University of Technology

Mechanical Engineering Dep.

Aircraft engineering \ Third year stage

Weekly Hours: 2hrs

AIRCRAFT ELECTRICITY & INSTRUMENTS

كهربائية واجهزة الطائرة

Lecturer: Dr. Akeel Ali Wannas

PART II: Aircraft Electricity

Chapter 1 : Electrical fundamentals

Chapter 2 : Generators and motors

Chapter 3 : Power supplies

Chapter 4 : Batteries

Chapter 1 : Electrical fundamentals

Lecture 1

Topics

1.1 Electrostatics and capacitors

1.2 Electric fields

1.3 Direct current

1.4 Current, voltage and resistance

1.1. Electrostatics and capacitors

Static charges can be produced by friction. In this case, electrons and protons in an insulator are separated from each other by rubbing two materials together in order to produce opposite charges. These charges will remain separated for some time until they eventually leak away due to losses in the insulating **dielectric** material or in the air surrounding the materials. Note that more charge will be lost in a given time if the air is damp.

Static electricity is something that can cause particular problems in an aircraft and special measures are taken to ensure that excessive charges do not build up on the aircraft's structure. The aim is that of equalizing the potential of all points on the aircraft's external surfaces. The static charge that builds up during normal flight can be dissipated into the atmosphere surrounding the aircraft by means of small conductive rods connected to the aircraft's trailing surfaces. These are known as **static dischargers** or **static wicks** – see Fig 1.1.

Figure 1.1 Static discharging devices

1.2. Electric fields

The force exerted on a charged particle is a manifestation of the existence of an electric field. The electric field defines the direction and magnitude of a force on a charged object. The field itself is invisible to the human eye but can be drawn by constructing lines which indicate the motion of a free positive charge within the field; the number of field lines in a particular region being used to indicate the relative strength of the field at the point in question.

Figures 1.2 and 1.3 show the electric fields between isolated unlike and like charges whilst Fig. 1.4 shows the field that exists between two charged parallel metal plates which forms a charge storage device known as a capacitor .

The strength of an electric field (E) is proportional to the applied potential difference and inversely proportional to the distance between the two conducting surfaces (see Fig. 1.5). The electric field strength is given by:

$$\mathrm{E} = \frac{\mathrm{V}}{\mathrm{d}}$$

where E is the electric field strength (in V/m), V is the applied potential difference (in V) and d is the distance (in m).

The amount of charge that can be stored by a capacitor is given by the relationship:

$$Q = C \times V$$

where Q is the charge in coulomb, C is the capacitance in farads, F, and V is the voltage in volts, V. This relationship can be re-arranged to make C or V the subject as follows:

$$C = \frac{Q}{V} \; and \; V = \frac{Q}{C}$$

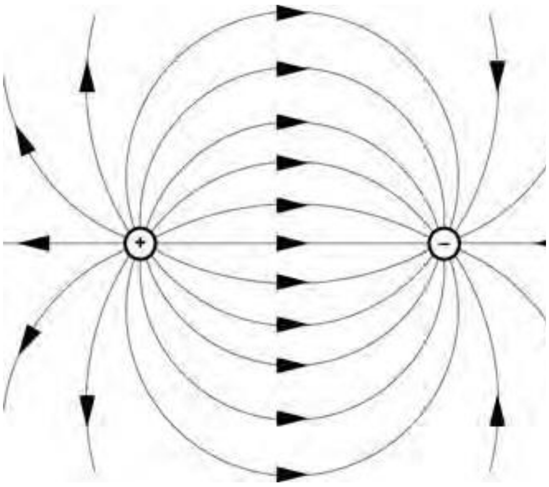

Figure 1.2 Electric field between isolated unlike charges

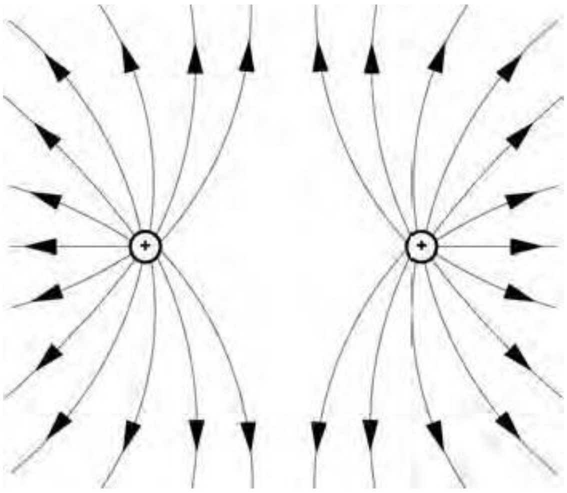

Figure 1.3 Electric field between isolated like charges

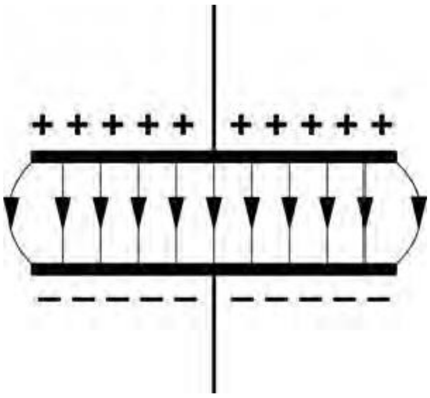

Figure 1.4 Electric field between the two charged parallel metal plates of a capacitor

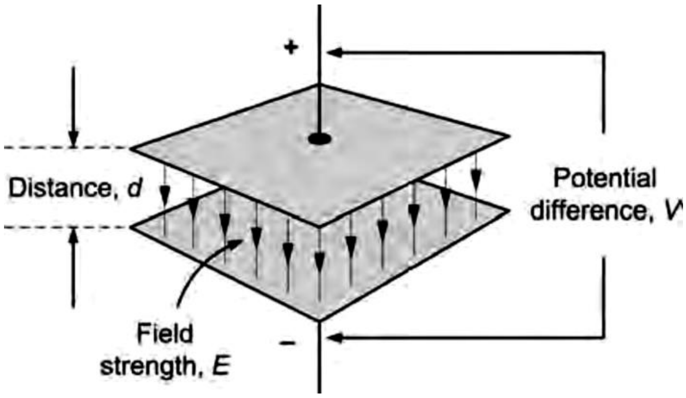

Figure 1.5 Electric field strength between two charged conducting surfaces

Example 1.1

Two parallel conductors are separated by a distance of 25 mm. Determine the electric field strength if they are fed from a 600 V DC supply.

Sol:

The electric field strength will be given by:

$$E = \frac{V}{d}$$

$Where\ V = 600V\ and\ d = 25mm = 0.025m.$

Thus:

$E = \frac{600}{0.025} = 25000V/m$=24kV/m

Example 1.2

The field strength between two parallel plates in a cathode ray tube is 18kV/m. If the plates are separated by a distance of 21 mm determine the potential difference that exists between the plates.

Sol:

The electric field strength will be given by:

$$\boldsymbol{E = \frac{V}{d}}$$

Re-arranging this formula to make V the subject gives:

$$V = E \times d$$

Now $E = 16kV/m = 18{,}000\, V/m\ and\ d = 21\, mm = 0.021\, m$, thus:

$$V = 18{,}000 \times 0.021 = 378V$$

Example 1.3

A potential difference of 150 V appears across the plates of a 2 μ F capacitor. What charge is present?

Sol:

The charge can be calculated from:

$$Q = C \times V$$

where C = 2 μ F and V =150 V, thus:

$$Q = 2\mu F \times 150V = 300\mu C.$$

Example 1.4

A 68 μ F capacitor is required to store a charge of 170 μ C. What voltage should be applied to the capacitor?

Sol:

The voltage can be calculated from:

$$\mathrm{V} = \frac{\mathrm{Q}}{\mathrm{C}}$$

where Q = 170 μ C and C = 68 μ F; thus:

$$V = \frac{3.4mC}{6.8\,\mu\,\mathrm{F}} = \frac{3{,}400\,\mu\,C}{6.8\,\mu\,\mathrm{F}} = 500V$$

Key maintenance point

When replacing a capacitor it is essential to ensure that the replacement component is correctly rated in terms of type, value, working voltage and temperature. Capacitors are prone to failure if their maximum working voltage is exceeded and they should be de-rated when operated at a relatively high ambient temperature according to manufacturers' specifications. It is also essential to observe the correct polarity when replacing an electrolytic (polarized) component. This is usually clearly marked on the external casing.

Key maintenance point

When working with high-voltage capacitors it is essential to ensure that the capacitor is fully discharged before attempting to replace the component. In most cases, any accumulated charge will safely drain away within a few seconds after removal of power. However, this should not be relied upon and a safe discharge path through a high-value resistor (say 1 MΩ) fitted with appropriate probes will ensure that capacitor is safe to work on.

Figure 1.6 A selection of capacitors with values ranging from 12 pF to 1000μF and working voltages ranging from 25 V to 450 V

Test your understanding 1.1

1. The two plates of a parallel plate capacitor are separated by a distance of 15 mm. If the potential difference between the plates is 300 V what will the electric field strength be?

2. The electric field between two conducting surfaces is 500 V/m. If the plates are separated by a distance of 2.5 mm, determine the potential difference between the plates.

1.3. Direct current

Direct current (DC) is current that flows in one direction only. DC circuits are found in every aircraft. An understanding of how and why these circuits work is an essential prerequisite to understanding more complex circuits. Because of their negative charge, electrons will flow from a point of negative potential to a point with more positive potential (recall that like charges attract and unlike charges repel). However, when we indicate the direction of current in a circuit we show it as moving from a point that has the greatest positive potential to a point that has the most negative potential. We call this **conventional current** and, although it may seem odd, you just need to remember that it flows in the opposite direction to that of the motion of electrons!

The most commonly used method of generating direct current is the electrochemical cell. A cell is a device that produces a charge when a chemical reaction takes place. When several cells are connected together they form a battery.

There are two types of cell: primary and secondary. **Primary cells** produce electrical energy at the expense of the chemicals from which they are made and once these chemicals are used up, no more electricity can be obtained from the cell. In **secondary cells**, the chemical action is reversible. This means that the chemical energy is converted into electrical energy when the cell is **discharged** whereas electrical energy is converted into chemical energy when the cell is being **charged**. You will find more information on aircraft batteries in later lectures.

Key point

Conventional current flows from positive to negative whilst electrons travel in the opposite direction, from negative to positive.

Key point

In a primary cell the conversion of chemical energy to electrical energy is irreversible and so these cells cannot be recharged. In secondary cells, the conversion of chemical energy to electrical energy is reversible. Thus these cells can be recharged and reused many times.

Key maintenance point

When removing and replacing batteries, it is essential to observe the guidance given in the aircraft maintenance manual (AMM) when removing, charging or replacing aircraft batteries. The AMM will describe the correct procedures for isolating the battery from the aircraft's electrical system prior to its physical removal.

Test your understanding 1.2

1. Explain the difference between a primary and a secondary cell.
2. Explain the difference between electron flow and conventional current.

1.4. Current, voltage and resistance

1.4.1. Current

Current, I, is defined as the rate of flow of charge and its unit is the ampere, A. One ampere is equal to one coulomb C per second, or:

$$\mathrm{I} = \frac{\mathrm{Q}}{\mathrm{t}}$$

Where t= time in seconds

So, for example: if a steady current of 3 A flows for two minutes, then the amount of charge transferred will be:

$$Q = I \times t = 3\mathrm{A} \times 120\mathrm{s} = 360 \text{ coulombs}$$

Example 1.5

A current of 45 mA flows from one point in a circuit to another. What charge is transferred between the two points in 10 minutes?

Sol:

$$Here\ we\ will\ use\ Q = I \times t\ where\ I = 45\ mA = 0.045\ A\ and$$
$$t = 10\ minutes = 10 \times 60 = 600s.$$

Thus:

$$Q = 0.045A \times 600s = 27C$$

Key point

Current is the rate of flow of charge. Thus, if more charge moves in a given time, more current will be flowing. If no charge moves then no current is flowing.

1.4.2. Potential difference (voltage)

The force that creates the flow of current (or rate of flow of charge carriers) in a circuit is known as the **electromotive force** (or e.m.f.) and it is measured in volts (V). The **potential difference** (or p.d.) is the voltage difference, or voltage drop between two points.

One volt is the potential difference between two points if one Joule of energy is required to move one coulomb of charge between them. Hence:

$$V = \frac{W}{Q}$$

where W = energy and Q = charge, as before. Energy is defined later in Section 1.6.

Test your understanding 1.3

1. How much charge will be transferred when a current of 6A flows for two minutes?
2. How long will it take for a charge of 0.2C to be transferred using a current of 0.5A?
3. If 0.4 J of energy is used to transfer 0.05C of charge between two points what is the potential difference between the two points?

1.4.3. Resistance

All materials at normal temperatures oppose the movement of electric charge through them; this opposition to the flow of the charge carriers is known as the resistance, R, of the material. This resistance is due to collisions between the charge carriers (electrons) and the atoms of the material. The unit of resistance is the ohm, with symbol Ω.

Note that 1V is the electromotive force (e.m.f.) required to move 6.21×10^{18} electrons (1C) through a resistance of 1 Ω in 1 second. Hence:

$$V = \left(\frac{Q}{t}\right) \times R$$

$where\ Q = charge, t = time, and\ R = resistance$

Re-arranging this equation to make R the subject gives:

$$R = \frac{V \times t}{Q}\,\Omega$$

Example 1.7

A 28 V DC aircraft supply delivers a charge of 5C to a window heater every second. What is the resistance of the heater?

Sol:

$Here\ we\ will\ use\ R = \frac{(V \times t)}{Q}\ where\ V = 28\ V, Q = 5C\ and\ t$=1 $s. Thus$:

$$R = \frac{V \times t}{Q} = \frac{28V \times 1s}{5C} = 5.6\ \Omega$$

Key point

Metals such as copper and silver are good conductors of electricity. Good conductors have low resistance whilst poor conductors have high resistance.

1.4.4. Ohm's law

The most basic DC circuit uses only two components; a cell (or battery) acting as a source of e.m.f., and a resistor (or load) through which a current is passing. These two components are connected together with wire conductors in order to form a completely closed circuit as shown in Fig. 1.7

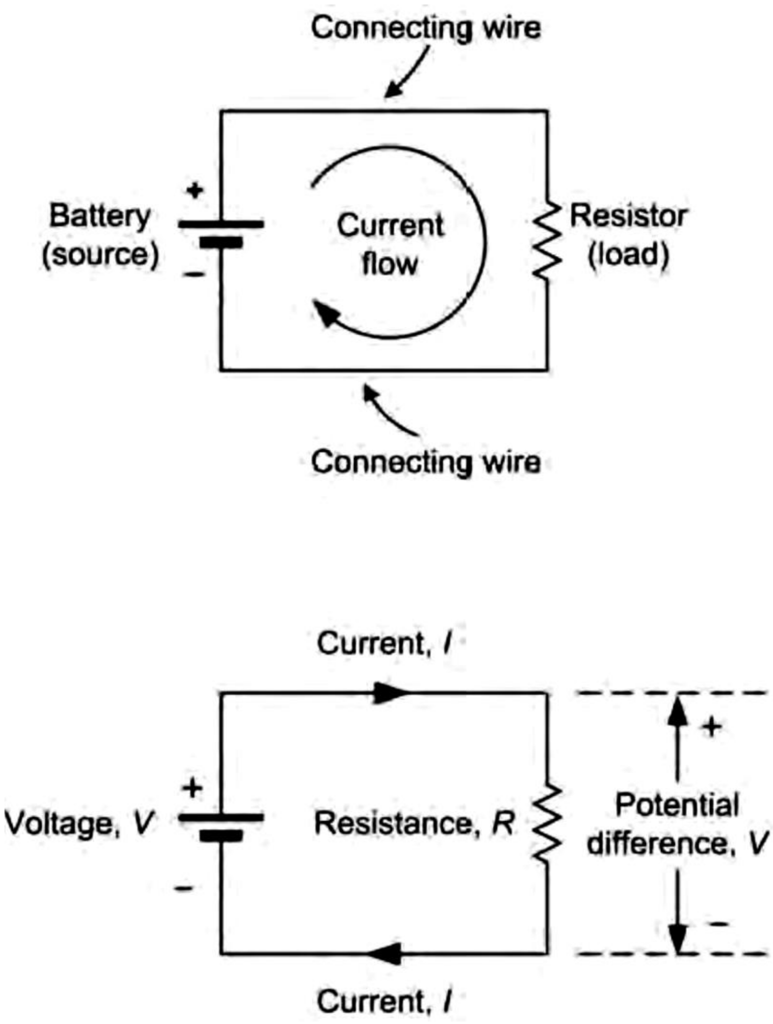

Figure 1.7 A simple DC circuit consisting of a battery (source) and resistor (load)

For any conductor, the current flowing is directly proportional to the e.m.f. applied. The current flowing will also be dependent on the physical dimensions (length and cross-sectional area) and material of which the conductor is composed. The amount of current that will flow in a conductor when a given e.m.f. is applied is inversely proportional to its resistance. Resistance, therefore, may be thought of as an opposition to current flow; the higher the resistance the lower the current that will flow (assuming that the applied e.m.f. remains constant).

