Pearson BTEC Level 5 Higher Nationals in Engineering (RQF)

Unit 45: Industrial Systems

Unit Workbook 1

in a series of 4 for this unit

Learning Outcome 1

Fundamental Concepts of Industrial Systems

1.2 Open and Closed Loop Systems

Systems can operate under an open or closed loop system, the difference between the two is what is happens to the data after the transfer functions take place. We consider all actions and processes as a function of time.

1.2.1 Open Loop

An open loop system does not use the collected data to feed back into the system and will just display the current status for manual intervention to fix any problems. The control action is not performed automatically by a processing unit within the system. Let's say we are using a cheap fan to cool something down, we press a button which give a varying fan speed, the button completes the circuit and starts the motor. We model systems with a block diagram. When drawing the block diagram for an open loop system, we have a linear path between the input and the output, with transfer function blocks in between. A block diagram for a fan can be found in Fig.1.2 below. The main characteristics of an open loop system can be simplified to:

- desired and real values are not compared,
- no self-control or regulation,
- input is a fixed operating position for the controller,
- external disturbances do not result in a direct output change, unless manual alteration takes place.

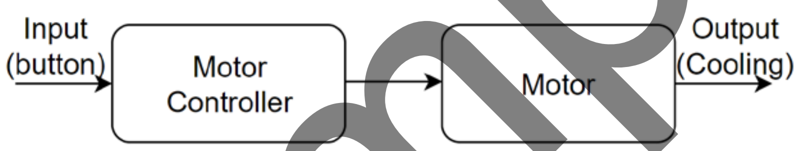

Fig.1.2: An open loop block diagram of a fan

1.2.2 Closed Loop

A closed loop system will collect data while it runs and will feedback into the system to correct to compensate for any disturbances without any external intervention. A closed loop system basically has its own element of control. Let's say our fan is now monitoring the temperature of the item we are cooling; the input is no longer the manual operator pressing the button, it is the desired temperature of the item. Fig.1.3 shows the block diagram for the closed loop fan.

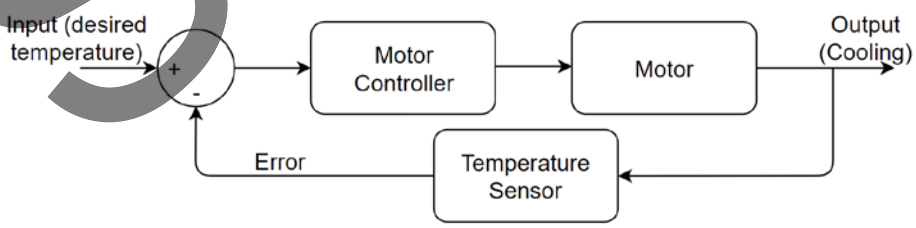

Fig.1.3: Closed loop diagram of a fan

Again, this is still a very basic system. Block diagrams can be huge pieces of work, with sensors analysing anything and everything. We can look at the block diagram for a car's power transmission in Fig.1.4, when the driver presses the pedal down to the floor as quickly as possible, the microprocessor that actually controls the throttle does not allow this, as it could damage the engine. Instead the throttle slowly opens for a more controlled and efficient acceleration. This is not all that is monitored on the engine, and a lot more is monitored to ensure the system is working at the optimal performance.

