Pearson BTEC Level 4 Higher Nationals in Engineering (RQF)

Unit 6: Mechatronics

Unit Workbook 4

in a series of 4 for this unit

Learning Outcome 4

Faults in a Mechatronic System

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Distribution boards should always be subjected to an insulation resistance (IR) test on each subsidiary circuit.

Circuit breakers

A circuit breaker is an automatic switch which is triggered to turn off when excessive current flows through it. The excessive current is usually the result of a serious fault condition but can sometimes be merely due to a bulb blowing. A common circuit breaker is shown in figure 6.

Figure 6 A *circuit breaker*

Testing of circuit breakers is termed 'Trip Profiling' and involves testing the switching mechanism and the response time to an excessive current.

Fuses

Common fuse wire is made from tinned copper. The diameter of the wire used will dictate the current rating of the fuse. Predictably, thinner fuse wire will rupture at lower currents. A cartridge fuse is used with an electrical plug, with fuse wire within it. Blade type fuses are commonly used in vehicle fuse boxes. Large power fuses can be made from silver, which provides more predictable performance. A number of fuse types is shown in figure 8.

Figure 8 A *selection of fuses*

Fuses are commonly tested by performing a continuity test with a multimeter.

Thermal devices

A common thermal device is the thermal fuse, which ruptures when the temperature in its vicinity reaches a pre-determined level. Such fuses are commonly used within the windings of motors to prevent overheating in the event of a fault condition. A typical thermal fuse is shown in figure 9.

Figure 9 A *thermal fuse*

Contactors

A contactor is a switch provided with electrical control. The controller will typically be part of a circuit which involves much less power than that which the switch itself connects to. For example, a 12-volt contactor could be employed to control a mains-operated motor. A typical contactor is shown in figure 11.

Figure 11 A *contactor*

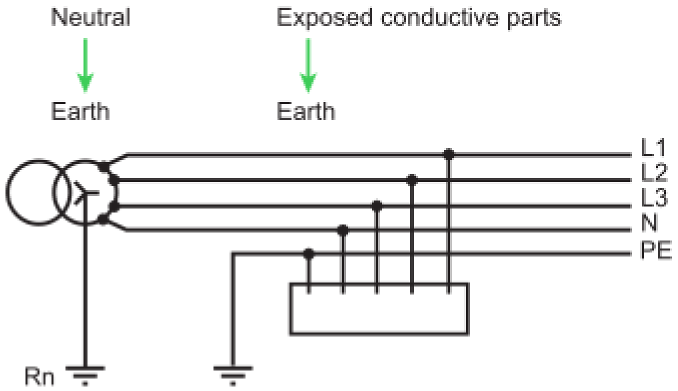

Figure 16 *The TT earthing scheme*

TN-C System

In this arrangement the neutral is used as a protective conductor, known as a PEN (Protective Earth and Neutral). The system is not allowed for portable devices, nor when the conductors have a cross-sectional area of less than $10mm^2$. An equipotential environment is necessary here, so the system needs regularly distributed earth electrodes. The arrangement is shown in figure 17.

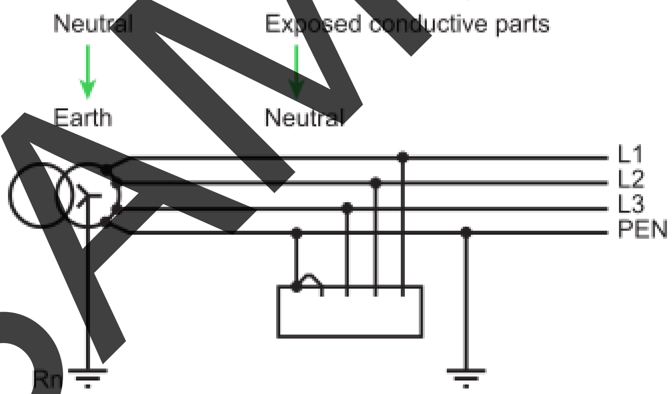

Figure 17 *The TN-C earthing scheme*

TN-S System

For portable equipment, and systems with wires less than $10mm^2$ in cross sectional area, this system is **mandatory**. The protective conductor and neutral are separated, with five wires used in the scheme, as shown in figure 18.

the motor itself is faulty then the cause could be a burnt-out wire, loose or corroded connection, compromised insulation or a faulty bearing. Systematic tests, measurements and observations will usually quickly reveal the cause, as discussed in the previous workbook.

Similar testing will apply to portable generators, but, in either case, adequate personal protection measures should be employed.

Types of electric motors

The various categories and types of electric motor are presented in figure 22.