Provided that temperature does not vary, the ratio of p.d. across the ends of a conductor to the current flowing in the conductor is a constant. This relationship is known as Ohm's law and it leads to the relationship:

$$\frac{V}{I} = a\ constant = R$$

where V is the potential difference (or voltage drop) in volts (V), I is the current in amps (A), and R is the resistance in ohms (Ω).

Example 1.8

A current of 0.1A flows in a 220Ω resistor. What voltage drop (potential difference) will be developed across the resistor?

Sol:

$$V = I \times R = 0.1A \times 220\Omega = 22\text{V}$$

Hence a p.d. of 22 V will be developed across the resistor.

Test your understanding 1.4

1. An aircraft cable has a resistance of 0.02 Ω per foot. If a 20 foot length of this cable carries a current of 0.5 A what voltage will be dropped across the ends of the cable?
2. A relay has a coil resistance of 400 Ω. What current is required to operate the relay from a 24 V supply?
3. A current of 125 A flows when an insulation tester delivers 500 V to a circuit. What is the resistance of the circuit?

Key maintenance point

When replacing a resistor it is essential to ensure that the replacement component is correctly rated in terms of type, value, power and temperature. Resistors are prone to failure if their maximum power is exceeded and they should be de-rated when operated at a relatively high ambient temperature according to manufacturers' specifications.

Chapter 1 : Electrical fundamentals

Lecture 2

Topics

1.4.5. Kirchhoff's laws

1.4.6. Series and parallel circuits

1.5. Power and energy

1.6. Electromagnetism and inductors

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1.4.5. Kirchhoff's laws

Used on its own, Ohm's law is insufficient to determine the magnitude of the voltages and currents present in complex circuits. For these circuits we need to make use of two further laws; Kirchhoff's current law and Kirchhoff's voltage law.

Kirchhoff's current law states that the algebraic sum of the currents present at a junction (or node) in a circuit is zero – see Fig. 1.8. Kirchhoff's voltage law states that the algebraic sum of the potential drops present in a closed network (or mesh) is zero – see Fig. 1.9.

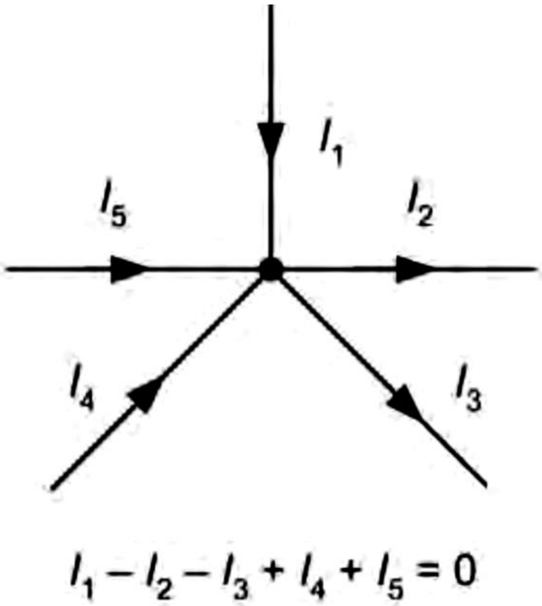


Figure 1.8 Kirchhoff's current law

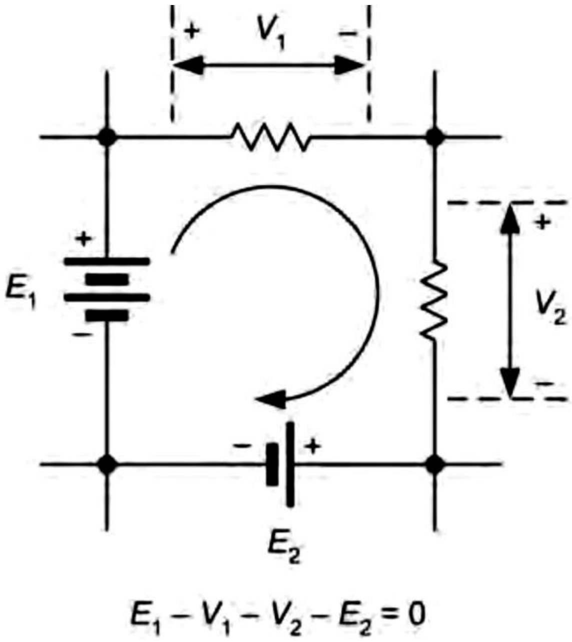


Figure 1.9 Kirchhoff's voltage law

1.4.6. Series and parallel circuits

Ohm's law and Kirchhoff's laws can be combined to solve more complex series–parallel circuits. Before we show you how this is done, however, it's important to understand what we mean by 'series' and 'parallel' circuit!

Figure 1.10 shows three circuits, each containing three resistors, R_1, R_2 and R_3:

- In Fig. 1.10(a), the three resistors are connected one after another. We refer to this as a series circuit. In other words the resistors are said to be connected in series. It's important to note that, in this arrangement, the same current flows through each resistor.
- In Fig. 1.10(b), the three resistors are all connected across one another. We refer to this as a parallel circuit. In other words the resistors are said to be connected in parallel. It's important to note that, in this arrangement, the same voltage appears across each resistor.
- In Fig. 1.16(c`), we have shown a mixture of these two types of connection. Here we can say that R1 is connected in series with the parallel

combination of R2 and R3. In other words, R2 and R3 are connected in parallel and R2 is connected in series with the parallel combination.

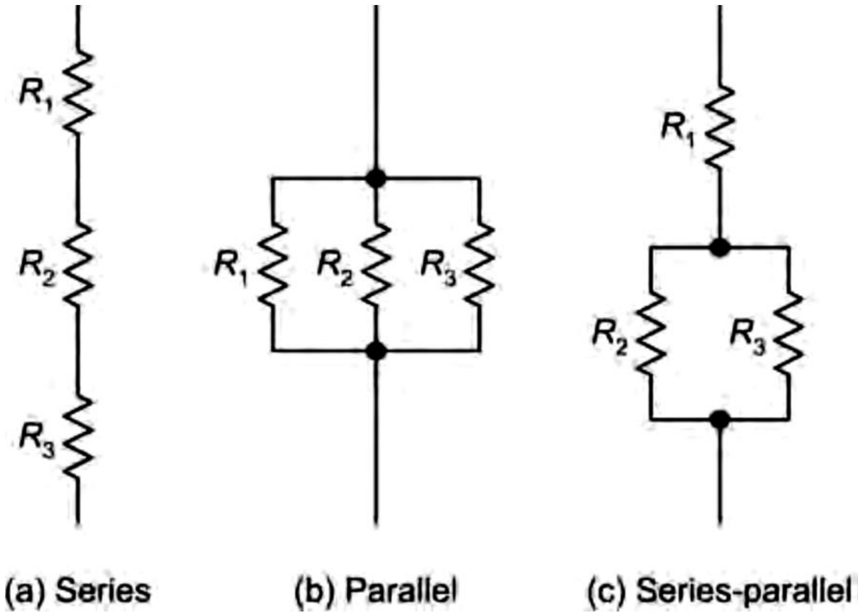


Figure 1.10 Series and parallel circuits

Example 1.9

Figure 1.11 shows a simple battery test circuit which is designed to draw a current of 2 A from a 24 V DC supply. The two test points, A and B, are designed for connecting a meter. Determine:

(a) the voltage that appears between terminals A and B (without the meter connected);

(b) the value of resistor, R.

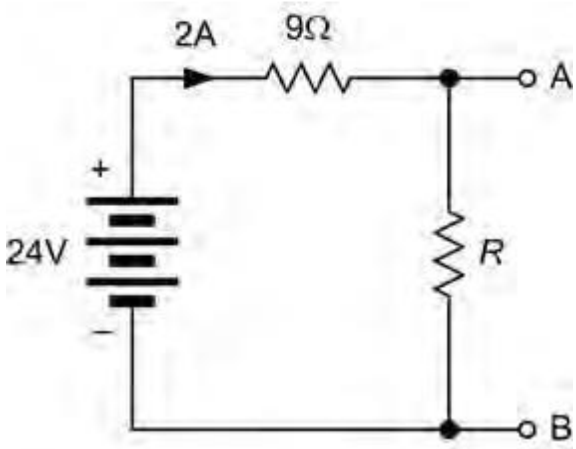


Figure 1.11

\We need to solve this problem in several small stages. Since we know that the circuit draws 2 A from the 24 V supply we know that this current must flow both through the 9 Ω resistor and through R (we hope that you have spotted that these two components are connected in series!).

We can determine the voltage drop across the 9 Ω resistor by applying Ohm's law:

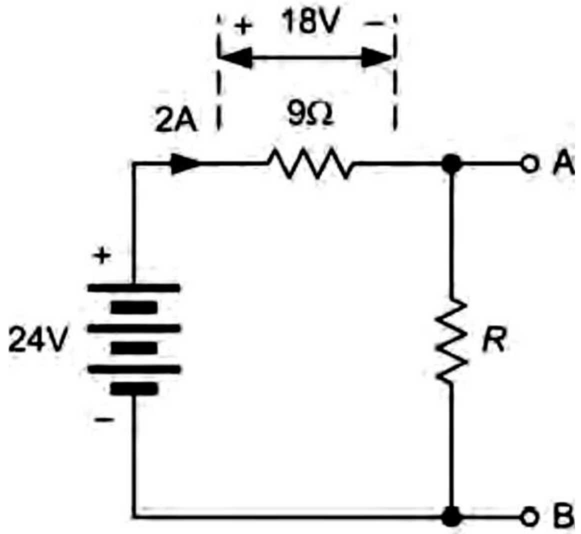
$$V = I \times R = 2 \times 9 = 18V$$

Next we can apply Kirchhoff's voltage law in order to determine the voltage drop, V, which appears

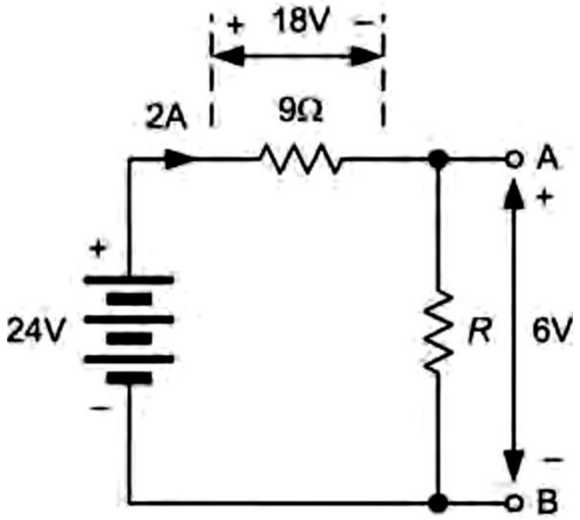
across R (i.e. the potential drop between terminals A and B):

$$+24 - 18 - x = 0 \rightarrow x = +6V$$

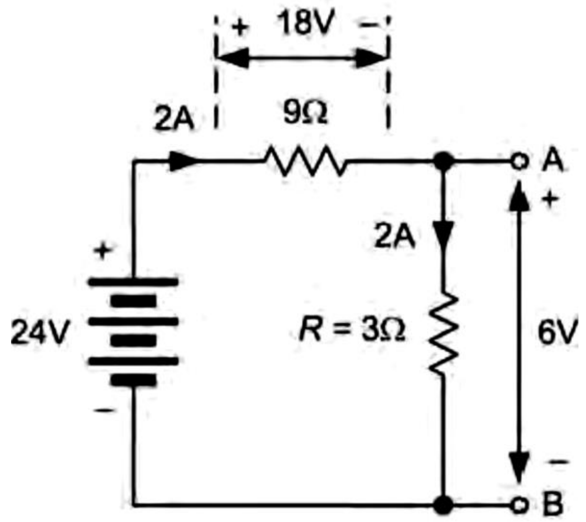
$$R = \frac{6}{2} = 3\Omega$$



Using Ohm's law to find the voltage dropped across the 9 Ω resistor



Using Kirchhoff's law to find the voltage that appears between terminals A and B



Using Ohm's law to fi nd the value of R

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Key point

Circuits with multiple branches can be solved using a combination of Kirchhoff's laws and Ohm's law.

Test your understanding 1.5

Determine the current and voltage present in each branch of the circuit shown in Fig. 1.12.

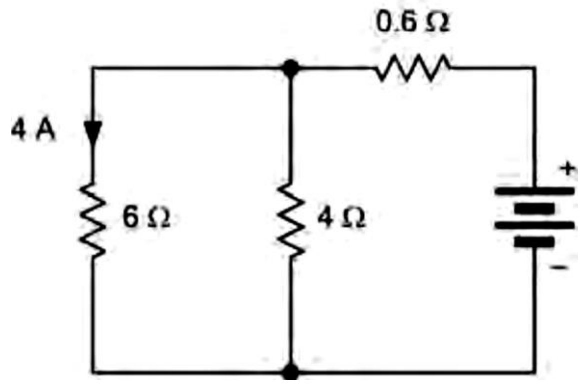


Figure 1.12 See Test your understanding 1.5

Key point

Circuits with multiple branches can be solved using a combination of Kirchhoff's laws and Ohm's law.

1.5. Power and energy

Power, P , is the rate at which energy is converted from one form to another and it is measured in watts (W). The larger the amount of power the greater the amount of energy that is converted in a given period of time.

$$1\,watt\ =\ 1\,joule\ per\ second$$

Or

$$Power, P = \frac{Energy, W}{time, t}$$

The power in an electrical circuit is equivalent to the product of voltage and current. Hence:

$$P = I \times V$$

where P is the power in watts (W), I is the current in amps (A), and V is the voltage in volts (V).

Example 1.10

A main aircraft battery is used to start an engine. If the starter demands a current of 1000 A for 30 s and the battery voltage remains at 12 V during this period, determine the amount of electrical energy required to start the engine.

