Pearson BTEC Levels 4 Higher Nationals in Engineering (RQF)

Unit 29: Electro, Pneumatic and Hydraulic Systems

Unit Workbook 3

in a series of 4 for this unit

Learning Outcome 3

Applications of Pneumatic and Hydraulic Systems

Background Theory

Defining Fluid

Before beginning the unit, it is important to know exactly what a fluid is. Fluids are commonly mistaken as a liquid, and while this is technically correct, fluids are defined as something that flows, which means that fluids actually encompass both liquids *and* gases. Fluids do not have a fixed shape and will yield easily to external pressure.

Pascal's Law

Pascal's law is an important consideration in fluid mechanics that was first coined by the French scientist Blaise Pascal. Pascal's Law states:

"A pressure change in one part of a fluid at rest in a closed container will transmit to every portion of the fluid and the walls of the container without any losses"

This is an important principle when considering hydraulic systems. Pressure P can be defined by Equation 1, where F is the force and A is the area.

$$P = \frac{F}{A} \quad [1]$$

Therefore, being stood on by a high heel is more painful than being stood on by a flat shoe. The force applied will still be the same, but the pressure on the concentrated heel will be much greater than a flat shoe.

Hydraulics

Pascal's principle is applied to hydraulic systems. A force applied to a given area can be used to exert a force elsewhere through fluid transmission.

Hydraulics operate with two classes of piston, the "Master" and the "Slave" piston, the master piston is the dictator in the system and controlled by the operator, while the slave piston is the one that will move as a result. One of the most common hydraulic systems in day-to-day life are the brakes in cars. Fig.1 shows a basic schematic of a hydraulic system in place, the master piston is shown as the one receiving the operator's "effort force" F_1, and the slave piston is applying the "load force" F_2.

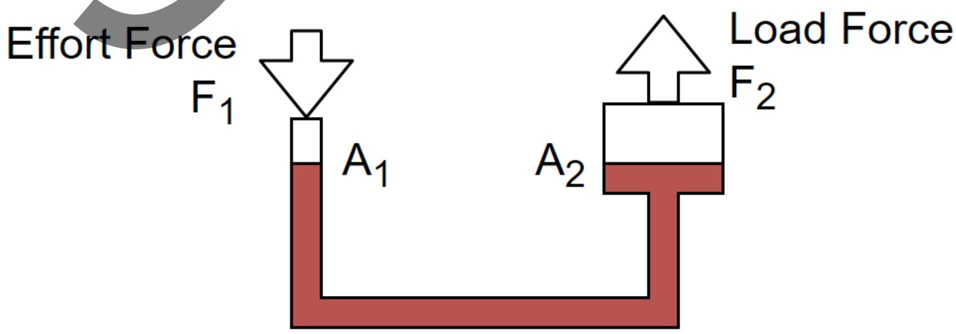


Figure 1 *Hydraulic diagram*

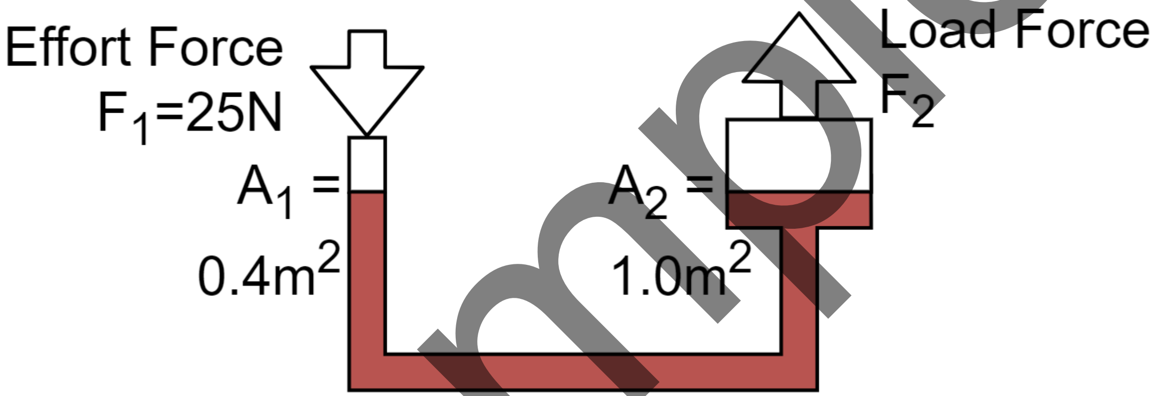
Since hydraulics are closed systems, energy and work transmitted out of the system is zero, which means that the pressures on each piston is the same, which means that the load force generated can be calculated using Equation 2.

$$equal\ pressures\ (says\ Pascal) \quad \therefore \quad \frac{F_1}{A_1} = \frac{F_2}{A_2} \quad \therefore \quad \mathrm{F_2 = F_1 \cdot \frac{A_2}{A_1}} \quad [2]$$

Example 1

A master piston, which has a cross sectional area of $0.4\ \mathrm{m}^2$ receives an effort force of $25\ \mathrm{N}$ to push a slave piston with a cross-sectional area of $1.0\ \mathrm{m}^2$. Calculate:

1. The pressure created on the fluid by the effort force.
2. The load force exerted.



1. The pressure is given as:

$$P = \frac{\mathrm{F_1}}{\mathrm{A_1}} = \frac{25}{0.4} = 62.5\ \mathrm{Nm^{-2}}$$

2. Since this is a closed system, the resultant load force can be calculated as:

$$\mathrm{F_2 = P \cdot A_2 = 62.5 \cdot 1.0 = 62.5\ N}$$

Hydraulics can be found in a lot of heavy equipment, such as cranes, diggers, etc. However, one of the most common uses is found in the brakes of a car. As the driver pushes the pedal, the small master cylinder pushes down on the hydraulic fluid, which will then push the slave pistons and clamp down on the brake discs, which will slow the turning speed of the wheels. A basic schematic of a car's brakes can be seen in Figure 2.