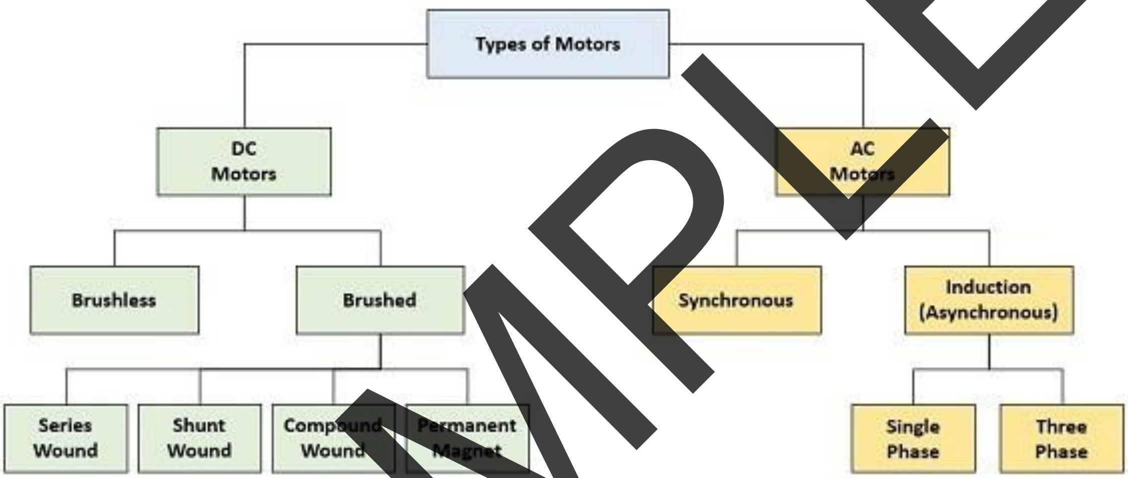

Figure 22 *Various types of electric motor*

DC Motors

Brushed

These are very commonly used and employed in consumer applications and light industry. Brushed motors can be sub-divided into four types, as explained below.

Series wound

The field winding (located in the stator) is connected in series with the rotor winding. Control of the motor speed is achieved by varying the supply voltage.

Compound wound

Uses a combination of series and shunt windings. The polarity of the shunt winding adds to the series field. This motor has a high starting torque and functions smoothly should the load vary slightly. It is used for compressors, rotary presses and elevators.

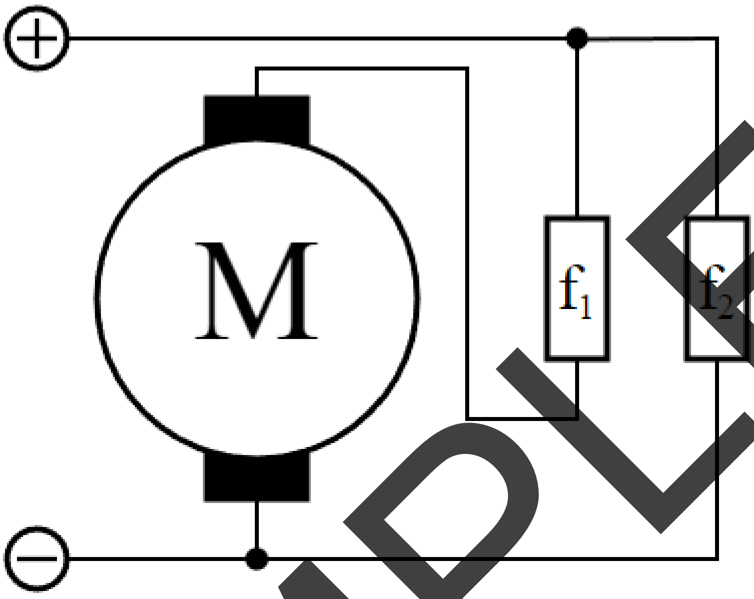

Figure 25 *Compound wound brushed motor*

Permanent magnet

Rather than use an electromagnet, this type uses permanent magnets in the stator, as shown in figure 26. It is used in precise control low-torque applications such as robotics and servo systems.