Sol:

$P = IV$

$where\ I = 1000\,A\ and\ V = 12\,V.\quad Thus$

$P = 1000 \times 12 = 12{,}000W = 12\,kW$

$Next\ we\ need\ to\ find\ the\ energy\ from$:

$W = Pt$

$where\ P = 12\,kW\ and\ t = 30\,s. Thus$

$W = 12\,kW \times 30s = 360\,kJ$

Test your understanding 1.5

1. A window heater is rated at 150W. How much energy is required to operate the heater for one hour?
2. A resistor is rated at 11Ω, 2W. What is the maximum current that should be allowed to flow in it?
3. An emergency locator transmitter is fitted with a lithium battery having a rated energy content of 18 kJ. How long can the unit be expected to operate if the transmitter consumes an input power of 2W?

1.6. Electromagnetism and inductors

Magnetism is an effect created by moving the elementary atomic particles in certain materials such as iron, nickel and cobalt. Iron has outstanding magnetic properties, and materials that behave magnetically, in a similar manner to iron, are known as ferromagnetic materials. These materials experience forces that act on them when placed near a magnet.

A magnetic field of flux is the region in which the forces created by the magnet have influence. This field surrounds a magnet in all directions, being strongest at the end extremities of the magnet, known as the poles. Magnetic fields are mapped by an arrangement of lines that give an indication of strength and direction of the flux as illustrated in Fig. 1.13.

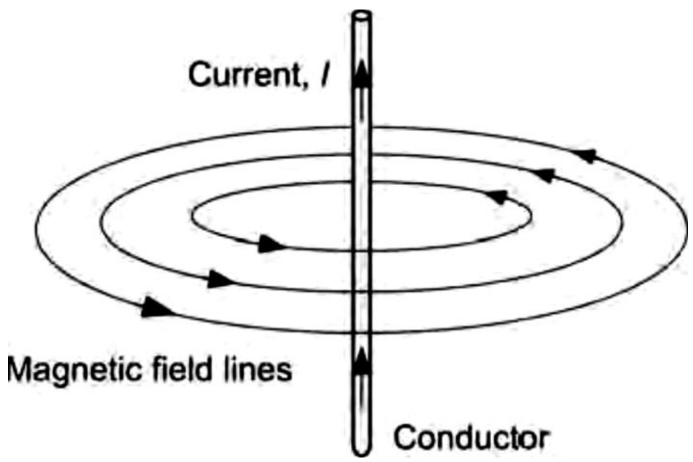


Figure 1.13 Field around a current-carrying conductor

Whenever an electric current flows in a conductor a magnetic field is set up around the conductor in the form of concentric circles, as shown in Fig. 1.13. The field is present along the whole length of the conductor and is strongest nearest to the conductor. Now like permanent magnets, this field also has direction. The direction of the magnetic field is dependent on the direction of the current passing through the conductor.

If we place a current-carrying conductor in a magnetic field , the conductor has a force exerted on it. Consider the arrangement shown in Fig. 1.14 , in which a current-carrying conductor is placed between two magnetic poles. The direction of the current passing through it is into the page going away from us. Then by the right-hand screw rule, the direction ofthe magnetic field, created by the current in the conductor, is clockwise, as shown. We also know that the flux lines from the permanent magnet exit at a north pole and enter at a south pole; in other words, they travel from north to south, as indicated by the direction arrows. The net effect of the coming together of these two magnetic force fields is that at position A, they both travel in the same direction and reinforce one another. While at position B, they travel in the opposite direction and tend to cancel one another. So with a stronger force field at position A and a weaker force at position B the conductor is forced upwards out of the magnetic field. If the direction of the current was reversed, i.e. if it was to travel towards us out of the page, then the direction of the magnetic field in the current-carrying conductor would be reversed and therefore so would the direction of motion of the conductor.

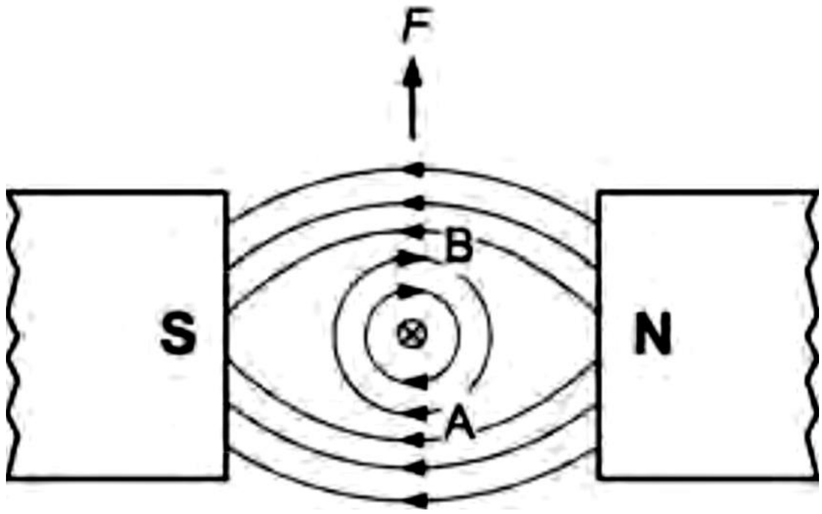


Figure 1.14 A current-carrying conductor in a magnetic field

Key point

A magnetic field of flux is the region in which the forces created by the magnet have influence. This field surrounds a magnet in all directions and is concentrated at the north and south poles of the magnet.

Key point

Whenever an electric current flows in a conductor a magnetic field is set up in the space surrounding the conductor. The field spreads out around the conductor in concentric circles with the greatest density of magnetic flux nearest to the conductor.

The magnitude of the force acting on the conductor depends on the current flowing in the conductor, the length of the conductor in the field, and the strength of the magnetic flux (expressed in terms of its flux density). The size of the force will be given by the expression:

$$F = B * I * l$$

where F is the force in newtons (N), B is the flux density in tesla (T), I is the current (A) and l is the length (m).

Flux density is a term that merits a little more explanation. The total flux present in a magnetic field is a measure of the total magnetic intensity present in the field and it is measured in webers (Wb) and represented by the Greek symbol, Φ . The flux density, B, is simply the total flux, Φ , divided by the area over which the flux acts, A . Hence:

$$B = \frac{\Phi}{A}$$

where B is the flux density (T), Φ is the total flux present (Wb), and A is the area (m^2).

In order to increase the strength of the field, a conductor may be shaped into a loop (Fig. 1.15) or coiled to form a solenoid (Fig. 1.16).

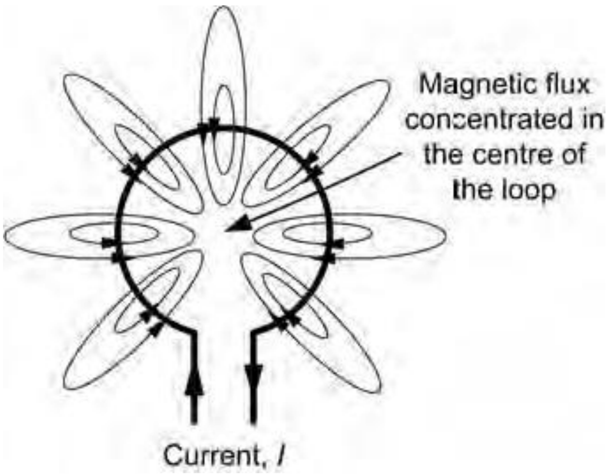


Figure 1.15 Magnetic field around a single turn loop

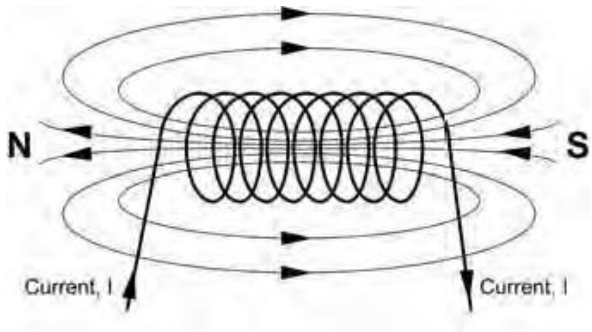


Figure 1.16 Magnetic field around a coil or solenoid

Example 11

A flux density of 0.25 T is developed in free space over an area of 20 cm^2. Determine the total flux.

Sol:

$$\Phi = B * A$$

$thus$

$$\Phi = 0.25 * 0.002 = 0.0005Wb$$

Key point

If we place a current-carrying conductor in a magnetic field, the conductor has a force exerted on it. If the conductor is free to move this force will produce motion.

Key point

Flux density is found by dividing the total flux present by the area over which the flux acts.

1.6.1. Electromagnetic induction

The way in which electricity is generated in a conductor may be viewed as being the exact opposite to that which produces the motor force. In order to generate electricity we require movement in to get electricity out. In fact we need the same components to generate electricity as those needed for the electric motor, namely a closed conductor, a magnetic field and movement.

Whenever relative motion occurs between a magnetic field and a conductor acting at right angles to the field, an e.m.f (**electromotive force**). is induced, or generated in the conductor. The manner in which this e.m.f. is generated is based on the principle of electromagnetic induction.

Consider Fig. 1.17, which shows relative movement between a magnet and a closed coil of wire. An e.m.f. will be induced in the coil whenever the magnet is moved in or out of the coil (or the magnet is held stationary and the coil moved). The magnitude of the induced e.m.f., , depends on the number of turns, N , and the rate at which the flux changes in the coil, $d\Phi/dt$. Note that this last expression is simply a mathematical way of expressing ***the rate of change of flux with respect to time.***

The e.m.f., e , is given by the relationship:

$$e = -N\frac{d\Phi}{dt}$$

where N is the number of turns and $d\Phi/dt$ is the rate of change of flux. The minus sign indicates that the polarity of the generated e.m.f. opposes the change.

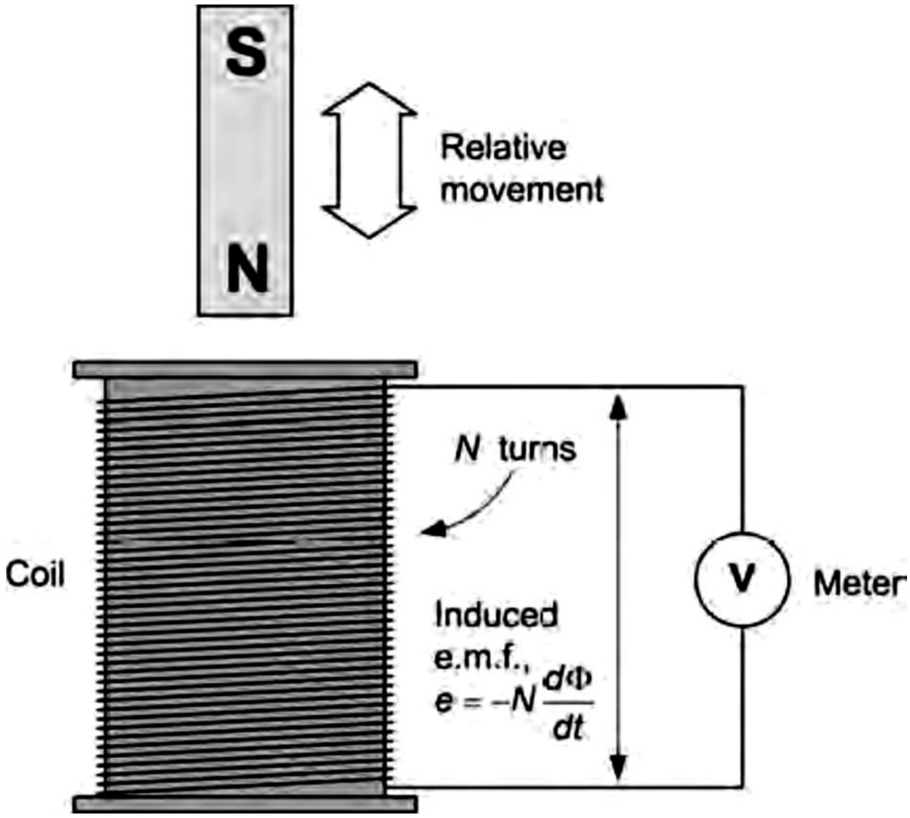


Figure 1.17 Demonstration of electro magnetic induction

Now the number of turns N is directly related to the length of the conductor, , moving through a magnetic field with flux density, B . Also, the velocity with which the conductor moves through the field determines the rate at which the flux changes in the coil as it cuts the flux field. Thus the magnitude of the induced (generated) e.m.f., e , is proportional to the flux density, length of conductor and relative velocity between the field and the conductor .

The magnitude of the induced e.m.f. also depends on:

● the length of the conductor l in m

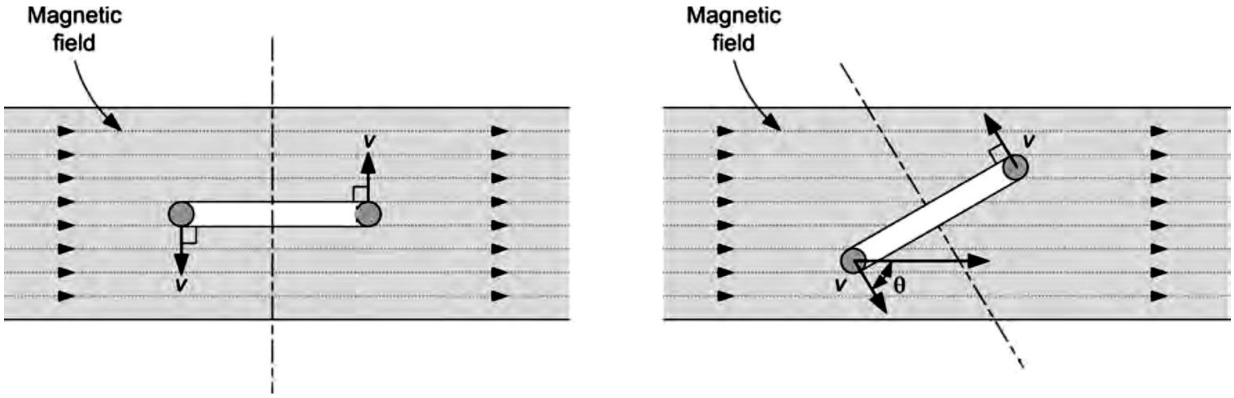
● the strength of the magnetic field, B , in tesla (T)

● the velocity of the conductor, v , in m/s.

Hence:

$$e \propto Blv$$

where B is the strength of the magnetic field (T), l is the length of the conductor in the field (m), and v is the velocity of the conductor (m/s).



(a) (b)

Figure 1.18 Cutting lines of flux and the e.m.f. generated: (a) cutting lines of flux at 90°,$e = Blv$; (b) cutting lines of flux at θ , $e = Blv \sin\theta$

Now you are probably wondering why the above relationship has the proportionality sign. In order to generator an e.m.f. the conductor must cut the lines of magnetic flux. If the conductor cuts the lines of flux at right angles (Fig. 1.18(a)) then the maximum e.m.f. is generated; cutting them at any other angle θ (Fig. 1.18(b)), reduces this value until $\theta = 0°$, at which point the lines of flux are not being cut at all and no e.m.f. is induced or generated in the conductor. So the magnitude of the induced e.m.f. is also dependent on $sin\theta$. So we may write:

$$e = Blv \sin\theta$$

1.6.2. Faraday's and Lenz's laws

When a magnetic flux through a coil is made to vary, an e.m.f. is induced. The magnitude of this e.m.f. is proportional to the rate of change of magnetic flux. What this law is saying in effect is that relative movement between the magnetic flux and the conductor is essential to generate an e.m.f. The voltmeter shown in

Fig. 1.18 indicates the induced (generated) e.m.f. and if the direction of motion changes the polarity of the induced e.m.f. in the conductor changes. Faraday's law also tells us that the magnitude of the induced e.m.f. is dependent on the relative velocity with which the conductor cuts the lines of magnetic flux.