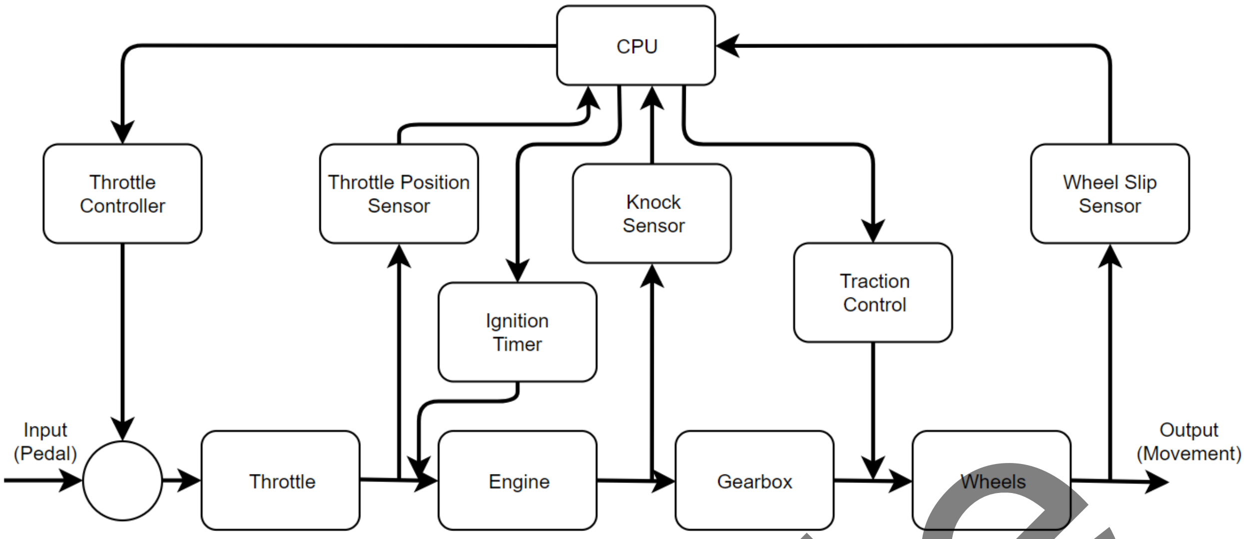

Fig.1.4: Power transmission block diagram

Of course, we can still go deeper, since there are about 60 different warning lights that a car could have, but the size of the block diagram for this would be difficult to read and doesn't really add to your knowledge. But some of the factors we could consider are:

- Environmental sensors such as:
  - Moisture for windscreen wipers
  - Light sensors for lights
- Brakes can incorporate different systems for feedback including:
  - Brake lights
  - Anti-lock brakes
  - The car could also use an air-brake
- We also haven't monitored the condition of the engine yet:
  - Oil Levels
  - Temperature
  - Fuel Levels
  - Fuel consumption
  - Remaining range of the car before it runs out of fuel
- Monitoring the condition of the catalytic converter
- There's also the passengers to consider:
  - Monitoring different aspects for cruise control
  - Climate control
  - Alerts for potential problems with the car
  - Airbags
  - Open Bonnet/Doors/Boot
  - A seatbelt is not fastened
- High performance road cars also have different performance settings that will adjust:
  - Suspension (ride height and firmness)
  - Aerodynamics

1.4 Motors

Motors are an electromechanical component that converts electrical energy into a rotational kinetic energy. Motors boast excellent efficiency (typically 80+%), they are also very reversible, and a generator is the same system, but instead kinetic energy is input to create electrical energy. Motors are designed to either run on an alternating current (AC) or direct current (DC), if you wish to power an AC motor with DC, then you must condition the current to match, and the same goes for powering DC with AC.

1.4.1 Motor Theory

It is well known that when electricity flows through a wire, it also generates a magnetic field, which is shown by the right-hand rule shown in Fig.1.7. Your thumb will follow the direction of the current in the wire, and you curled fingers will follow the direction of the magnetic field. The strength of the magnetic field is amplified by using a coil and increasing the number of turns.

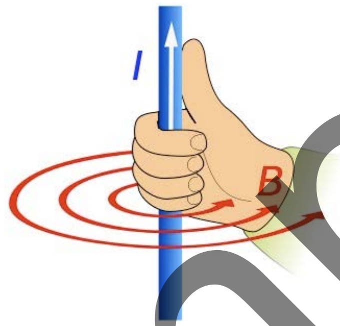

Fig.1.7: The right-hand rule.

So, what happens when a wire with a current is put into a magnetic field? Well, we know that magnetic fields interact with each other, and will create a force upon each other to either attract or repel, depending on the direction of the magnetic field. The maximum force generated by the conflicting magnetic fields occurs when the current of the wire is perpendicular to the magnetic field. The direction of the force is also determined by another right-hand rule shown in Fig.1.8.