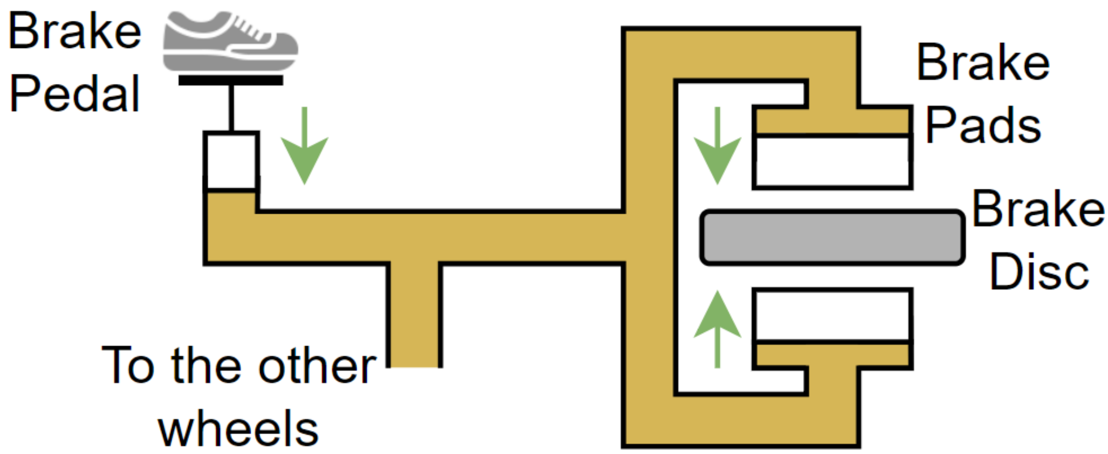


Figure 2 *A schematic of a vehicle's braking system*

This is a basic system and is very unlikely to be found in any modern vehicle. This configuration is prone to "locking", in which the brake disc does not rotate, and the wheel will slip. The solution for this is anti-lock brakes, which will incorporate a tachometer and several "bleed" valves in the hydraulics. Once the system detects that the brakes are locking (the tachometer will sense zero rotation in the wheel), the bleed valves will open and reduce the pressure on the brake pads, release the disc and allow it to rotate once again. With the disc rotating once again, the valves close and the brake pads are again pushed against the brake disc. Essentially creating a rapid clapping motion to optimise braking performance.

Measuring Pressure

Pressures will be defined as a measure of *absolute* or *gauge* pressure:

- *Absolute Pressure* is the pressure relative to a vacuum (0 Pa), absolute gauges are preferred when the measured pressure is below the atmospheric pressure.
- *Gauge Pressure* is the pressure measurement relative to atmospheric pressure ($1 \text{ bar} = 101.3 \text{ kPa}$).

Pressure can be measured by a manometer, which is a U-shaped system partially filled with liquid, typically this working liquid is mercury due to its high density relative to other liquids ($13{,}560 \text{ kg/m}^3$). One side of the u-bend is sealed by the gas being measured, while the other side can be sealed off as a vacuum (absolute measurement) or left open to the atmosphere (gauge measurement).

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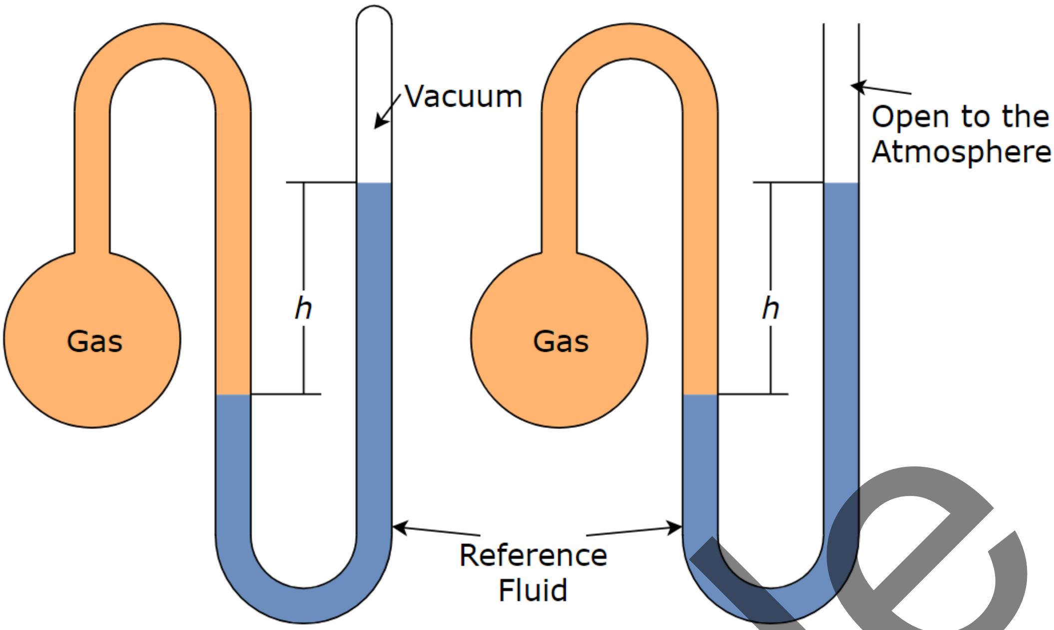