Lenz's law states that the current induced in a conductor opposes the changing field that produces it. It is therefore important to remember that the induced current always acts in such a direction so as to oppose the change in flux. This is the reason for the minus sign in the formula that we met earlier:

$$e = -N\frac{d\Phi}{dt}$$

Key point

The induced e.m.f. tends to oppose any change of current and because of this we often refer to it as aback e.m.f.

Example 1.12

A closed conductor of length 15 cm cuts the magnetic flux field of 1.25 T with a velocity of 25 m/s. Determine the induced e.m.f. when:

(a) the angle between the conductor and field lines is 60°

(b) the angle between the conductor and field lines is 90°.

Sol:

(a) The induced e.m.f. is found using $= Blv\ sin\ \theta$, hence:

$$e = 1.25 * 0.15 * 25 * sin60 = 4.06V$$

(b) $$e = 1.25 * 0.15 * 25 = 4.69V$$

Chapter 1 : Electrical fundamentals

Lecture 3

Topics

1.6.3. Self-inductance and mutual inductance

1.6.4. Inductors

1.7. Alternating current and transformers

1.8 Safety

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1.6.3. Self-inductance and mutual inductance

We have already shown how an induced e.m.f. (i.e. a back e.m.f.) is produced by a flux change in an inductor. The back e.m.f. is proportional to the rate of change of current (from Lenz's law), as illustrated in Fig. 1.19.

This effect is called self-inductance (or just inductance) which has the symbol L. Self-inductance is measured in henries (H) and is calculated from:

$$e = -L\frac{di}{dt}$$

where L is the self-inductance, di/dt is the rate of change of current and the minus sign indicates that the polarity of the generated e.m.f. opposes the change (you might like to compare this relationship with the one shown earlier for electromagnetic induction).

The unit of inductance is the henry (H) and a coil is said to have an inductance of 1 H if a voltage of 1 V is induced across it when a current changing at the rate of 1 A/s is fl owing in it.

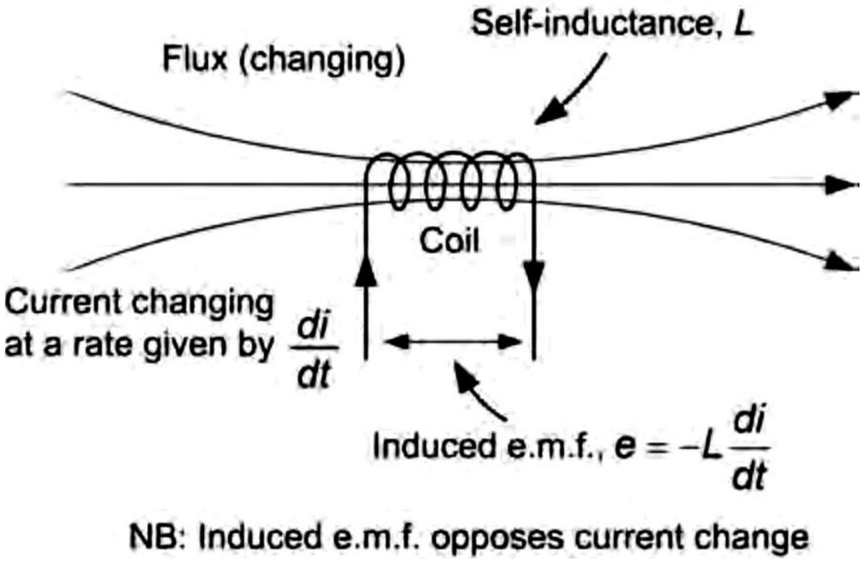

Figure 1.19 Self-inductance

Finally, when two inductors are placed close to one another, the flux generated when a changing current flows in the first inductor will cut through the other inductor (see Fig. 1.20). This changing flux will, in turn, induce a current in the second inductor. This effect is known as mutual inductance and it occurs whenever two inductors are inductively coupled. This is the principle of a very useful component, the transformer, which we shall meet later.

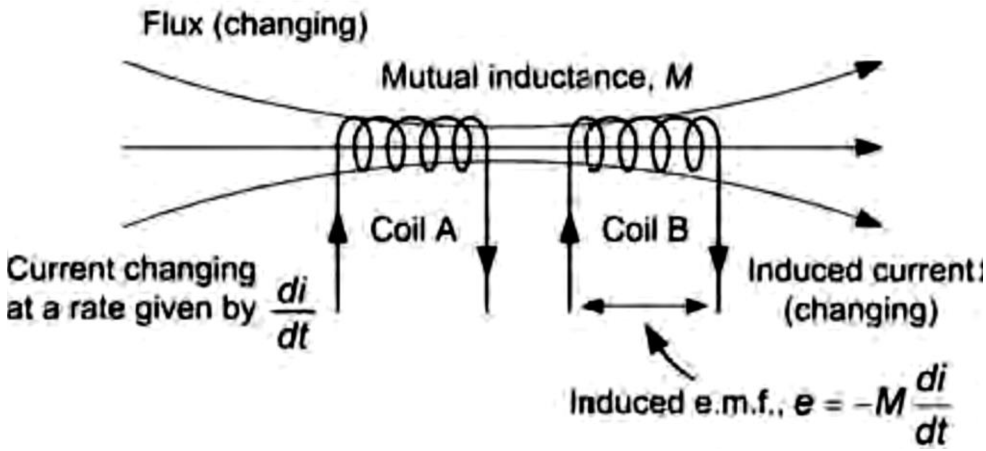

Figure 1.20 Mutual inductance

1.6.4. Inductors

Inductors provide us with a means of storing electrical energy in the form of a magnetic field. Typical applications include **chokes, filters, and frequency selective circuits**. The electrical characteristics of an inductor are determined by a number of factors including the material of the core (if any), the number of turns, and the physical dimensions of the coil.

In practice every coil comprises both inductance and resistance and the circuit of Fig. 1.21 shows these as two discrete components. In reality the inductance, L, and resistance, R, are both distributed throughout the component but it is convenient to treat the inductance and resistance as separate components in the analysis of the circuit.

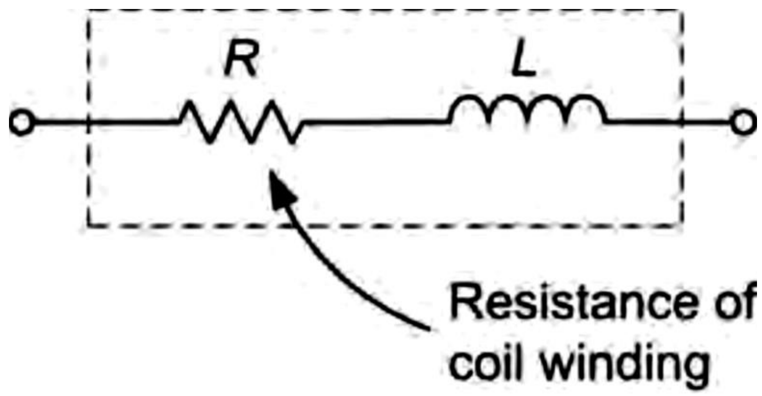

Figure 1.21 A real inductor has resistance as well as inductance

Key point

An e.m.f. is produced when the magnetic flux passing through an inductor changes.

Key point

The current induced in a conductor always opposes the change that produces it.

Test your understanding 1.6

1. A 1.5 m length of wire moves perpendicular to a magnetic flux field of 0.75 T. Determine the e.m.f. that will be induced across the ends of the wire if it moves at 10 m/s.
2. An e.m.f. of 30V is developed across the terminals of an inductor when the current flowing in it changes from zero to 10A in half a second. What is the value of inductance?

1.7. Alternating current and transformers

Direct currents are currents which, even though their magnitude may vary, essentially fl ow only in one direction. In other words, direct currents are unidirectional. Alternating currents, on the other hand, are bidirectional and continuously reversing their direction of flow, as shown in Fig. 1.22.

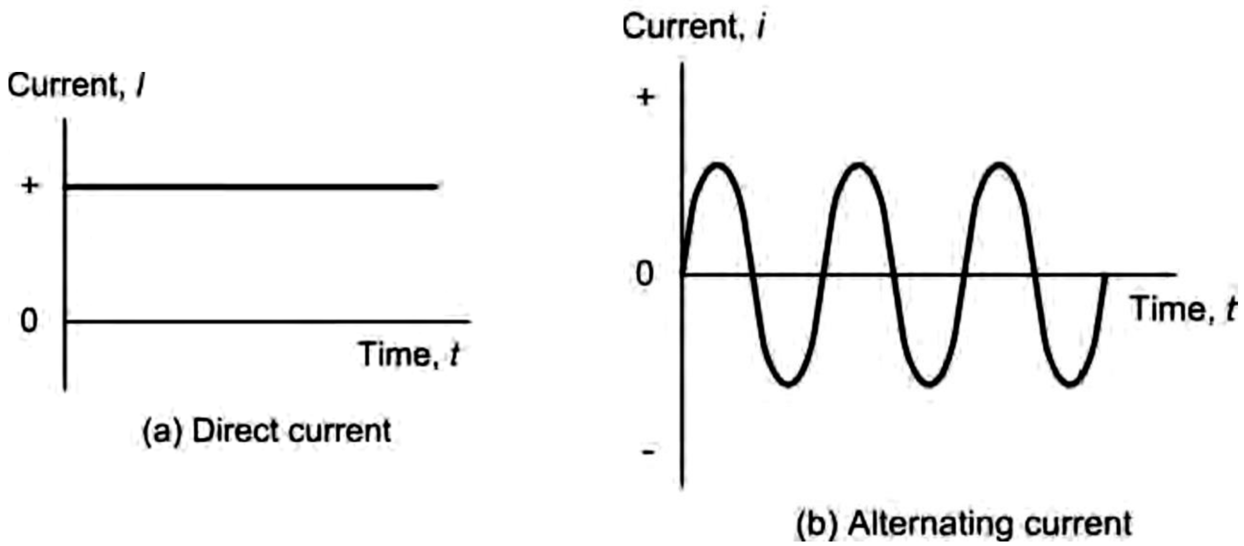

Figure 1.22 Comparison of direct and alternating current

A graph showing the variation of voltage or current present in a circuit is known as a waveform. There are many common types of waveform encountered in electrical circuits including sine (or sinusoidal), square, triangle, ramp or sawtooth (which may be either positive or negative), and pulse. Complex waveforms like speech or music usually comprise many components at different frequencies. Pulse waveforms found in digital circuits are often categorized as either repetitive or non-repetitive (the former comprises a pattern of pulses which regularly repeats whilst the latter comprises pulses which constitute a unique event). Several of the most common waveform types are shown in Fig. 1.23 .

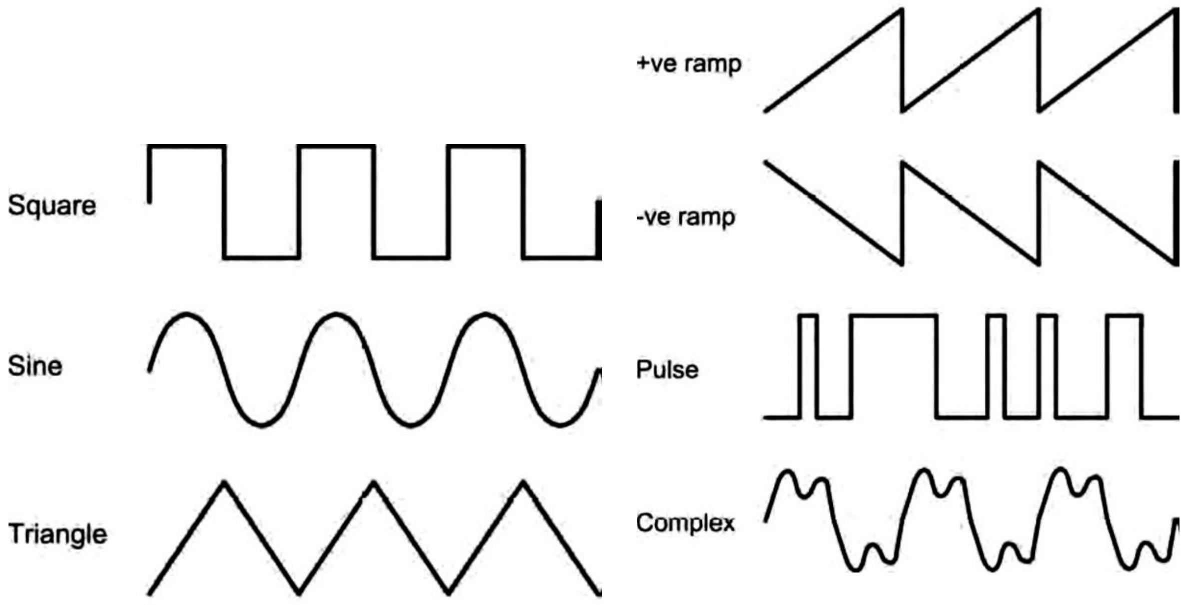

Figure 1.23 Various waveforms

1.7.1 Frequency and periodic time

The frequency of a repetitive waveform is the number of cycles of the waveform that occur in unit time. Frequency is expressed in hertz (Hz). A frequency of 1 Hz is equivalent to one cycle per second. Hence, if an aircraft supply has a frequency of 400 Hz, 400 cycles of the supply will occur in every second (Fig. 1.24).

The periodic time (or period) of a waveform is the time taken for one complete cycle of the wave (see Fig. 1.25). The relationship between periodic time and frequency is thus:

$$t = \frac{1}{f} \; or \; f = \frac{1}{t}$$

where t is the periodic time (in seconds) and f is the frequency (in Hz).

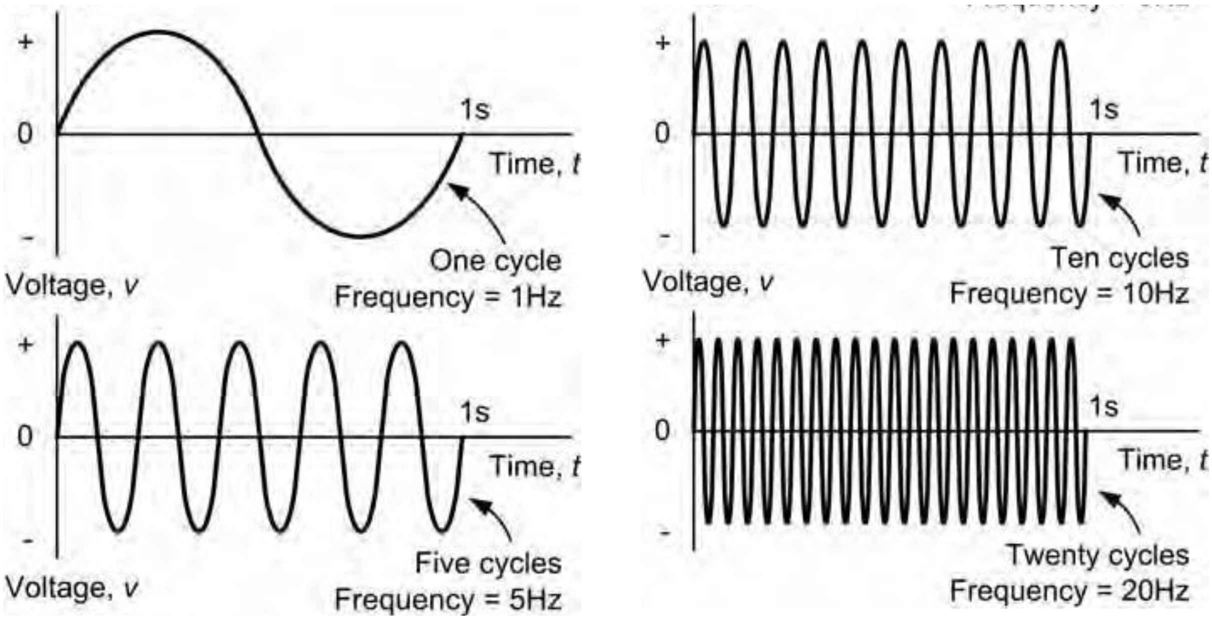

Figure 1.24 Waveforms with different frequencies

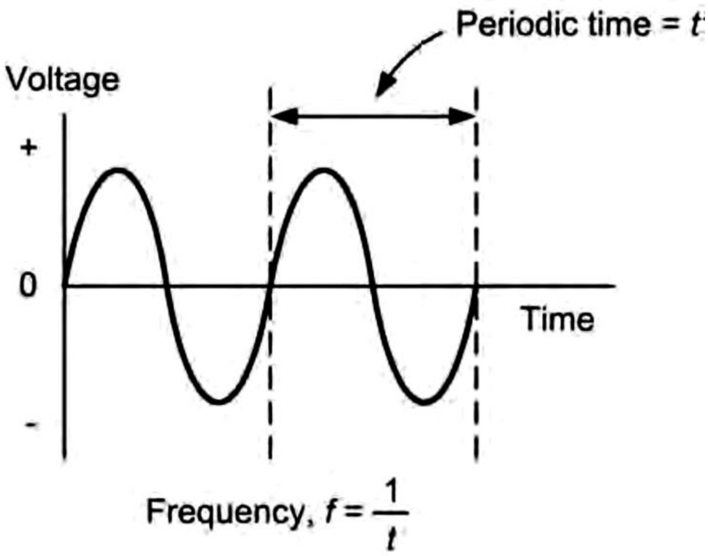

Figure 1.25 Periodic time

1.7.2 Average, peak, peak–peak, and r.m.s. values

The average value of an alternating current which swings symmetrically above and below zero will obviously be zero when measured over a long period of time.