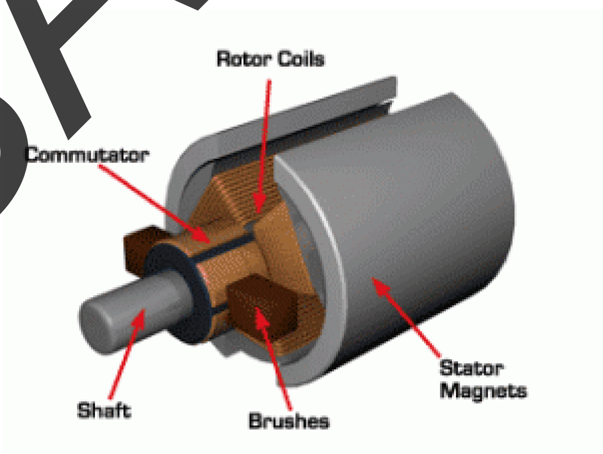

Figure 26 *Permanent magnet DC motor*

AC Motors

Synchronous

These motors have their speed of rotation synchronised with the frequency of the supply current, with the speed remaining constant with changing loads. Constant speed operation means that these motors find uses in robotics and process control.

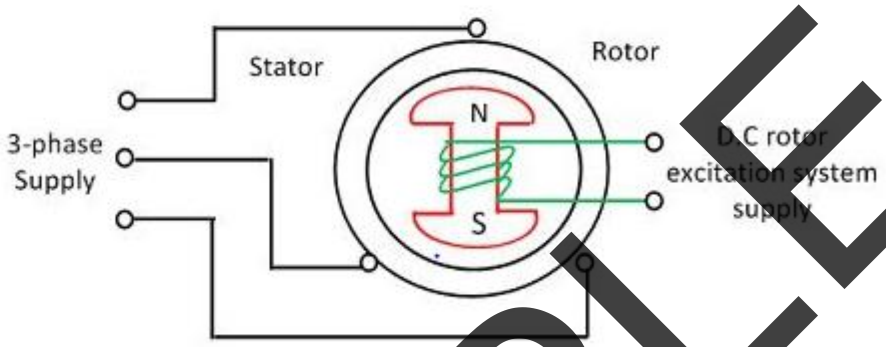

Figure 28 *Synchronous AC motor*

Asynchronous (Induction)

These are the most common types of AC motor. They use the electromagnetic field from the stator winding to induce an electric current in the rotor, and thereby torque.

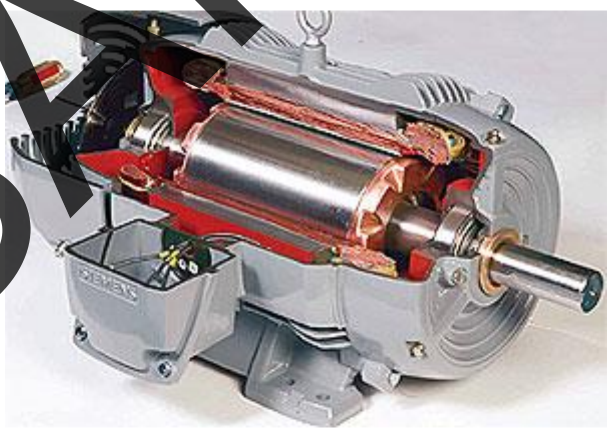

Figure 29 *Induction motor*

Single Phase

Single phase induction motors find uses in low-load applications such as household appliances.

Self-excited

The generator produces its own current to energise the field coils. As for motors, we may have series, shunt and compound arrangement for the field and armature windings.

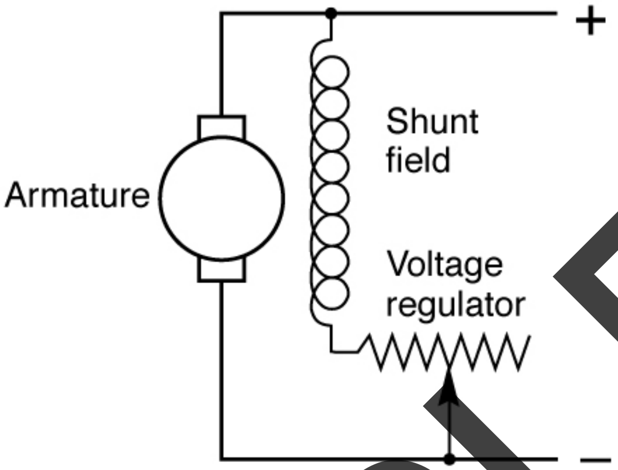

Figure 31 *Self-excited DC generator*

AC Generators

These can be categorised as either;

- Synchronous generator
- Induction generator

Synchronous generator

The coil is connected to slip rings, and the load is connected to brushes which rest on these slip rings. The slip rings are arranged in such a way that every 180 degrees of rotation sees the current direction reversed in the load; hence, an AC current is generated.