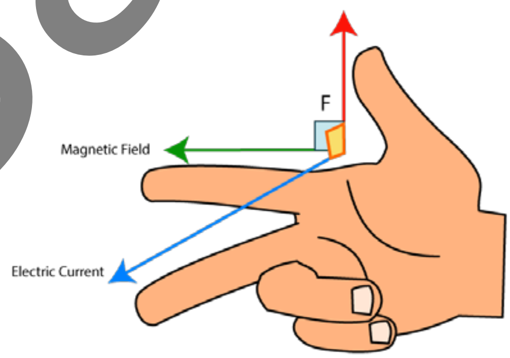

Fig.1.8: Right-hand rule for a wire in a magnetic field

The magnet is always trying to push the coil into the "zero torque position" and create an equilibrium in the system, where the wire is parallel to the magnetic flux. This means that, if current is flowing in one direction through the coil, then the system will stop. But if the current were to be reversed at zero torque position, then the system will carry on and rotate to the next zero torque position. This means that the force on the coil, relative to the coil's angle will produce a sine wave, which therefore means that torque will move in the same direction. The graph showing the force and torque relative to the coil's angle to the magnetic field is shown in Fig.1.9.

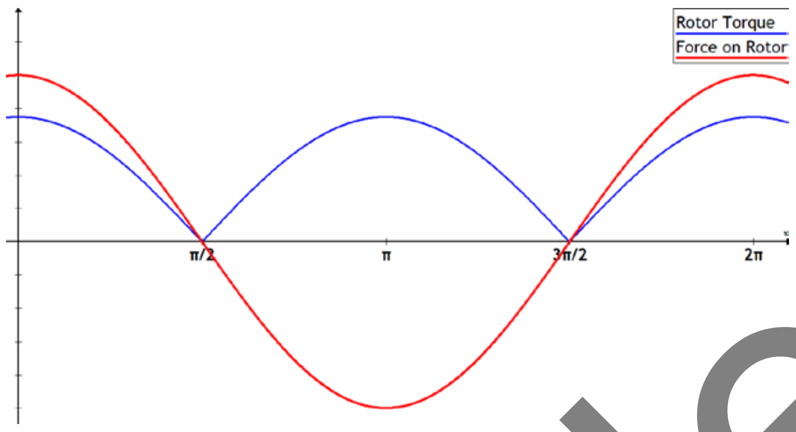

Fig.1.9: Rotor torque and the force acting on the rotor.

Torque is very inconsistent though, and ideally the torque will have as little variation as possible. An engineer can add more magnets, with its affect shown in Fig.1.10, when the original system with two poles (one magnet) is replaced for a similar system, but instead it has ten poles (five magnets); this is essentially reducing the time between "maximum torque positions", this still gives zero torque positions, and so it is still somewhat inconsistent.

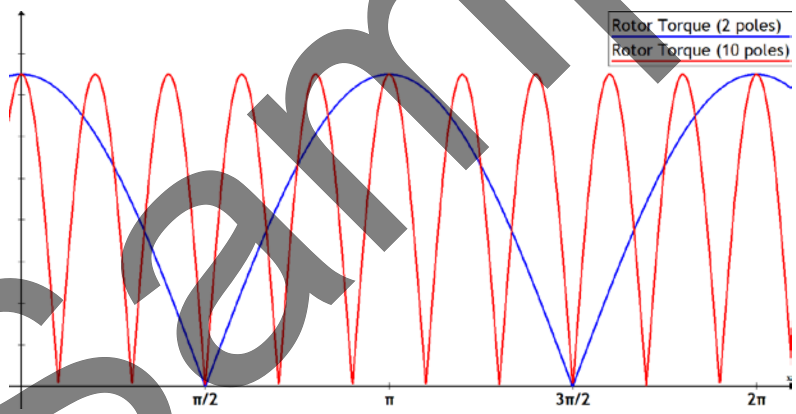

Fig.1.10: Torque output of a one-magnet motor and a five-magnet motor.

The lack of consistent torque still presents a problem, so we look at the other option of adding more coils in parallel to the motor. Adding more coils (or "phases") to the system is another solution (the national grid uses three-phase AC). This does produce higher losses (more wiring makes more resistance), but we can see from Fig.1.11, that when the torque is zero for one phase, the other phases are not. We also know from basic mechanics that the summation of Forces means we get a higher overall torque output to the system. Most systems will stick with three-phases, this is the considered the standard and a fair compromise between overall output and losses. We also have to consider the costs of adding another phase of wiring and signal conditioning used when building a multi-phase system.