Figure 3 *An absolute pressure manometer (left) and a gauge pressure manometer (right)*

The pressure reading for the absolute pressure manometer is given as Equation 3, where ρ is the density of the reference fluid, g is acceleration due to gravity and h is the height difference in the reference fluid:

$$P = \rho g h \quad [3]$$

The pressure reading for the gauge will be the same as Equation 3, however, to find the absolute pressure of a gauge manometer, Equation 4 is required:

$$P_{abs} = P_{atm} + P = P_{atm} + \rho g h \quad [4]$$

Example 2

A manometer reading is showing a height difference of $+3$ cm, the working fluid is mercury ($13{,}560\ \mathrm{kg/m^3}$). Calculate the absolute pressure of the system if:

a) The manometer is sealed off to a vacuum.
b) The manometer is open to atmospheric pressure (101.3 kPa).

You are to assume that acceleration due to gravity is $9.81\ \mathrm{m/s^2}$

Answer:

a) If the manometer is sealed off to a vacuum, then the absolute pressure is given as:

Thrust on Immersed Surfaces

The thrust (or force) on a horizontal surface submerged in a fluid is calculated as:

$$F = P_a A = \rho g h A \quad [5]$$

Where:

- P_a is the average pressure acting on the surface (Pa)
- A is the submerged area (m^2)
- ρ is the fluid density
- h is the depth
- g is the acceleration due to gravity

As discussed, the change in pressure is linear, therefore the pressure profile can be described as Figure 4.

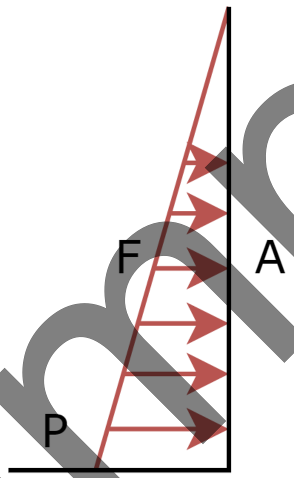

Figure 4 *The effect of varying pressure on the force*

Thus, the average force on a vertical surface F_a can be considered as Equation 6:

$$F_a = \frac{P_t + P_b}{2} A = \rho g A \frac{h_t + h_b}{2} \quad [6]$$

Where:

- P_t and P_b are the pressures at the top and bottom of the surface, respectively.
- h_t and h_b are the height of the top and bottom of the surface, respectively.

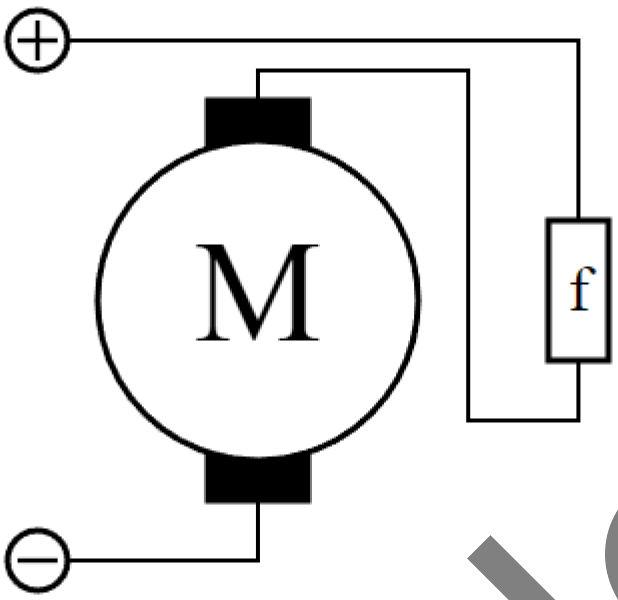

Figure 6 *Series wound brushed motor*

Shunt wound

This type has the field winding connected in parallel with the rotor winding. It can deliver increased torque, without a reduction in speed, by increasing the motor current. This type of motor is suitable for lathes, conveyers, grinders and vacuum cleaners.

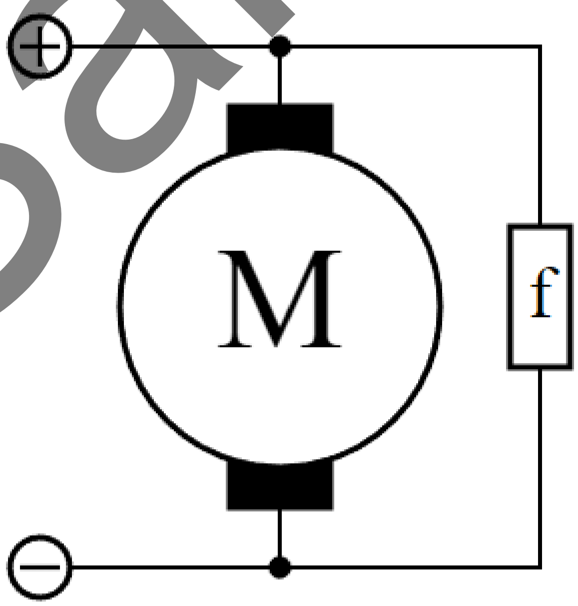

Figure 7 *Shunt wound brushed motor*

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.