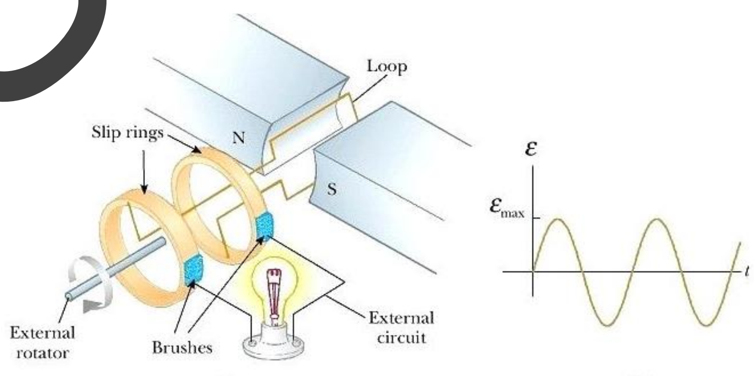

Figure 32 *Synchronous AC generator*

Induction (Asynchronous) Generator

Here, an AC supply to the stator causes a rotating magnetic field which causes the rotor to begin to turn. The rotor is made to turn faster (by a prime mover) than the synchronous speed of the magnetic field produced by the stator. The prime mover is often a petrol engine. The generator then becomes asynchronous.

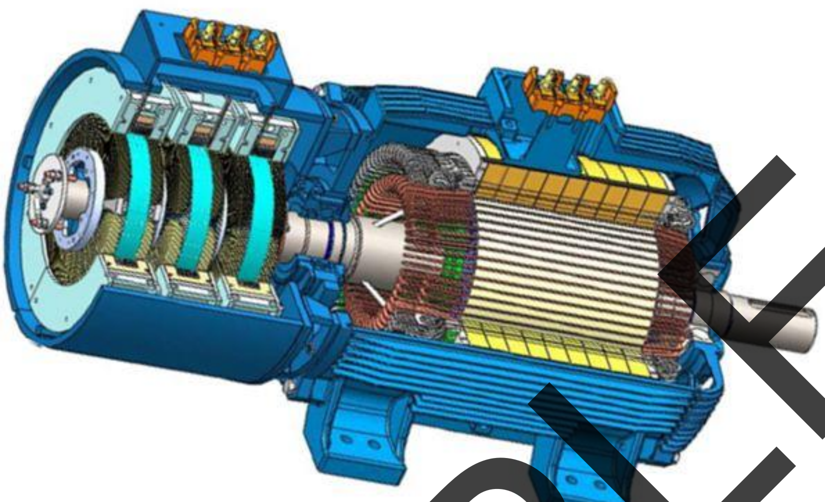

Figure 33 *AC induction generator*

Starting Methods

For motors rated at only a few kilowatts it only necessary to connect the supply and the motor starts by itself. However, where the motor is rated at well more than a few kilowatts we need to ensure that the motor does not affect the general power supply and perhaps dim lights or trigger circuit breakers.

When a large induction motor is started it can draw five or six times its rated current, and greatly lowers the power factor during the start-up. We therefore need to use starting methods to overcome these problems. Four starting methods are discussed next.

Star/Delta Starter

This is a very common starting method. To begin the starting process the motor windings are connected in a Star (wye) arrangement, causing the voltages applied to each phase to drop by nearly 50%. Once the motor reaches close to its designed running speed the windings are reverted to a Delta (Mesh) arrangement.

$$E_2 = \left(\frac{N_2}{N_1}\right) E_1$$

The rotor e.m.f. when running (E_r) is proportional to the slip, s, therefore…

$$E_r = sE_2$$

$$\therefore \quad \boldsymbol{E_r = s\left(\frac{N_2}{N_1}\right) E_1}$$

Synchronous speed and rotor speed

Let…

$n_s = synchronous\ speed$

$n_r = rotor\ speed$

$$\therefore \quad \boldsymbol{n_r = n_s(1 - s)}$$

Efficiency and Power

Efficiency, η, can be quantified as…

$$\boldsymbol{\eta = \frac{output\ power}{input\ power} \times 100\%}$$

The main losses in an induction motor are;

- Stator losses
- Rotor copper losses
- Friction and winding losses

Torque

Let…

$R_2 = Rotor\ resistance$

- More complex analogue filters using capacitors, inductors and resistors.

Cooling and Protection Devices

Cooling

Some strategies to provide cooling for motors and generators can be;

- Radiative cooling – heat is transferred from the motor to its casing, which dispels it to the atmosphere
- Heat sink – a large device with multiple fins used to radiate excessive heat
- Forced air cooling with an electric fan
- Liquid cooling, usually using ethylene glycol or another liquid to circulate around the motor housing and coils.