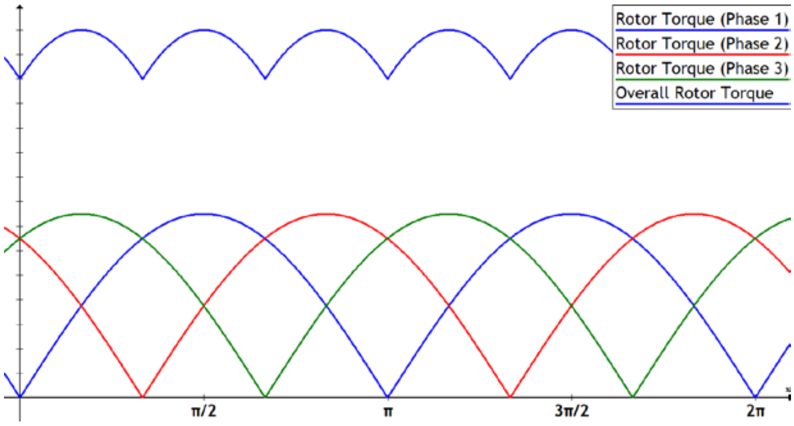

Fig.1.11: The phase torque output.

1.4.2 AC Motors

AC motors are called such because they run from an AC. The AC current is supplied to the motor by brushing the commutator, by using a brush to transfer the electrical energy, there is no entanglement with the wiring. A schematic of a simple AC motor can be seen in Fig.1.12 below. The electrical current cutting through the magnetic field will create a force that will begin to rotate the coil (and therefore the shaft). When the coil has rotated 180°, the AC current will now be operating in the opposite direction, and so rotation will still continue in the same direction (clockwise when considering Fig.1.12).

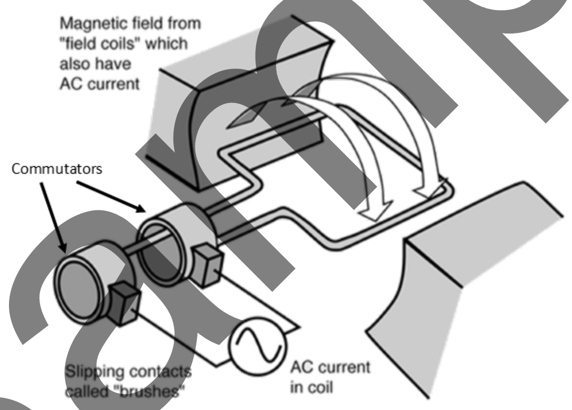

Fig.1.12: AC motor diagram.

The torque output of the motor, τ, is given as Eq.1.1 where K_τ is the torque constant $(N \cdot m \cdot A^{-1})$ and I_A is the current in the armature (coil windings) of the motor.

$$\tau = I_A K_\tau \qquad \text{(Eq.1.1)}$$

The back-electromotive force (the voltage generated as the system rotates) can also be calculated (meaning the desired rotational speed of a generator can be calculated) using Eq.1.2, where V is the electromotive force, K_v is the voltage constant of the motor which is typically given by the manufacturer, and ω is the rotational speed of the system.

$$V = K_V \times \omega \qquad \text{(Eq.1.2)}$$

The units of this will depend on the units for K_v, manufacturer specifications will state the units for K_v as either v/rpm or $V/rad \cdot s^{-1}$, and so the units for ω will be either rpm or $rad \cdot s^{-1}$, respectively.

AC motors can also be run by conditioning a DC signal by using an inverter, an inverter consists of a series of switches which produces a stepping alternating current to power a motor, shown in Fig.1.13.