The peak value (or maximum value or amplitude) of a waveform is a measure of the extent of its voltage or current excursion from the resting value (usually zero).

The peak-to-peak value for a wave which is symmetrical about its resting value is twice its peak value.

The root mean square (r.m.s.) or effective value of an alternating voltage or current is the value which would produce the same heat energy in a resistor as a direct voltage or current of the same magnitude.

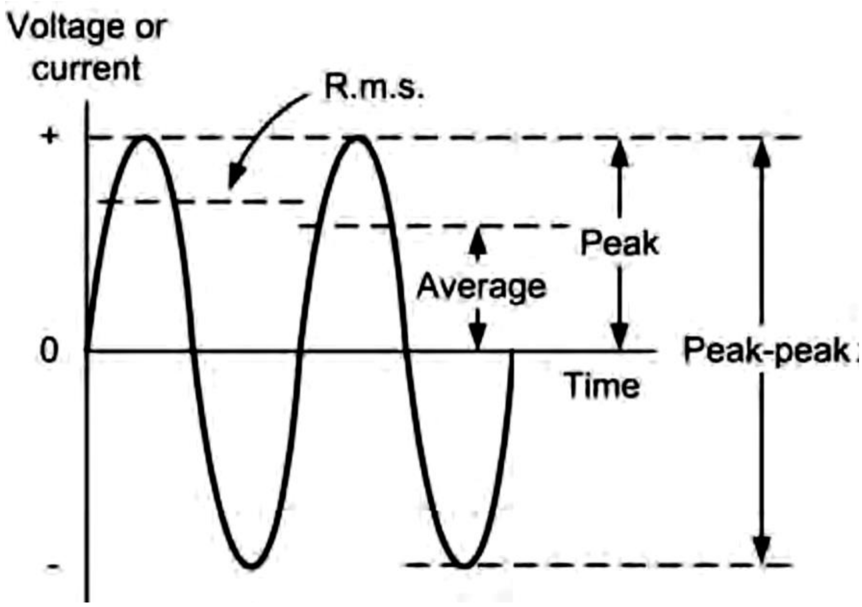

Figure 1.26 Average, r.m.s., peak and peak–peak values of a sine wave

1.7.3 Three-phase supplies

In many practical applications, including aircraft, it can be advantageous to use a multiphase supply rather than a single-phase supply. The most common system uses three separate voltage sources (and three wires) and is known as threephase . The voltages produced by the three sources are spaced equally in time such that the angle between them is 120° (or 360°/3). The waveforms for a threephase supply are shown in Fig. 1.37 (note that each is a sine wave and all three sine waves have the same frequency and periodic time). We shall be returning to this topic in greater detail in the later lectures when we introduce three-phase power generation.

1.7.4 Reactance

In an AC circuit, reactance, like resistance, is simply the ratio of applied voltage to the current flowing. Thus:

$$I = \frac{V}{X}$$

where X is the reactance in ohms (Ω), V is the alternating potential difference in volts (V) and I is the alternating current in amps (A).

In the case of **capacitive reactance** (i.e. the reactance of a capacitor) we use the suffix, C, so that the reactance equation becomes:

$$X_c = \frac{V_C}{I_C}$$

Similarly, in the case of **inductive reactance** (i.e. the reactance of an inductor) we use the suffix, L, so that the reactance equation becomes:

$$X_L = \frac{V_L}{I_L}$$

The voltage and current in a circuit containing **pure reactance** (either capacitive or inductive) will be out of phase by 90°. In the case of a circuit containing pure capacitance the current will lead the voltage by 90° (alternatively we can say that the voltage lags the current by 90°). This relationship is illustrated by the waveforms shown in Fig. 1.27.

In the case of a circuit containing **pure inductance** the voltage will lead the current by 90° (alternatively we can also say that the current lags the voltage by 90°). This relationship is illustrated by the waveforms shown in Fig. 1.28.

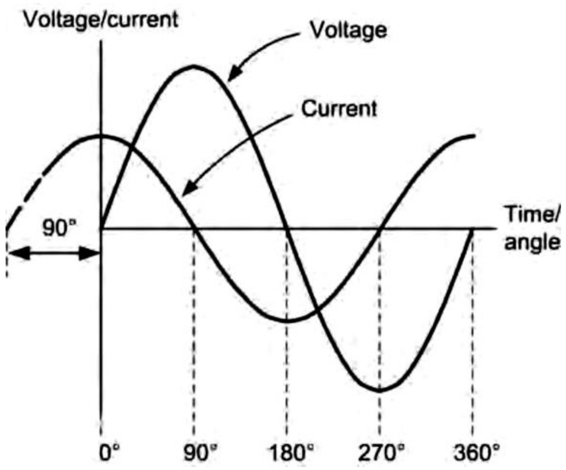

Figure 1.27 Voltage and current waveforms for a pure capacitor (the current leads the voltage by 90°)

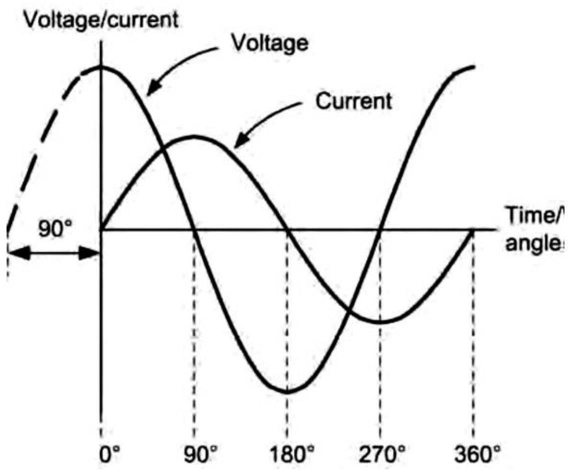

Figure 1.28 Voltage and current waveforms for a pure capacitor (the voltage leads the current by 90°)

The reactance of an inductor (inductive reactance) is directly proportional to the frequency of the applied alternating current and can be determined from the following formula:

$$X_L = 2\pi f L$$

where X_L is the reactance in Ω , f is the frequency in Hz, and L is the inductance in H.

The reactance of a capacitor (capacitive reactance) is inversely proportional to the frequency of the applied alternating current and can be determined from the following formula:

$$X_C = \frac{1}{2\pi f C}$$

where X_C is the reactance in Ω , f is the frequency in Hz, and C is the capacitance in F.

Key point

When alternating voltages are applied to capacitors or inductors the magnitude of the current flowing will depend upon the value of capacitance or inductance and on the frequency of the voltage. In effect, capacitors and inductors oppose the flow of current in much the same way as a resistor. The important difference being that the effective resistance (or reactance) of the component varies with frequency (unlike the case of a conventional resistor where the magnitude of the current does not change with frequency).

1.7.5 Impedance

Circuits that contain a mixture of both resistance and reactance (either capacitive reactance or inductive reactance or both) are said to exhibit impedance. Impedance, like resistance and reactance, is simply the ratio of applied voltage to the current flowing. Thus:

$$Z = \frac{V}{I}$$

where Z is the impedance in ohms (Ω), V is the alternating potential difference in volts (V) and I is the alternating current in amps (A).

Because the voltage and current in a pure reactance are at 90° to one another (we say that they are in quadrature) we can’t simply add up the resistance and reactance present in a circuit in order to fi nd its impedance. Instead, we can use the impedance triangle shown in Fig. 1.29 . The impedance triangle takes into account the 90° phase angle and from it we can infer that the impedance of a series circuit (R in series with X) is given by:

$$Z = \sqrt{R^2 + X^2}$$

where Z is the impedance (in Ω), X is the reactance, either capacitive or inductive (expressed in Ω), and R is the resistance (also in Ω).

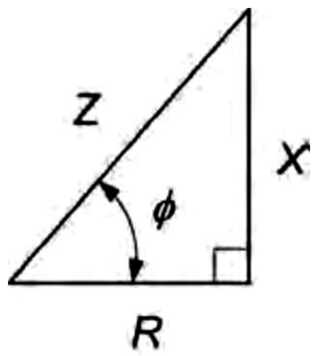

Figure 1.29 The impedance triangle

Key point

Resistance and reactance combine together to make impedance. In other words, impedance is the resultant of combining resistance and reactance in the impedance triangle. Because of the quadrature relationship between voltage and current in a pure capacitor or inductor, the angle between resistance and reactance in the impedance triangle is always 90°.

1.7.6 Resonance

It is important to note that a special case occurs when $X_C = X_L$ in which case the two equal but opposite reactances effectively cancel each other out. The result of this is that the circuit behaves as if only resistance, R, is present (in other words, the impedance of the circuit, $Z = R$). In this condition the circuit is said to be resonant. The frequency at which resonance occurs is given by:

$$X_C = X_L$$

$$\frac{1}{2\pi f C} = 2\pi f L$$

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where f is the resonant frequency (in Hz), L is the inductance (in H) and C is the capacitance (in F).

1.7.7 Power factor

The power factor in an AC circuit containing resistance and reactance is simply the ratio of true power to apparent power. Hence:

$$Power\ factor = \frac{true\ power}{apparent\ power}$$

The true power in an AC circuit is the power that is actually dissipated as heat in the resistive component. Thus:

$$True\ power = I^2 R$$

where I is r.m.s. current and R is the resistance. True power is measured in watts (W).

The apparent power in an AC circuit is the power that is apparently consumed by the circuit and is the product of the supply current and supply voltage (which may not be in phase). Note that, unless the voltage and current are in phase (i.e. φ= 0°), the apparent power will not be the same as the power which is actually dissipated as heat. Hence:

$$Apparent\ power = IV$$

where I is r.m.s. current and V is the supply voltage. To distinguish apparent power from true power, apparent power is measured in volt-amperes (VA).

Now since $V = IZ$ we can rearrange the apparent power equation as follows:

$$Apparent\ power = IV = I \times IZ = I^2 Z$$

Now returning to our original equation:

$$Power\ factor = \frac{true\ power}{apparent\ power} = \frac{I^2 R}{IV} = \frac{I^2 R}{I^2 Z} = \frac{R}{Z}$$

$$Power\ factor = \frac{R}{Z} = \cos\phi$$

Example 1.13

An AC load has a power factor of 0.8. Determine the true power dissipated in the load if it consumes a current of 2A at 110 V.

Sol:

$$Power\ factor = \frac{true\ power}{apparent\ power} = \frac{R}{Z} = \cos\phi$$

$$true\ power = 0.8 * 2 * 110 = 176W$$

Example 1.13

A coil having an inductance of 150mH and resistance of 250Ω is connected to a 115 V 400 Hz AC supply.

Determine:

(a) the power factor of the coil

(b) the current taken from the supply

(c) the power dissipated as heat in the coil.

Sol:

(a) First we must find the reactance of the inductor, X_L , and the impedance, Z , of the coil at 400Hz.

$$X_L = 2\pi * 400 * 150 * 10^{-3} = 376\,\Omega$$

And

$$Z = \sqrt{R^2 + X_L^2} = \sqrt{250^2 + 376^2} = 452\,\Omega$$

We can now determine the power factor from:

$$Power\ factor = \frac{R}{Z} = \frac{250}{452} = 0.553$$

(b) The current taken from the supply can be determined from:

$$I = \frac{V}{Z} = \frac{115}{452} = 0.254$$

(c) The power dissipated as heat can be found from:

$$true\ power = Power\ factor * VI$$

$$= 0.553 * 115 * 0.254 = 16.15W$$

Key point

In an AC circuit the power factor is the ratio of true power to apparent power. The power factor is also the cosine of the phase angle between the supply current and supply voltage.

Test your understanding 1.6

1. Determine the reactance of a 60mH inductor at (a) 20 Hz and (b) 4 kHz.
2. Determine the reactance of a 220nF capacitor at (a) 400 Hz and (b) 20 kHz. A 0.5μF capacitor is connected to a 110 V 400 Hz supply. Determine the current flowing in the capacitor.
4. A resistor of 120 Ω is connected in series with a capacitive reactance of 160 Ω. Determine the impedance of the circuit and the current flowing when the circuit is connected to a 200 V AC supply.
5. A capacitor or 2μF is connected in series with a 100 Ω resistor across a 24 V 400 Hz AC supply. Determine the current that will be supplied to the circuit and the voltage that will appear across each component.
6. An 8mH coil has a resistance of 10 Ω. Calculate the current fl owing when the coil is connected to a 250 V 50 Hz supply.
7. Determine the phase angle and power factor for Question 6.
8. An AC load has a power factor of 0.6. If the current supplied to the load is 5 A and the supply voltage is 110 V determine the true power dissipated by the load.
9. An AC load comprises a 110 Ω resistor connected in parallel with a 20μF capacitor. If the load is connected to a 220 V 50 Hz supply, determine the apparent power supplied to the load and its power factor.
10. A filter consists of a 2μF capacitor connected in series with a 50mH inductor. At what frequency will the filter be resonant?

1.7.8 Transformers

Transformers provide us with a means of stepping up or stepping down an AC voltage. For a step-up transformer , the output (or secondary) voltage will be greater than the input (or primary) whilst for a step-down transformer the secondary voltage will be less than the primary voltage. Since the primary and secondary power must be the same (no increase in power is possible), an increase in secondary voltage can only be achieved at the expense of a corresponding reduction in secondary current, and vice versa (in fact, the secondary power will be very slightly less than the primary power due to losses within the transformer).

The principle of the transformer is illustrated in Fig. 1.46 . The primary and secondary windings are wound on a common low-reluctance magnetic core consisting of a number of steel laminations. All of the alternating flux generated by the primary winding is therefore coupled into the secondary winding (very little flux escapes due to leakage). A sinusoidal current flowing in the primary winding produces a sinusoidal flux within the transformer core.