Protection

Some strategies to provide protection to/from motors and generators can be;

- Fuses
- Circuit breakers
- Thermal overload device
- Overvoltage protection
- Undervoltage (excess current) protection
- Phase imbalance protection
- Ground fault protection
- Differential protection
- Short circuit protection
- Use of RTD (resistance temperature detector)

Sensors and Transducers

Transducers

Transducers are the name given to components that converts variations in a physical quantity (pressure, brightness, temperature) into an electrical signal, or vice versa. They are used in data acquisition to produce the electrical signal and feed it to a microcontroller, the microcontroller will analyse the signal and decide if the system needs appropriate adjustment.

Theory

Most data acquisition signals can be described as analogue, digital, or pulse. While analogue signals typically vary smoothly and continuously over time, digital signals are present at

- **Reproducibility** is the closeness of agreement between measurements of the same thing carried out in different circumstances, e.g. by a different person, or a different method, or at a different time.

Tolerance

Theory

Tolerance, also known as 'acceptance criteria'. It is the maximum acceptable difference bet ween the actual value of a quantity and the value specified for it. For example, if an electrical resistor has a specification of 10Ω and there is a tolerance of $\pm 10\%$ on that specification, the minimum acceptable resistance would be 9Ω and the maximum would be 11Ω. Many factors can reduce accuracy or precision and increase the uncertainty of your measurement result. Some of the most common are:

- **Environmental conditions** – changes in temperature or humidity can expand or contract materials as well as affect the performance of measurement equipment.
- **Inferior measuring equipment** – equipment which is poorly maintained, damaged or not calibrated will give less reliable results.
- **Poor measuring techniques** – having consistent procedures for your measurements is vital.
- **Inadequate staff training** – not knowing how to make the right measurement, not having the confidence to challenge the results and not being willing to seek advice can all have a negative impact.

Error Analysis and Significant Figures

Errors using inadequate data are much less than those using no data at all. (C. Babbage)

Theory

No measurement of a physical quantity can be entirely accurate. It is important to know, therefore, just how much the measured value is likely to deviate from the unknown, true, value of the quantity. The art of estimating these deviations should probably be called uncertainty analysis, but for historical reasons is referred to as error analysis.

Significant Figures

Whenever you make a measurement, the number of meaningful digits that you write down implies the error in the measurement. For example, if you say that the length of an object is $0.428m$, you imply an uncertainty of about $0.001m$. To record this measurement as either 0.4 or 0.42819667 would imply that you only know it to $0.1m$ in the first case or to $0.00000001m$ in the second. You should only report as many significant figures (S.F) as are consistent with the estimated error. The quantity $0.428m$ is said to have three S.F that is, three digits that make sense in terms of the measurement. Notice that this has nothing to do with the "number of decimal places". The same measurement in centimetres would be $42.8cm$ and still be a three S.F number. The accepted convention is that only one uncertain digit is to be reported for a measurement. In the example if the estimated error is $0.02m$ you would report a result of $0.43 \pm 0.02\ m$, not $0.428 \pm 0.02\ m$.

Students frequently are confused about when to count a zero as a S.F. The rule is: If the zero has a non-zero digit anywhere to its left, then the zero is significant, otherwise it is not. For example, 5.00 has three S.F; the number 0.0005 has only one S.F, and 1.0005 has five S.F. A number like 300 is not well defined. Rather one should write $3 \cdot 10^2$ to one S.F, or $3.00 \cdot 10^2$ to 3.

Absolute and relative errors

The absolute error in a measured quantity is the uncertainty in the quantity and has the same units as the quantity itself. For example, if you know a length is $0.428m \pm 0.002m$, the $0.002m$ is an absolute error.

The relative error (also called the fractional error) is obtained by dividing the absolute error in the quantity by the quantity itself. The relative error is usually more significant than the absolute error. For example, a $1mm$ error in the diameter of a skate wheel is probably more serious than a $1mm$ error in a truck tire. Note that relative errors are dimensionless. When reporting relative errors, it is usual to multiply the fractional error by 100 and report it as a percentage.

Systematic errors

Systematic errors arise from a flaw in the measurement scheme which is repeated each time a measurement is made. If you do the same thing wrong each time you make the measurement, your measurement will differ systematically (that is, in the same direction each time) from the correct result. Some sources of systematic error are:

- Errors in the calibration of the measuring instruments.
- Incorrect measuring technique: For example, one might make an incorrect scale reading because of parallax error.
- Bias of the experimenter. The experimenter might consistently read an instrument incorrectly or might let knowledge of the expected value of a result influence the measurements.