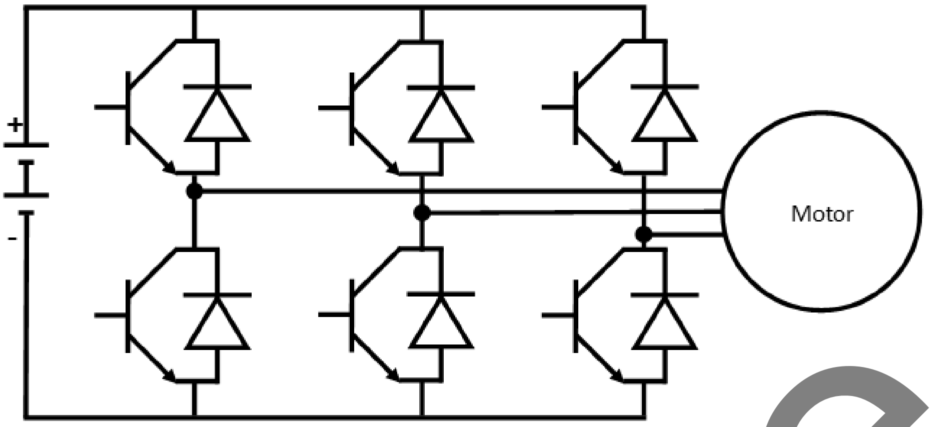

Fig.1.13: A DC to AC converter for a motor.

1.4.3 DC Motors

As I'm sure you've guessed, DC motors run off DC. The principle of operations is the same as an AC motor, and their design is very similar too. The difference between the two systems is the power supply, and also the design of the commutator. Whereas the AC commutators are whole rings, for a DC motor they are split into two. The reason being is that once the commutators have rotated 180°, they come into contact with the brush of the opposite polarity, which will then continue the rotation further. Fig.1.14 below shows a diagram of a DC motor.

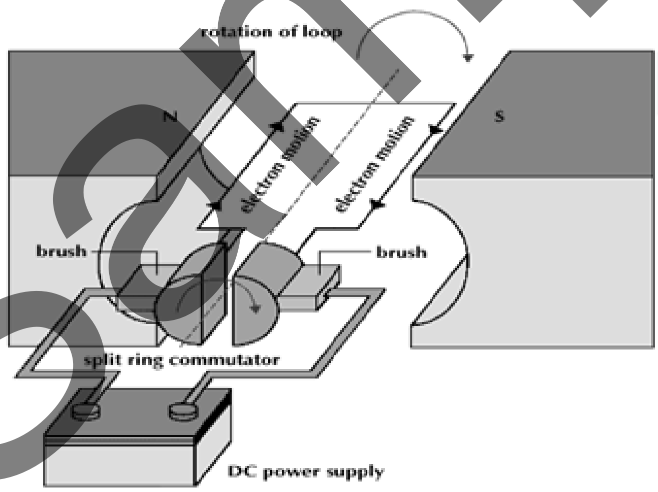

Fig.1.14: DC motor diagram

1.4.4 Practical Motors

A Schematic of a motor is shown below in Fig.1.15, we can break categorise the motor into two distinct parts, the stator and the rotor. While Fig.1.12 and Fig.1.14 show the coil rotating in the magnetic field, in practical applications it is typically the magnets that rotate while the coils are stationary. The magnets are mounted onto the rotor, and the coils are mounted in gaps on the stator. The magnetic field flows through the stator to help draw the magnetic field in towards the coils and create a strong magnetic circuit in the motor.

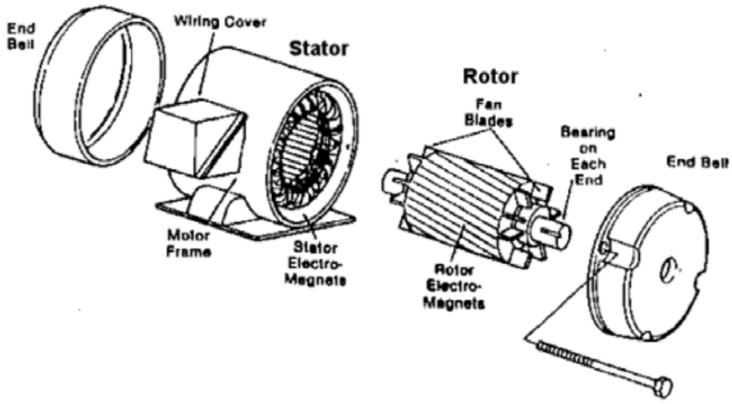

Fig.1.15: Motor schematic

There is a wide range of motors available on the market, all with their advantages and disadvantages. Knowing all about these systems are not necessary to complete this Unit, but a list of motors available for further research can be found in Section 1.4.5. This list is by no means complete, and there are motors that are designed for special application.