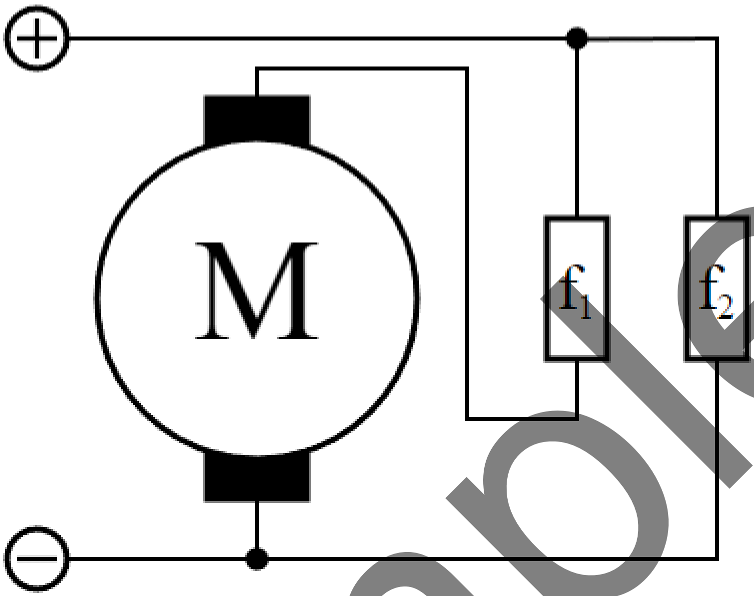

Figure 8 *Compound wound brushed motor*

Permanent magnet

Rather than use an electromagnet, this type uses permanent magnets in the stator, as shown in figure 9. It is used in precise control low-torque applications such as robotics and servo systems.

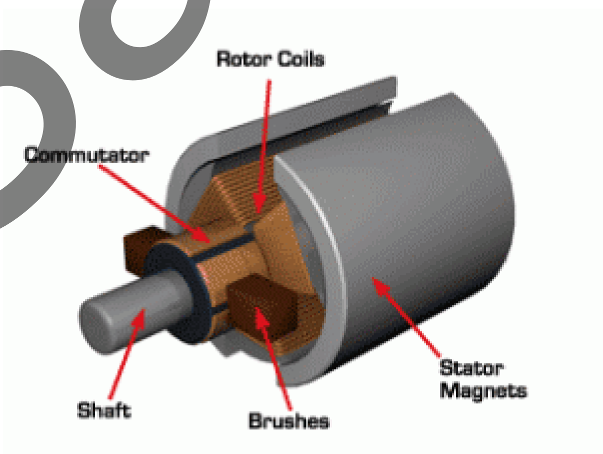

Figure 9 *Permanent magnet DC motor*

Brushless

Since these do not contain brushes they last longer. Wireless (Hall Effect) sensors are used by the controller to detect the angular position of the rotor. These motors are used in fans, pumps and compressors, or other applications where reliability and durability are required.