Clearly, systematic errors do not average to zero if you average many measurements. If a systematic error is discovered, a correction can be made to the data for this error. If you measure a voltage with a meter that later turns out to have a $0.2V$ offset, you can correct the originally determined voltages by this amount and eliminate the error. Although random errors can be handled routinely, there is no prescribed way to find systematic errors. One must simply sit down and think about all the possible sources of error, and then do small experiments to see if these sources are active. The goal of a good experiment is to reduce the systematic errors to a value smaller than the random errors. For example, a metre stick should have been manufactured such that the millimetre markings are positioned much more accurately than one millimetre.

Mistake or Blunder

A procedural error that should be avoided by careful attention. These are illegitimate errors and can generally be corrected by carefully repeating the operations.

Discrepancy

A significant difference between two measured values of the same quantity, the implication being that the difference between the measured values is greater than the combined experimental uncertainty.

Relative error

Error of measurement divided by a true value of the Measurand. Relative error is often reported as a percentage. The relative or "percent error" could be 0% if the measured result happens to coincide with the expected value, but such a statement suggests that somehow a perfect measurement was made. Therefore, a statement of the uncertainty is also necessary in order to properly convey the quality of the measurement.

Standard Error (Standard Deviation of the Mean)

The sample standard deviation divided by the square root of the number of data points shown by Eq.1.2, where $\sigma^2 = \sum \frac{(xi-x)^2}{(n-1)}$ is the sample variance.

$$SE = \frac{\sigma}{\sqrt{n}} \qquad \text{(Eq.1.2)}$$

An inductive proximity sensor detects the presence of a metallic target. Ferrous metals, such as steel or iron, are more easily detected, but aluminium and copper may also be detected with reduced sensitivity. Figure 35 shows an inductive proximity detector.

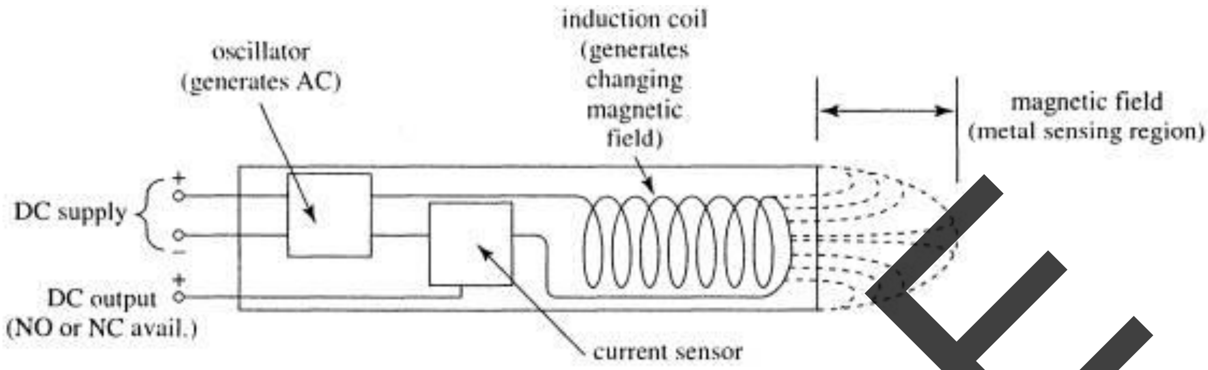

Figure 35 Principle *of an inductive proximity detector*

In figure 35 we see that a DC supply powers an AC oscillator. This oscillator provides a varying sinusoidal current to a coil. The coil can be wound on a ferrite or iron core. The electromagnetic field produced by the coil in this state emanates magnetic flux (shown dotted) from the side of the coil.

When a metallic object locates itself inside the flux emanating from the coil here will be a change in the overall inductance of the coil, changing the level of current flow. This change in current is detected by the current sensor, which then outputs a signal which can be in the form of a DC level, or either activating normally-open or normally-closed contacts. A typical inductive proximity detector is shown in figure 36.

Figure 36 A *tubular inductive proximity detector*

Hall Effect Sensor

In this type of sensor, a current is applied to a thin strip of metal. If a magnet is brought near to the metal strip the electrons which form the current are drawn to one side of the strip's long edge. This causes a voltage difference across the metal strip, which is used to indicate the presence of the magnet. This effect is depicted in figure 37.

in the coil. This current is then amplified and sent to a further stage, perhaps a loudspeaker. The principle of operation of a moving coil microphone is depicted in figure 39.