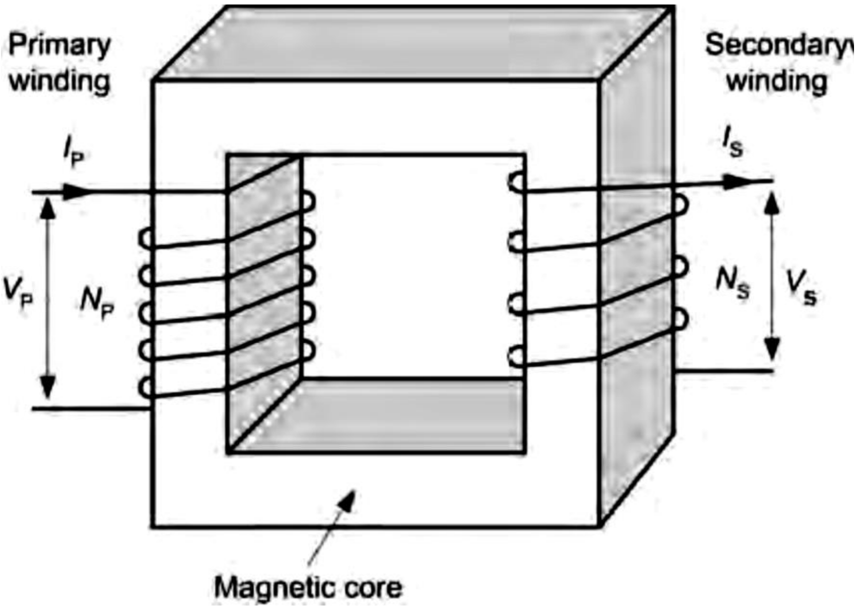

Figure 1.46 The principle of the transformer

Key maintenance point

When replacing a transformer it is essential to ensure that the replacement component is correctly rated. The specifications for a transformer usually include the rated primary and secondary voltage and current, the power rating expressed in volt-amperes, VA (this is the maximum power that the transformer can deliver under a given set of conditions), the frequency range for the transformer (note that a transformer designed for operation at 400 Hz will not work at 50 Hz or 60 Hz), and the per-unit regulation of the transformer (this is the ability of the transformer to maintain its rated output when under load).

1.8 Safety

When working on aircraft electrical and electronic systems, personal safety (both yours and of those around you) should be paramount in everything that you do. Hazards can exist within many circuits-even those that, on the face of it, may appear to be totally safe. Inadvertent mis-connection of a supply, incorrect earthing, reverse connection of components, and incorrect fitting can all result in serious hazards to personal safety as a consequence of fi re, explosion or the generation of toxic fumes. In addition, there is a need to ensure that your work will not compromise the safety and integrity of the aircraft and not endanger the passengers and crew that will fly in it.

Potential hazards can be easily recognized and it is well worth making yourself familiar with them but perhaps the most important point to make is that electricity acts very quickly and you should always think carefully before working on circuits where mains or high voltages (i.e. those over 50 V or so) are present. Failure to observe this simple precaution can result in the very real risk of electric shock.

Voltages in many items of electronic equipment, including all items which derive their power from the aircraft’s 400 Hz AC supply, are at a level which can cause sufficient current fl ow in the body to disrupt normal operation of the heart.

The threshold will be even lower for anyone with a defective heart. Bodily contact with AC supplies and other high-voltage circuits can thus be lethal.

Key maintenance point

It is essential to remove electrical power from an aircraft before removing or installing components in the power panels. Failure to observe this precaution can result in electric shock as well as damage to components and equipment.

Test your understanding 1.6

Q1. What is meant by static electricity?
Q2. What is the function of static dischargers in aircrafts?
Q3. What to do when replacing a capacitor?
Q4. What to do when working with high-voltage capacitors before replacing it?
Q5. Define the following: direct current, Primary cells and secondary cells.
Q6. What difference between flow current and electron?
Q7. What to do when removing and replacing the battery?
Q8. What to do when replacing a resistor?
Q9. What to do when dealing with multiple branches circuits?
Q10. What is meant by Electromagnetism in conductor?
Q11. What is meant by inductance in conductor?
Q12. What happens when a conductor passes through a magnetic field as the current passes through the conductor? Explain this with the necessary equations.
Q13. Why the coils are created by several overlapping loops?
Q14. What are the factors affecting the generation of e.m.f?
Q15. This phrase is a summary of any law ("the magnitude of the induced e.m.f. is dependent on the relative velocity with which the conductor cuts the lines of magnetic flux").
Q16. This phrase is a summary of any law ("the induced current always acts in such a direction so as to oppose the change in flux").
Q17. What is the reason for the minus sign in the formula ($e = -N\frac{d\Phi}{dt}$)?

Chapter 2 : Generators and motors

Lectures 4&5

Topics

2.1 Generator and motor principles

2.2 AC generators

2.3 Three-phase generation and distribution

2.4 AC motors

2.5 Practical aircraft generating systems

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2.1 Generator and motor principles

Key point

An e.m.f. will be induced across the ends of a conductor when there is relative motion between it and a magnetic field. The induced voltage will take its greatest value when moving at right angles to the magnetic field lines and its least value (i.e. zero) when moving along the direction of the field lines. See Fig (2.1)

$$e = Blv \sin\theta$$

2.1.1 A simple AC generator

Key point

In a simple AC generator a loop of wire rotates inside the magnetic field produced by two opposite magnetic poles. Contact is made to the loop as it rotates by means of slip-rings and brushes. See Fig(2.2) and Fig(2.3)

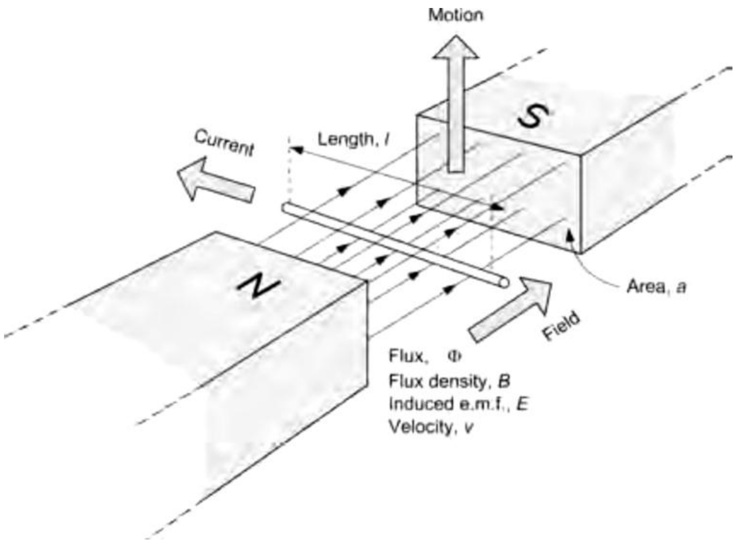

Figure 2.1 A conductor moving inside a magnetic field

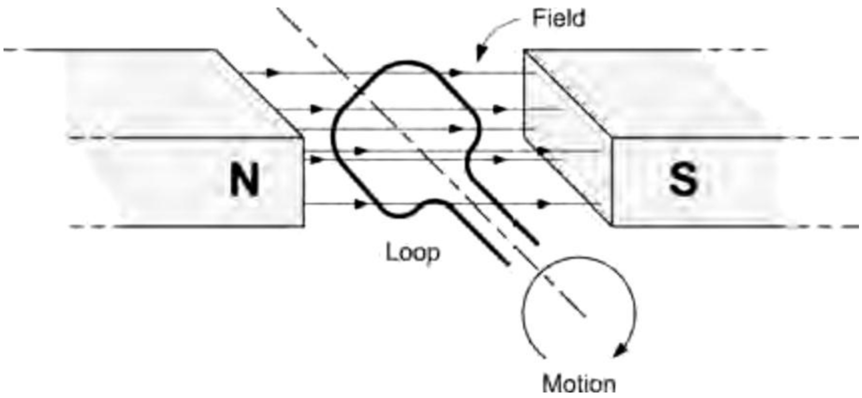

Figure 2.2 A loop rotating within a magnetic field

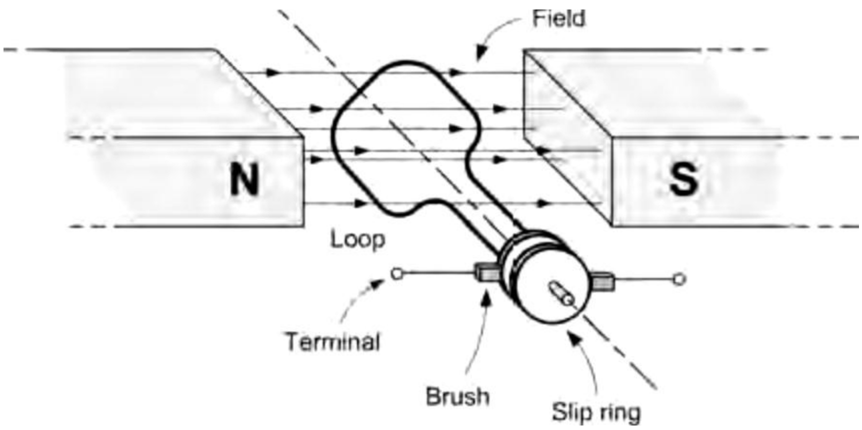

Figure 2.3 Brush arrangement

2.1.2 DC generators

Key point

A simple DC generator uses an arrangement similar to that used for an AC generator but with the slip-rings and brushes replaced by a commutator that reverses the current produced by the generator every 180^o. See Fig(2.4 & 2.5)

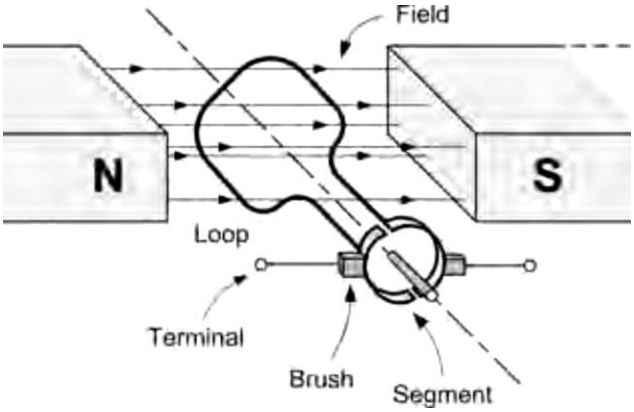

Figure 2.4 Commutator arrangement

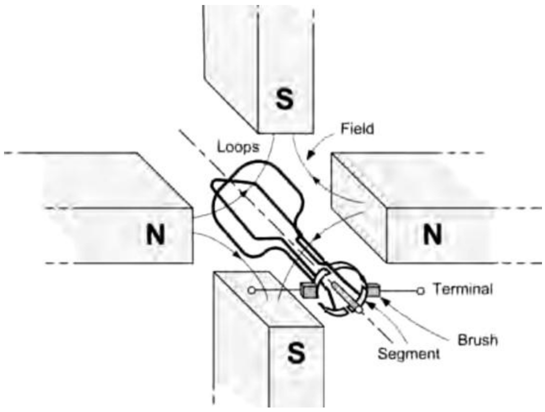

Figure 2.5 An improved DC generator

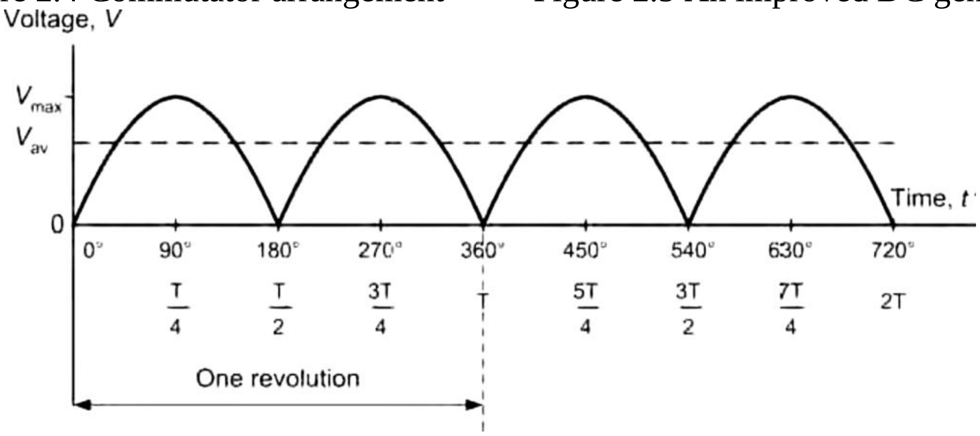

Figure 2.6 E.m.f. generated (compare with Fig. 2.4)

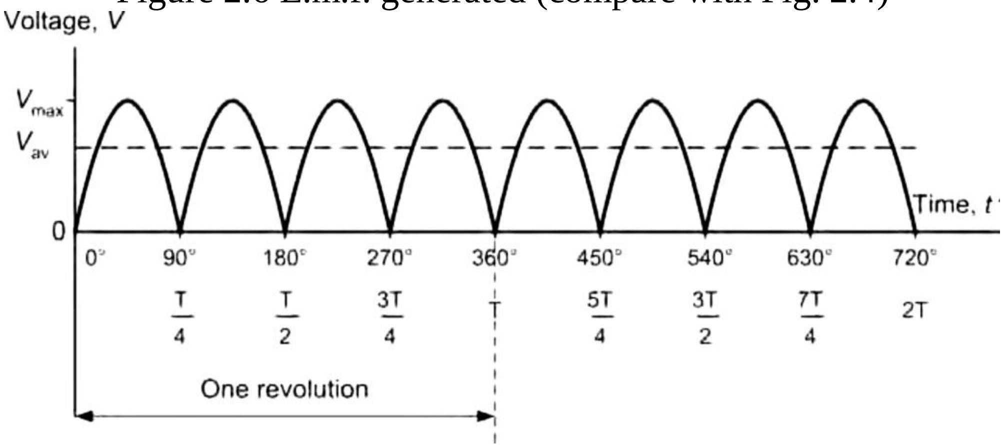

Figure 2.7 E.m.f. generated (compare with Fig. 2.5)

2.2. AC generators

AC generators, or alternators , are based on the principles that relate to the simple AC generator. However, in a practical AC generator the magnetic field is rotated rather than the conductors from which the output is taken. Furthermore, the magnetic field is usually produced by a rotating electromagnet (the rotor) rather than a permanent magnet. There are a number of reasons for this including:

(a) the conductors are generally lighter in weight than the magnetic field system and are thus more easily rotated

(b) the conductors are more easily insulated if they are stationary

(c) the currents which are required to produce the rotating magnetic field are very much smaller than those which are produced by the conductors. Hence the slip-rings are smaller and more reliable.

Figure 2.8 shows the simplified construction of a single-phase AC generator . The stator consists of five coils of insulated heavy gauge wire located in slots in the high-permeability laminated core. These coils are connected in series to make a single stator winding from which the output voltage is derived.

The two-pole rotor comprises a field winding that is connected to a DC fi eld supply via a set of sliprings and brushes. As the rotor moves through one complete revolution the output voltage will complete one full cycle of a sine wave.

By adding more pairs of poles to the arrangement shown in Fig. 2.8 it is possible to produce several cycles of output voltage for one single revolution of the rotor. The frequency of the output voltage produced by an AC generator is given by:

$$f = \frac{pN}{60}$$

where f is the frequency of the induced e.m.f. (in Hz), p is the number of pole pairs, and N is the rotational speed (in rev/min).