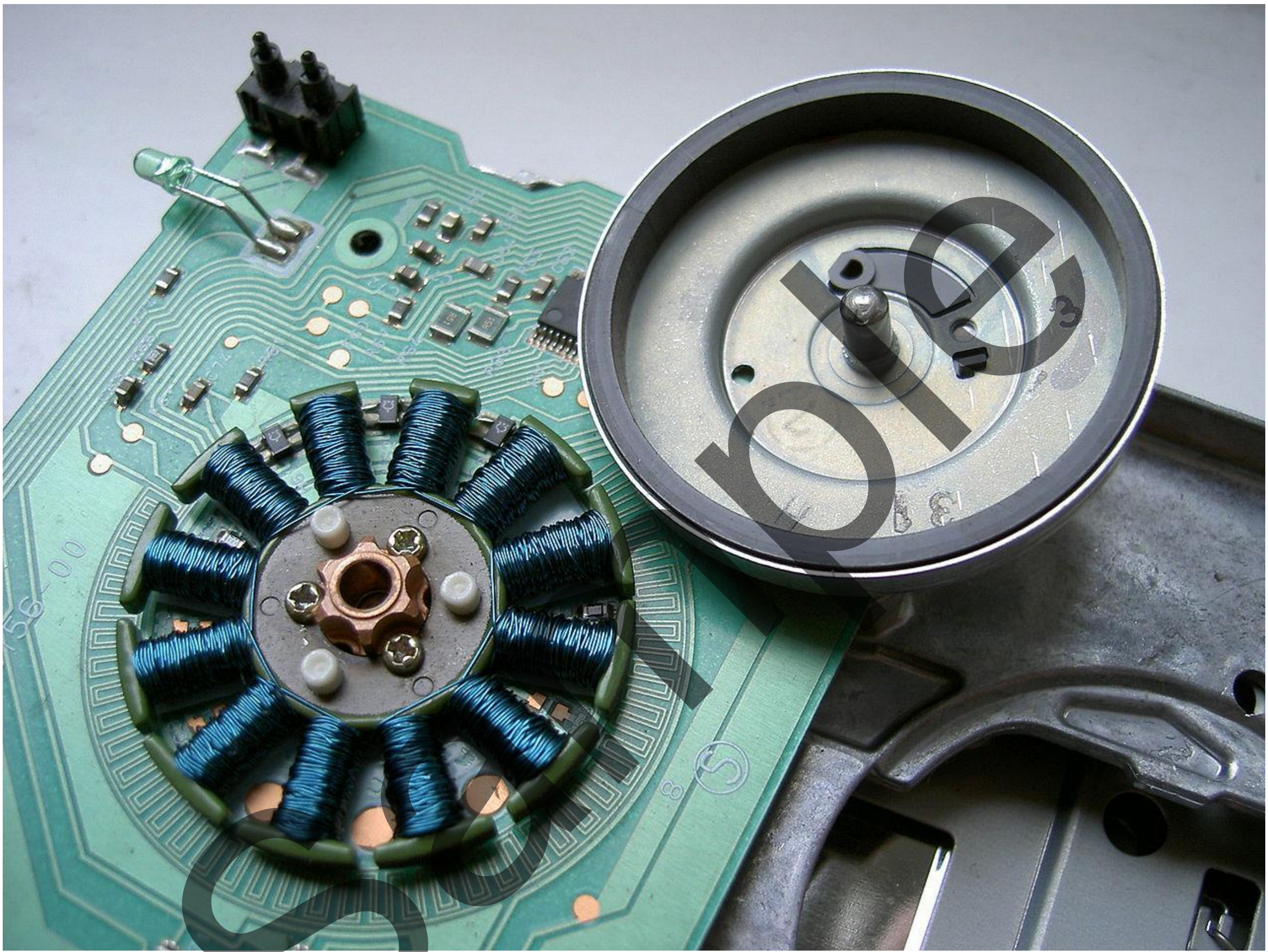

Figure 10 *Brushless DC motor*

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.

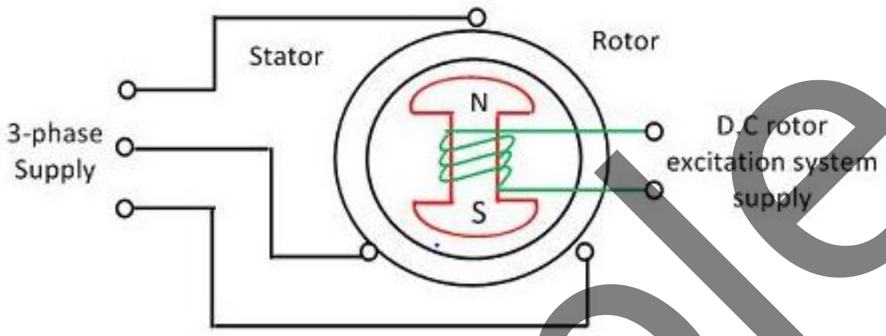

Figure 11 *Synchronous AC motor*

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.

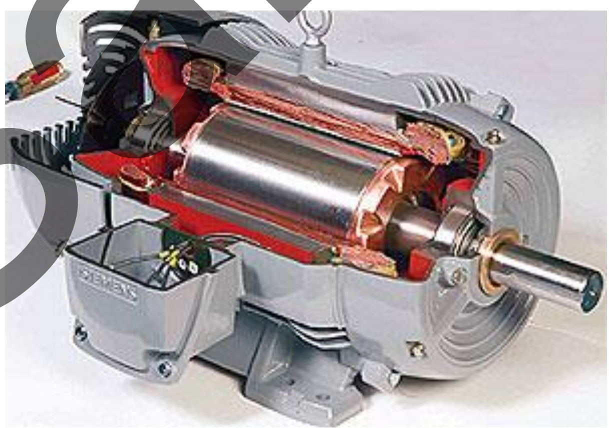

Figure 12 *Induction motor*

Single Phase

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

- Overhead door control
- Car park access system
- Parts inspection system

Figure 13: *The unitary Micro820 PLC from Allen-Bradley*

Modular PLCs

This type of PLC exhibits more features than a basic system because modules may be slotted together. These modules may include …

- Power supply
- CPU (central processing unit)
- Outputs
- Inputs

Such modular PLCs are commonly expanded with modules to increase the number of inputs and/or outputs available.

ADVANTAGES

- Expansion
- Cost effective replacement of faulty modules

DISADVANTAGES

- More expensive than a typical unitary PLC

Modular PLCs are often used in applications where many inputs and outputs are required, such as process control in the manufacturing sector.

Figure 14: *Modular PLC units available from Siemens*

Rack-mounted PLCs

This type of PLC exhibits more features than both the unitary and modular types. They tend to be of a modular design, but these modules are usually supplied on cards which plug into slots on a rack, housed in a cabinet

ADVANTAGES

- Easy expansion
- Plentiful inputs and outputs
- Communication with other systems
- Direct replacement of faulty cards

DISADVANTAGES

- More expensive than a typical unitary or modular PLC
- Largest power consumption of the three types of PLC

Rack-mounted PLCs are often used in complex applications where many inputs and outputs are required, such as large process control systems in the manufacturing sector.

Figure 15: *Rack-mounted PLC system available from Unico*

Speed

The speed of a PLC is mainly governed by the clock supplied to the CPU (processor). Typical clock speeds can range from 1 MHz up to 1 GHz, and beyond, depending on the sophistication of the system.

Memory

The working program which controls the operation of a PLC is stored in RAM (random access memory). The RAM in a PLC can range anywhere from a few hundred kB up to hundreds of MB, again, depending on the sophistication of the system.