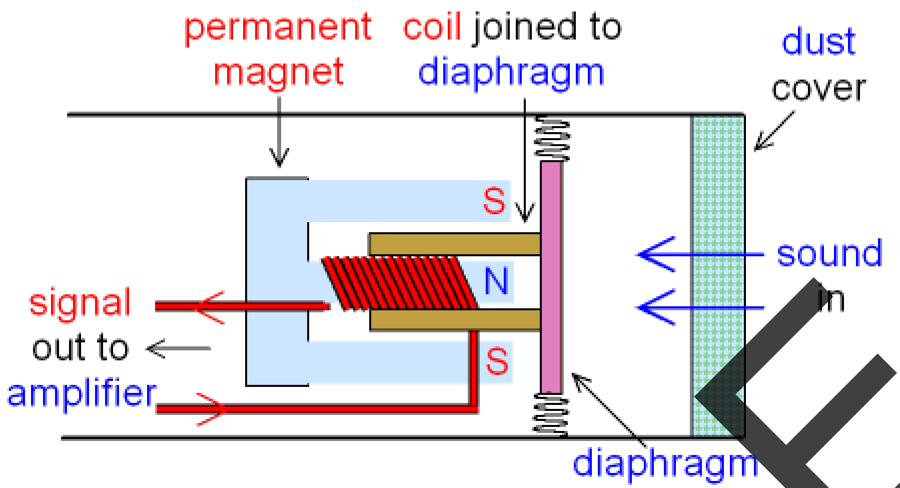

Figure 39 *Principle of operation of a moving coil microphone*

Antenna

An antenna can act as a sensor and operates on the principle of electromagnetic induction. As shown in figure 40, an incident electromagnetic wave (green) causes slight variations in the voltage induced in the antenna (red and blue). There are many variations of antenna, but the principle of operation is generally the same.

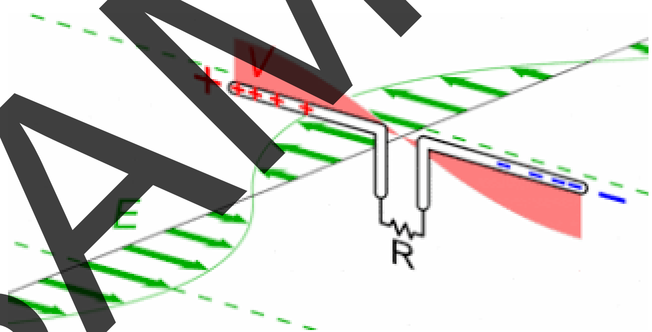

Figure 40 *Antenna as a receiver*

Electromagnetic Flow Meter

An electromagnetic flow meter can measure the flow of a conductive liquid in a pipe. A magnetic field is generated in a vertical cross-section of the pipe, and voltage detecting electrodes are placed horizontally across the pipe section. As the fluid contains countless positively and negatively charged ions, as it passes through the measurement section the positively charged ions are caused to move to one side of the pipe, and the negatively charged ions to the other side of the pipe, as depicted in figure 41.

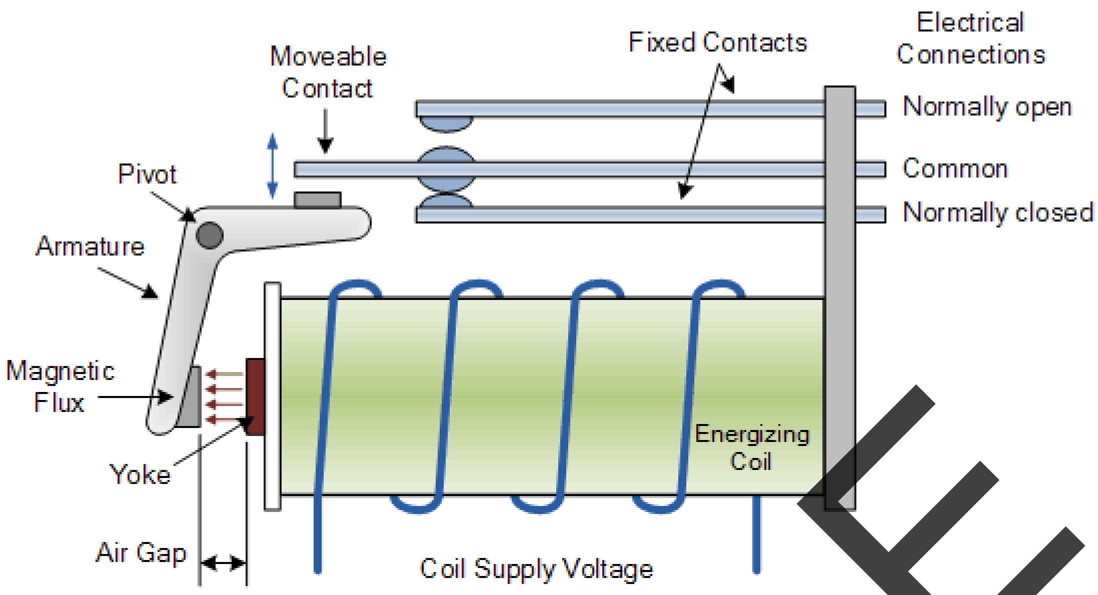

Figure 42 *Principle of operation of an electromagnetic relay*

A relay can be used to switch on a motor via a low voltage control circuit. Relays are common in high power switching applications, for example in railway signalling systems.