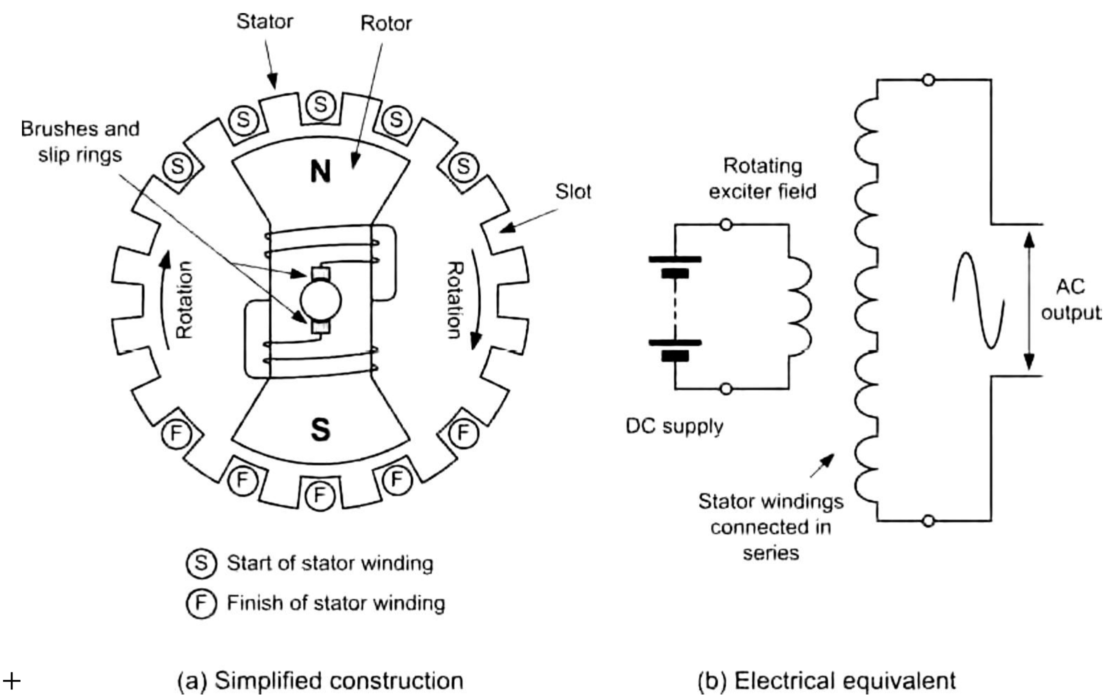

Figure 2.8 Simplified construction of a single-phase AC generator

Key point

In a practical AC generator, the magnetic field excitation is produced by the moving rotor whilst the conductors from which the output is taken are stationary and form part of the stator.

2.2.1 Two-phase AC generators

By adding a second stator winding to the single-phase AC generator shown in Fig. 2.8 , we can produce an alternator that produces two separate output voltages which will differ in phase by 90°. This arrangement is known as a two-phase AC generator.

When compared with a single-phase AC generator of similar size, a two-phase AC generator can produce more power. The reason for this is attributable to the fact that the two-phase AC generator will produce two positive and two negative pulses per cycle whereas the single-phase generator will only produce one positive and one negative pulse. Thus, over a period of time, a multi-phase supply will transmit a more evenly distributed power and this, in turn, results in a higher overall efficiency

Key point

Three-phase AC generators are more efficient and produce more constant output than comparable single-phase AC generators.

2.2.2 Three-phase AC generators

The three-phase AC generator has three individual stator windings, as shown in Fig. 2.9. The output voltages produced by the three-phase AC generator are spaced by 120° as shown in Fig. 2.10. Each phase can be used independently to supply a different load or the generator outputs can be used with a three phase distribution system like those described in the next section. In a practical three-phase system the three output voltages are identified by the coloursred, yellow, and blue or by letters A, B, and C respectively

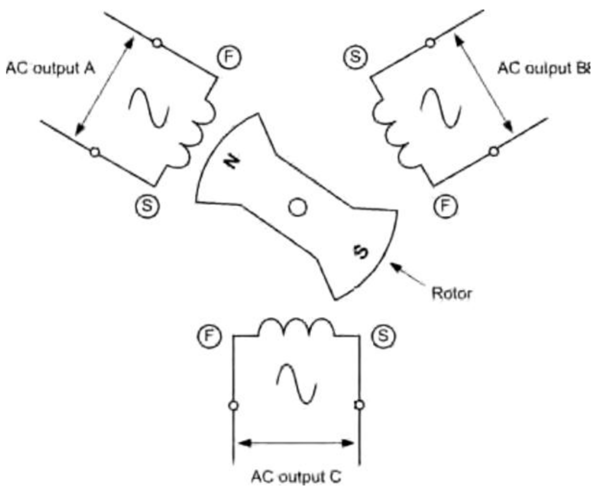

Figure 2.9 Simplified construction of a three-phase AC generator

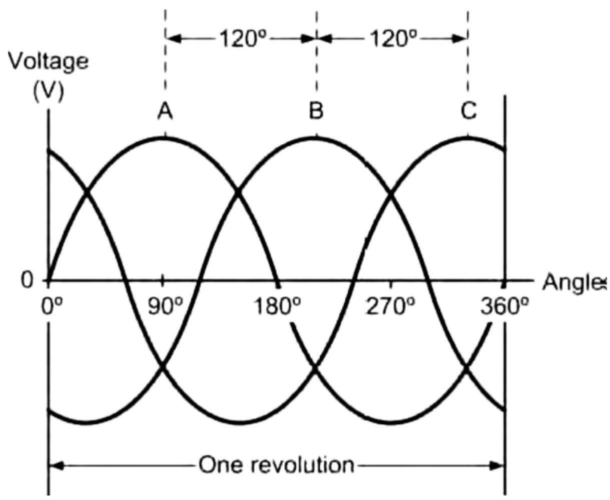

Figure 2.10 Output voltage produced by the three-phase AC generator shown in Fig. 2.9

Test your understanding 2.1

An alternator uses a 12-pole rotor and is to operate at a frequency of 400Hz. At what speed must it be driven?

2.3 Three-phase generation and distribution

When three-phase supplies are distributed there are two basic methods of connection:

● star (as shown in Fig. 2.11)

● delta (as shown in Fig. 2.12)

A complete star-connected three-phase distribution system is shown in Fig. 2.13. This shows a three-phase AC generator connected a three-phase load. Ideally, the load will be balanced in which case all three load resistances (or impedances) will be identical.

The relationship between the line and phase voltages shown in Fig. 2.13 can be determined from the phasor diagram shown in Fig. 2.14. This diagram shows the relative directions of the three alternating phase voltages (V_P) and the voltages between the lines (V_L). From this diagram it is important to note that three line voltages are 120° apart and that the line voltages lead the phase voltages by 30°. In order to obtain the relationship between the line voltage, V_L , and the phase voltage, V_P , we need to resolve any one of the triangles, from which we find that:

$$\mathrm{V_L} = 2(\mathrm{V_P} \times \cos 30^{\circ})$$

$$\cos 30^{\circ} = \frac{\sqrt{3}}{2}$$

$$\mathrm{V_L} = \sqrt{3}\, V_P$$

Note also that the phase current is the same as the line current, hence:

$$I_L = I_P$$

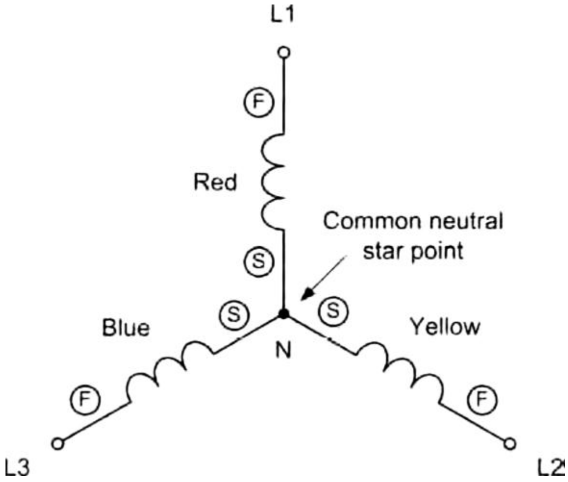

Figure 2.11 Star connection

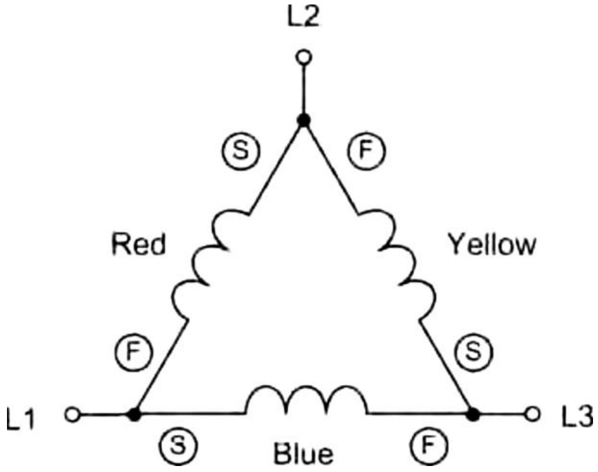

Figure 2.12 Delta connection

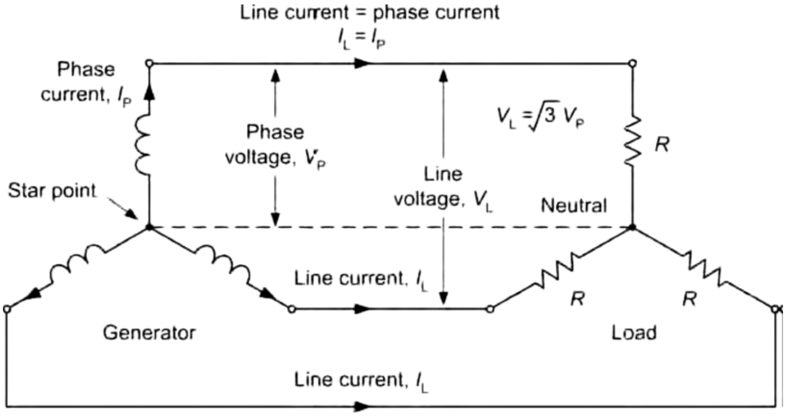

Figure 2.13 A complete star-connected three-phase distribution system

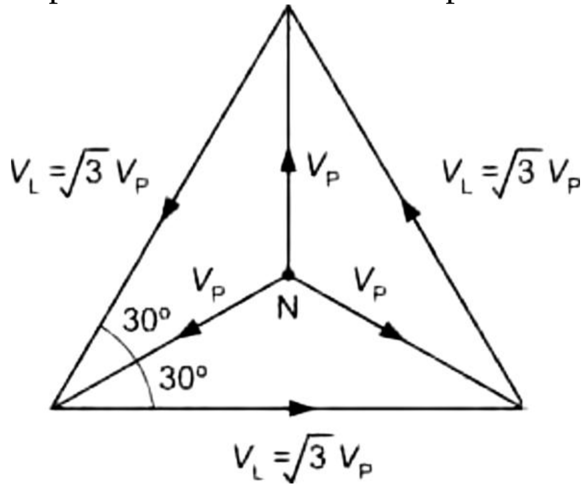

Figure 2.14 Phasor diagram for the three phase star-connected system

An alternative, delta-connected three-phase distribution system is shown in Fig. 2.15 . Once again this shows a three-phase AC generator connected a three-phase load. Here again, the load will ideally be balanced in which case all three load resistances (or impedances) will be identical.

In this arrangement the three line currents are 120° apart and that the line currents lag the phase currents by 30°. Using a similar phasor diagram to that which we used earlier, we can show that:

$$I_L = \sqrt{3}\, I_P$$

It should also be obvious that:

$$V_L = V_P$$

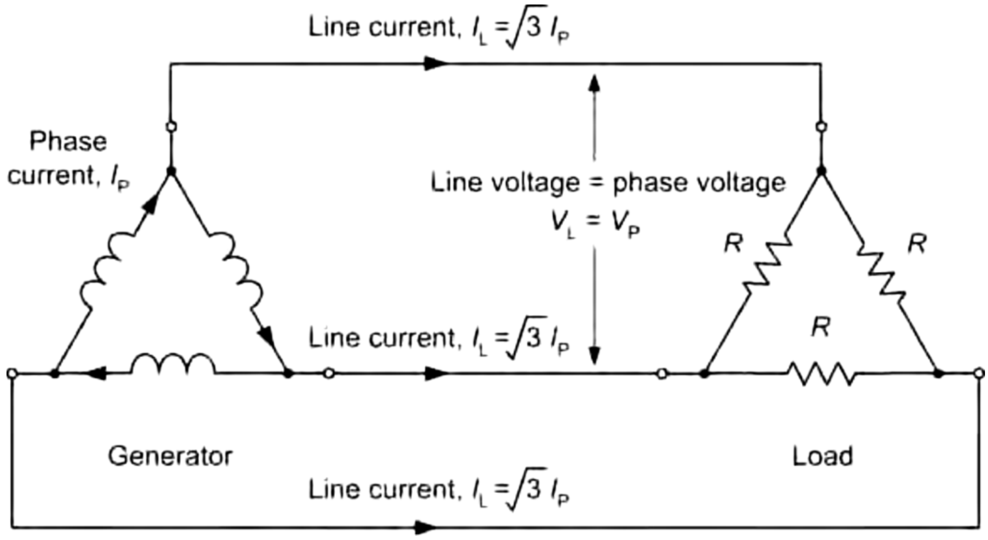

Figure 2.15 A complete delta-connected three-phase distribution system

2.3.1 Power in a three-phase system

In an unbalanced three-phase system the total power will be the sum of the individual phase powers. Hence:

$$P = P_1 + P_2 + P_3$$

Or

$$P = V_1 I_1 \cos \phi_1 + V_2 I_2 \cos \phi_2 + V_3 I_3 \cos \phi_3$$

However, in the balanced condition the power is simply:

$$P = 3V_P I_P \cos \phi$$

where V_P and I_P are the phase voltage and phase current respectively and φ is the phase angle.

Using the relationships that we derived earlier, we can show that, for both the star and delta-connected systems the total power is given by:

$$P = \sqrt{3} V_L I_L \cos \phi$$

Key point

The total power in a three-phase system is the sum of the power present in each of the three phases.

Test your understanding 2.2

1. The phase voltage in a star-connected AC system is 220 V. What will the line voltage be?

2. The phase current in a delta-connected system is 12A. What will the line current be?

3. A three-phase system delivers power to a load consisting of three 12 Ω resistors. If a current of 8 A is supplied to each load, determine the total power supplied by the system.

4. In a three-phase system the line voltage is 105 V and the line current is 8 A. If the power factor is 0.75 determine the total power supplied.

2.4 AC motors

AC motors offer significant advantages over their DC counterparts. AC motors can, in most cases, duplicate the operation of DC motors and they are significantly more reliable. The main reason for this is that the commutator arrangements (i.e. brushes and slip-rings) fitted to DC motors are inherently troublesome. Because the speed of an AC motor is determined by the frequency of the AC supply that is applied it, AC motors are well suited to constant speed applications.

AC motors are generally classified into two types:

- synchronous motors
- induction motors.

The synchronous motor is effectively an AC generator (i.e. an alternator) operated as a motor. In this machine, AC is applied to the stator and DC is applied to the rotor. The induction motor is different in that no source of AC or DC power is connected to the rotor. Of these two types of AC motor, the induction motor is by far the most commonly used.

Key point

The principle of all AC motors is based on the generation of a rotating magnetic field. It is this rotating field that causes the motor's rotor to turn.

2.4.1 Producing a rotating magnetic field

Before we go any further it's important to understand how a rotating magnetic field is produced. Take a look at Fig. 2.15 which shows a three-phase stator to which three-phase AC is applied. The windings are connected in delta configuration, as shown in Fig. 2.61. It is important to note that the two windings for each phase (diametrically opposite to one another) are wound in the same direction.