Scan Time

The Scan Time of a PLC is the time taken for it to review and store the data files which contain the statuses of all the inputs and outputs. Again, depending on the sophistication of the system, the scan time can be as long as several hundred milliseconds, or as short as several microseconds (or even less).

Voltage and Current Limits

PLCs can interface with analogue input and output devices. Analogue signals are continuously variable, but the range of these signals must be limited to suitable working voltage and current ranges. These will depend upon the PLC you are working with, but a typical voltage range might be 0 to 10 V DC, and a typical current range 4 mA to 20 mA.

Input Devices

There are very many input devices which can be employed with a PLC. Here is a list …

- **mechanical switch for position detection**
- **proximity switch**
- **photoelectric switch**
- **encoder**
- **temperature sensor**
- **pressure sensor**
- potentiometer
- strain gauge
- thermistor
- thermotransistor

Let's have a look at some of the ones highlighted in Bold type;

Mechanical Switch for Position Detection

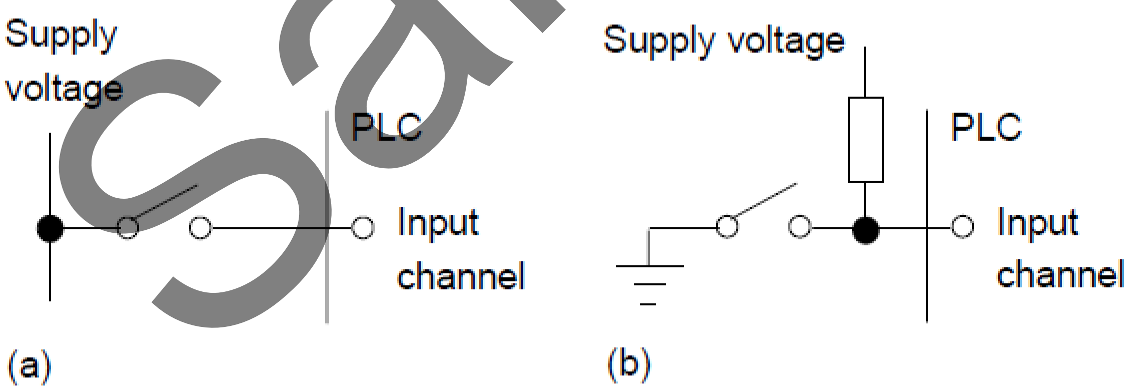

Figure 16: *Switching arrangements for position detection*

A mechanical switch may be closed when the presence of a specimen is detected. Configuration (a) causes a DC voltage to be applied to the PLC input when the specimen is present. Arrangement (b) causes 0V DC (ground) to be applied to the PLC input when the specimen is detected.

Proximity Switch

There are three main types of proximity switch;

EDDY CURRENT TYPE

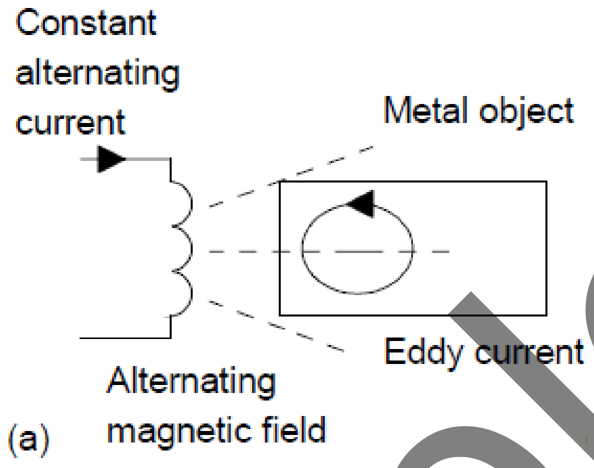

Figure 17: *Proximity switch using eddy currents*

The ac current through the coil produces a constant alternating magnetic field. Eddy currents are induced into any close-by metallic object, causing a back e.m.f. (reverse voltage spike) which influences the ac supply current. An integral transistor circuit can be used to assign logic low or logic high when this occurs.

REED SWITCH TYPE

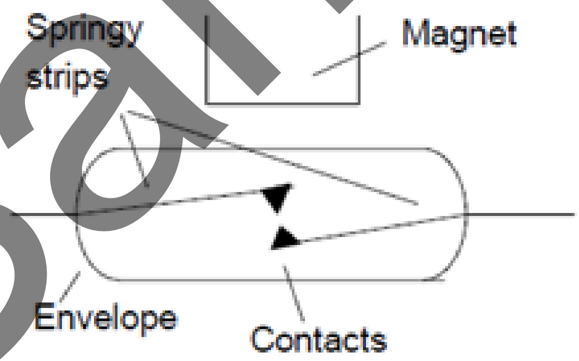

Figure 18: *Proximity switch using Reed contacts*

Reed contacts are normally close, but not touching. The presence of the magnetic field produced by the magnet causes the contacts to touch, completing a circuit. The removal of the magnet causes the contacts to spring back open.