Rotary

A rotary actuator converts electrical energy into rotational/torque energy. The rotational energy may be continuous or, perhaps, movement to a fixed /pre-determined angular position, as in servo or stepper motors. Servo motors are commonplace in mechatronics, robotics and drone technology. Examples of rotary actuators are shown in figures 45, 46 and 47.

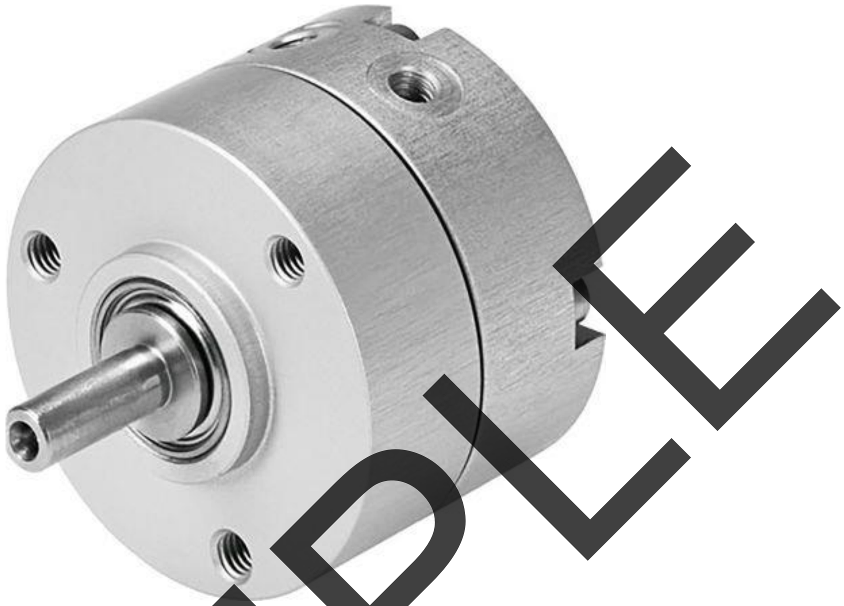

Figure 45 *A linear actuator*

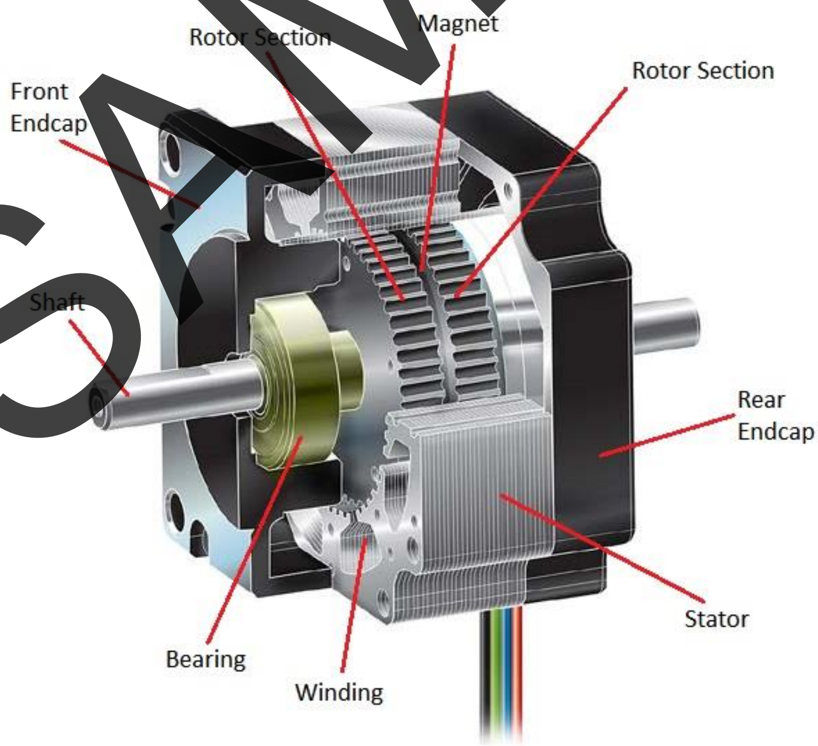

Figure 46 *A stepper motor (actuator)*