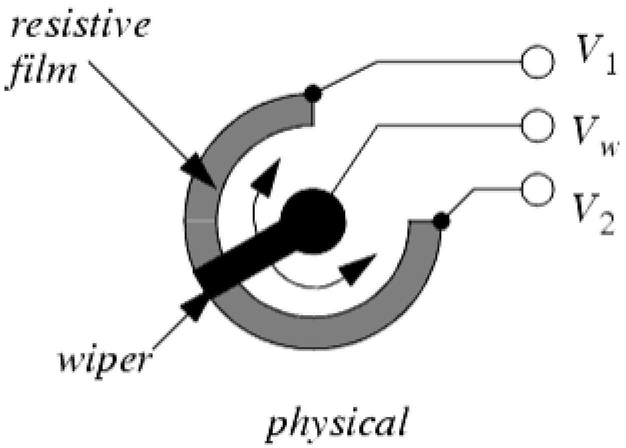


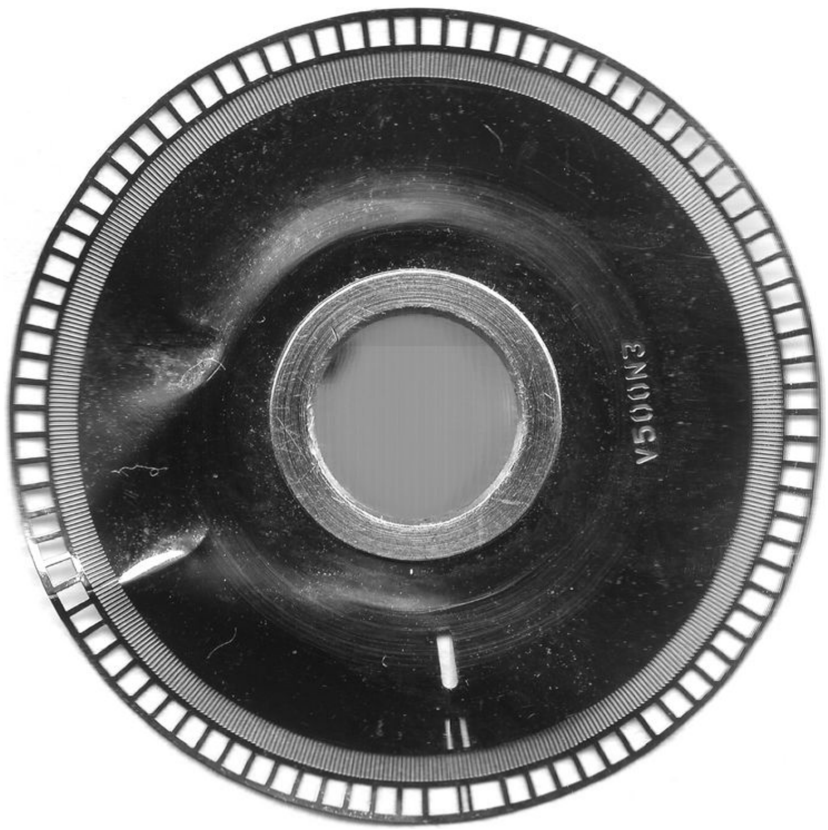



A
B
Index
2 Channel - shaft encoder
Idx
B
A

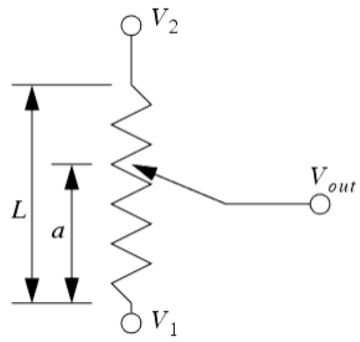
- The Shaft Encoder.

- Used for rotational displacement





Rotational potentiometers were discussed before, but potentio-meters are also available in linear /sliding form.



$$V_{out} = V_1 + (V_2 - V_1)\left(\frac{a}{L}\right)$$

These are capable of measuring linear displacement over long distances the figure above shows the output voltage when using the potentiometer as a voltage divider.