CAPACITIVE TYPE

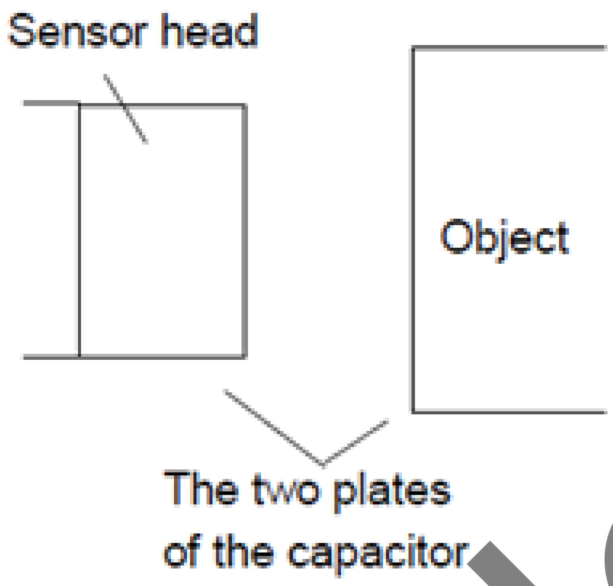

Figure 19: *Proximity switch using capacitor dielectric properties*

An object moving between the plates of a capacitor will change the dielectric's permittivity, and hence the capacitance – a change which can be processed as high or low.

Photoelectric Switch

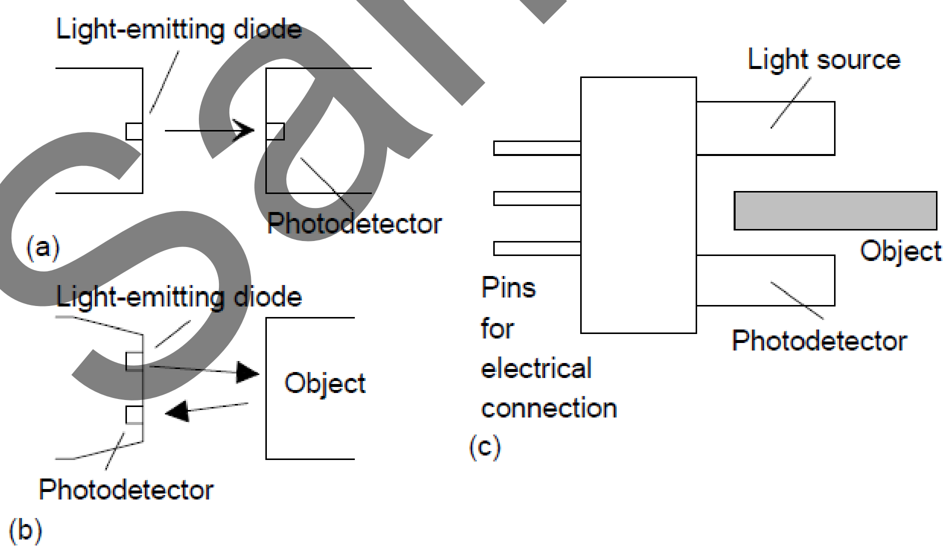

Figure 20: *Object detection using light sources and detectors*

- Transmissive type: detected object breaks a beam of light – (a)
- Reflective type: object reflects a beam of light onto a detector – (b)

In both types the light is emitted by an LED (infrared). The detector could be a photodiode, phototransistor or photo-conductive cell.

Encoder

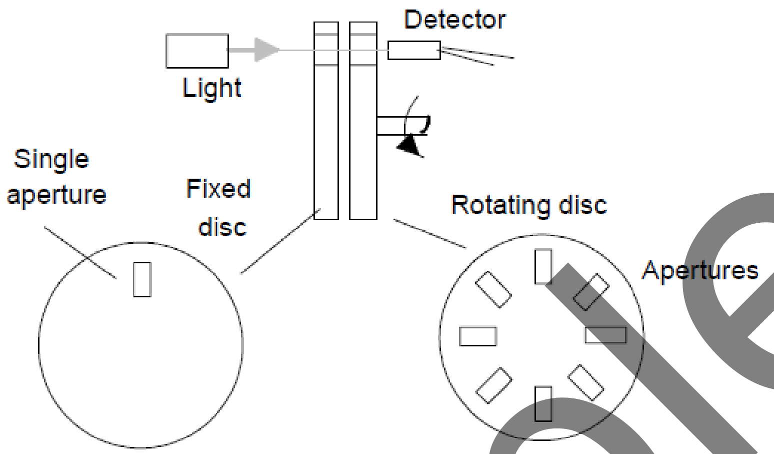

Figure 21: *Angle detection using an encoder*

LED light passes through slots in a disc and is detected. When the disc is rotated the detected beam is goes and off. Therefore, a pulse is detected for each slot which passes by. The number of pulses is proportional to the angle through which the disc has rotated. With 60 slots then 6 degrees corresponds to moving from one slot to the next (total of 360 degrees, of course). Offset slots can produce much higher resolutions.

Temperature Sensor

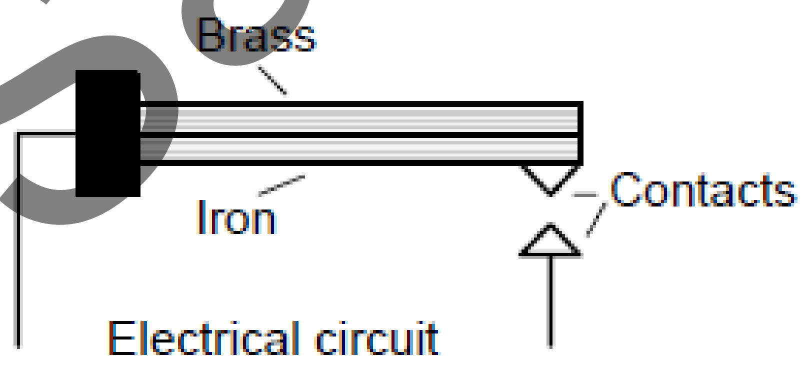

Figure 22: *Temperature detection using bi-metallic strips*

Two metal strips (commonly brass and iron) are bonded together. Each metal expands at different rates when the temperature varies. When the temperature increases the strip curves, causing the contacts to touch. For this to happen we need the metal with the highest expansion (brass) on the outside.

Pressure Sensor

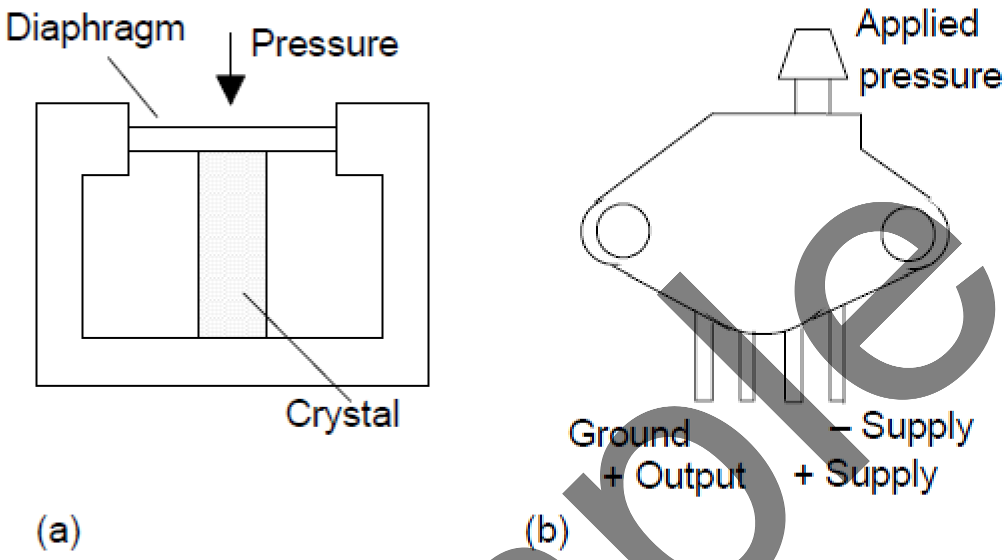

Figure 23: *Pressure detection using a piezoelectric crystal*

Squeezing a piezoelectric crystal displaces charge on it – a voltage appears across it – (a). The Motorola MPX100AP (b) has a vacuum on one side of the diaphragm – it measures absolute pressure.

Many analogue input devices can have their signals digitised using an Analogue-to-Digital Converter (ADC), as in Figure 24;

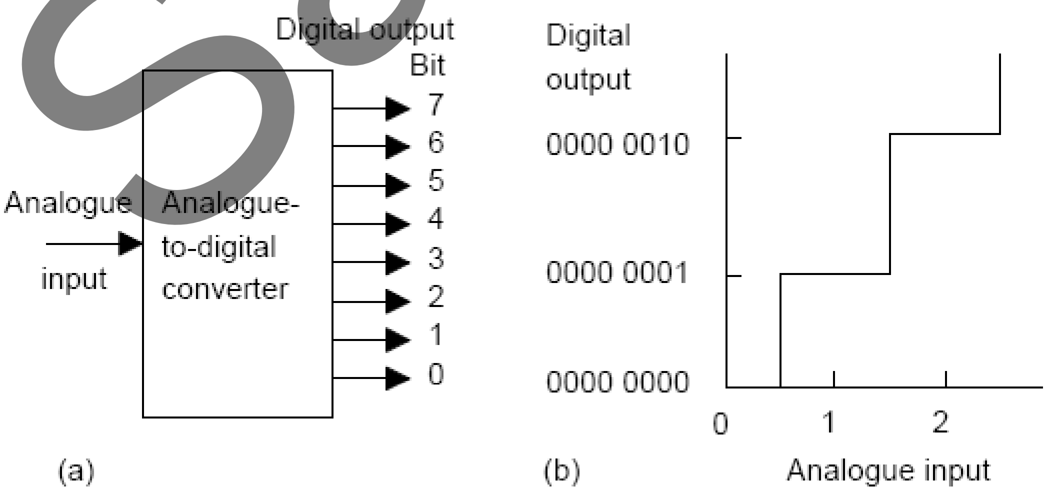

Figure 24: *Digitising an analogue input signal*

Figure 28: *RS-232 male connector*

Although there are 25 pins in the RS-232 connector, only eight of these are commonly used. The pin assignments and descriptions for these are;

- Pin1: Ground (commonly connected to chassis)
- Pin 2: Transmitted data
- Pin 3: Received data
- Pin 4: RTS (Request To Send)
- Pin 5: CTS (Clear To Send)
- Pin 6: DTS (Data Set Ready)
- Pin 7: Signal ground (common signal return path)
- Pin 20: DTR (Data Terminal Ready)

Signals sent through pins 4, 5, 6 and 20 are used to ensure that the receiving end is ready to receive, the sending end is ready to send, and the data is ready to be sent.

A logic 1 is represented by a voltage between -5V and -25V (normally -12V)

A logic 0 is represented by a voltage between +5V and +25V (normally +12V)