At any instant the magnetic field generated by one particular phase depends on the current through that phase. If the current is zero, the magnetic field is zero. If the current is a maximum, the magnetic field is a maximum. Since the currents in the three windings are 120° out of phase, the magnetic fields generated will also be 120° out of phase.

Key point

If three windings are placed round a stator frame, and three-phase AC is applied to the windings, the magnetic fields generated in each of the three windings will combine into a magnetic field that rotates. At any given instance, these fields combine together in order to produce a resultant field that which acts on the rotor. The rotor turns because the magnetic field rotates. See Fig 2.17

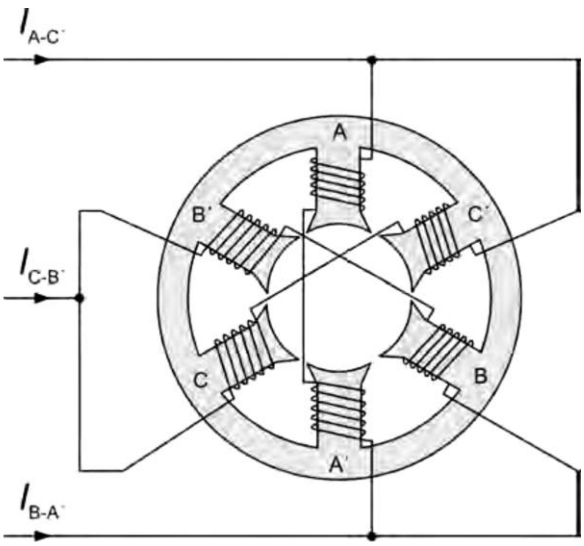

Figure 2.16 Arrangement of the field windings of a three-phase AC motor

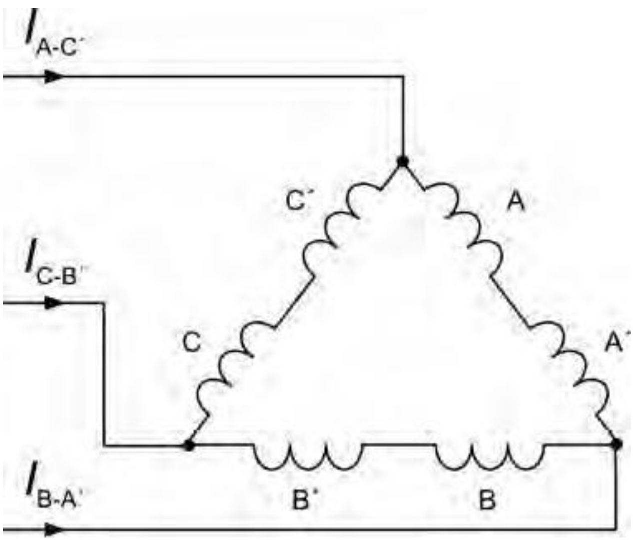

Figure 2.16 AC motor as a delta-connected load

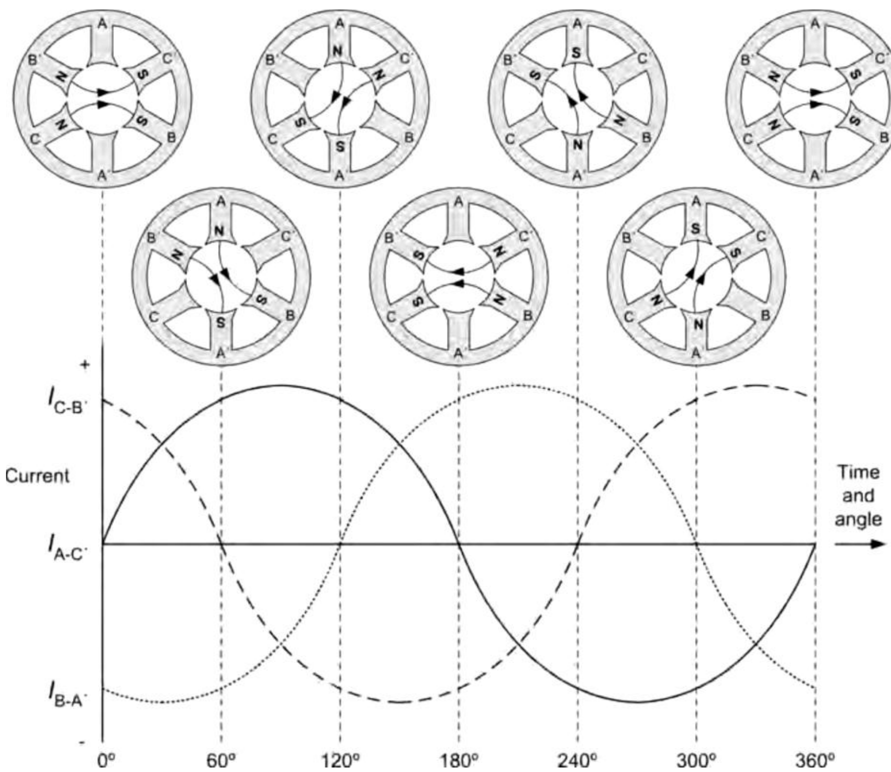

Figure 2.17 AC waveforms and magnetic field direction

2.4.2 Synchronous motors

Key point

The synchronous motor is so called because its rotor is synchronized with the rotating field setup by the stator. Its construction is essentially the same as that of a simple AC generator (alternator).

Key point

Synchronous motors are not self-starting and must be brought up to near synchronous speed before they can continue rotating by themselves. In effect, the rotor becomes ‘frozen’ by virtue of its inability to respond to the changing field!

2.4.3 Three-phase induction motors

Key point

The induction motor is the most commonly used AC motor because of its simplicity, its robust construction and its relatively low cost. These advantages arise from the fact that the rotor of an induction motor is a self-contained component that is not actually electrically connected to an external source of voltage.

Key point

The induction motor has the same stator as the synchronous motor. The rotor is different in that it does not require an external source of power. Current is induced in the rotor by the action of the rotating field cutting through the rotor conductors. This rotor current generates a magnetic field which interacts with the stator field, resulting in a torque being exerted on the rotor and causing it to rotate.

Key point

The rotor of an induction motor rotates at less than synchronous speed, in order that the rotating field can cut through the rotor conductors and induce a current flow in them. This percentage difference between the synchronous speed and the rotor speed is known as slip. Slip varies very little with normal load changes, and the induction motor is therefore considered to be a constant-speed motor.

2.4.5 Single- and two-phase induction motors

Key point

Induction motors are available that are designed for three-phase, two-phase and single-phase operation. The three-phase stator is exactly the same as the three-phase stator of the synchronous motor. The two-phase stator generates a rotating field by having two windings positioned at right angles to each other. If the voltages applied to the two windings are 90 ° out of phase, a rotating field will be generated.

Key point

A synchronous motor uses a single- or three-phase stator to generate a rotating magnetic field, and an electromagnetic rotor that is supplied with DC. The rotor acts like a magnet and is attracted by the rotating stator field. This attraction will exert a torque on the rotor and cause it to rotate with the field.

Key point

Once the rotor is started rotating, however, it will continue to rotate and come up to speed. A field is set up in the rotating rotor that is 90 ° out of phase with the stator field. These two fields together produce a rotating field that keeps the rotor in motion.

2.4.6 Capacitor starting

In an induction motor designed for capacitor starting, the stator consists of the main winding together with a starting winding which is connected in parallel with the main winding and spaced at right angles to it. A phase difference between the current in the two windings is obtained by connecting a capacitor in series with the auxiliary winding. A switch is included solely for the purposes of applying current to the auxiliary winding in order to start the rotor (see Fig. 2.18)

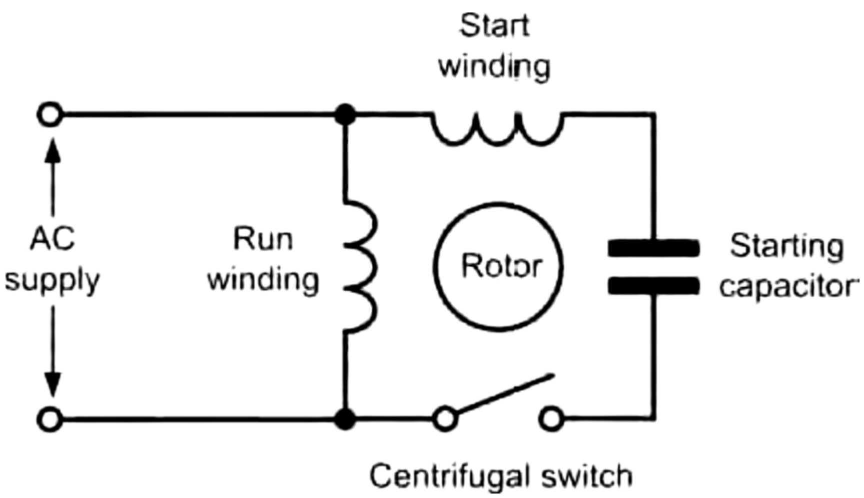

Figure 2.18 Capacitor starting arrangement

On starting, the switch is closed, placing the capacitor in series with the auxiliary winding. The capacitor is of such a value that the auxiliary winding is effectively a resistive–capacitive circuit in which the current leads the line voltage by approximately 45°. The main winding has enough inductance to cause the current to lag the line voltage by approximately 45°. The two field currents are therefore approximately 90° out of phase. Consequently the fields generated are also at an angle of 90°. The result is a revolving field that is sufficient to start the rotor turning.

After a brief period (when the motor is running at a speed which is close to its normal speed) the switch opens and breaks the current flowing in the auxiliary winding. At this point, the motor runs as an ordinary single-phase induction motor. However, since the two-phase induction motor is more efficient than a single-phase motor, it can be desirable to maintain the current in the auxiliary winding so that motor runs as a two-phase induction motor.

Since the current and voltage in an inductor are also 90 ° out of phase, inductor starting is also possible. Once again, a starting winding is added to the stator. If this starting winding is placed in series with an inductor across the same supply as the running winding, the current in the starting winding will be out of phase with the current in the running winding. A rotating magnetic field will therefore be generated, and the rotor will rotate.

Key point

In order to make a single-phase motor selfstarting, a starting winding is added to the stator. If this starting winding is placed in series with a capacitor across the same supply as the running winding, the current in the starting winding will be out of phase with the current in the running winding. A rotating magnetic field will therefore be generated, and the rotor will rotate. Once the rotor comes up to speed, the current in the auxiliary winding can he switched-out, and the motor will continue running as a single-phase motor.

2.4.7 Shaded pole motors

A different method of starting a single-phase induction motor is based on a shaded-pole . In this type of motor, a moving magnetic field is produced by constructing the stator in a particular way. The motor has projecting pole pieces just like DC machines; and part of the pole surface is surrounded by a copper strap or shading coil .

As the magnetic field in the core builds, the field flows effortlessly through the unshaded segment. This field is coupled into the shading coil which effectively constitutes a short-circuited loop. A large current momentarily flows in this loop and an opposing field is generated as a consequence. The result is simply that the unshaded segment initially experiences a larger magnetic field than does the shaded segment. At some later time, the fields in the two segments become equal. Later still, as the magnetic field in the unshaded segment declines, the field in the shaded segment strengthens. This is illustrated in Fig. 2.19.

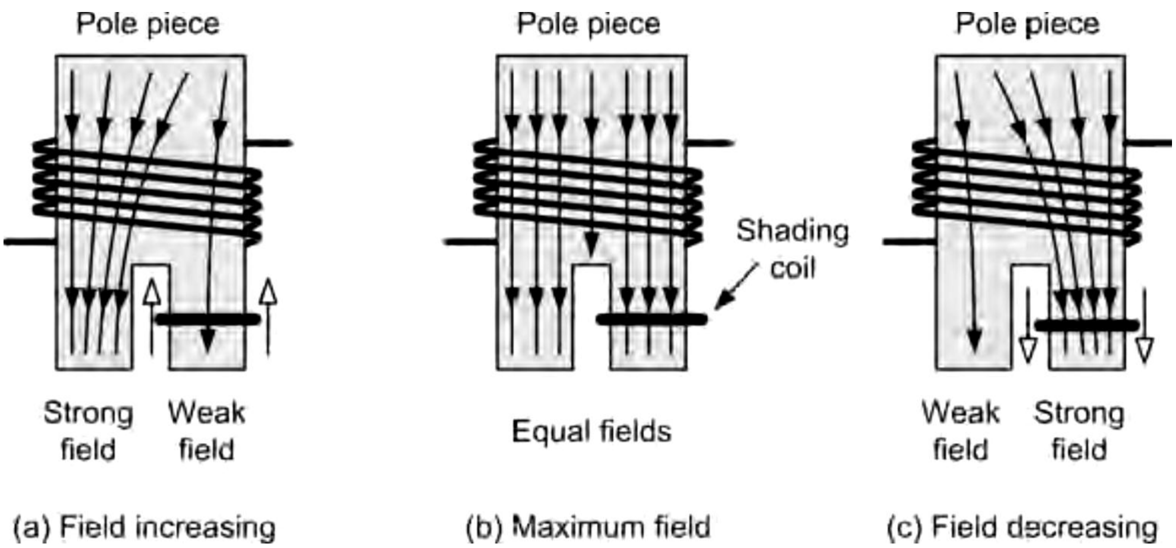

Figure 2.19 Action of a shaded pole

Key point

In the shaded pole induction motor, a section of each pole face in the stator is shorted out by a metal strap. This has the effect of moving the magnetic field back and forth across the pole face. The moving magnetic field has the same effect as a rotating field, and the motor is self-starting when switched on.

Test your understanding 2.3

1. Explain the difference between synchronous AC motors and induction motors.

2. Explain the main disadvantage of the synchronous motor.

3. An induction motor has four poles and is operated from a 400 Hz AC supply. If the motor operates with a slip of 1.8% determine the speed of the output rotor.

4. An induction motor has four poles and is operated from a 60 Hz AC supply. If the rotor speed is 1675 r.p.m. determine the percentage slip.

5. Explain why a single-phase induction motor requires a means of starting.

2.5 Practical aircraft generating systems

Generators are a primary source of power in an aircraft and can either produce direct or alternating current (DC or AC) as required. They are driven by a belt drive (in smaller aircraft), or engine/APU accessory gearbox in larger aircraft. Generators will have sufficient output to supply all specified loads and charge the battery(s). Most avionic equipment requires a regulated and stable power supply depending on its function, e.g. in the case of lighting, it would be inconvenient if the intensity of lighting varied with engine speed. Generator output is affected by internal heat and this has to be dissipated.

2.5.1 DC generators

DC generators are less common on modern aircraft due to their low power-to-weight ratio, poor performance at low r.p.m. and high servicing costs. The latter is due to the need for inspection and servicing of brushes and commutators since they have irregular surfaces/contact area and conduct the entire load current. Carbon brushes are porous and will absorb substances including moisture; this provides an amount of inherent lubrication. At altitude, the atmosphere is dryer and this leads to higher brush wear. Without any lubrication, arcing occurs and static charges build up; brush erosion is accelerated. Additives can be incorporated into the brushes that deposit a lubricating fi lm on the commutator; this needs time to build up a sufficient protection; brushes need to be run in for several hours before the protective layer forms (this is often mistaken for contamination). The alternative is an in-built lubrication that is consumed as part of the natural brush wear, i.e. no fi lm is deposited.

Key maintenance point

Automotive style alternators are normally installed on general aviation and light aircraft to overcome the shortfalls of DC generators. Larger aircraft use brushless AC generators

2.5.2 Alternators

Automotive style alternators comprise a rotor, stator and rectifier pack. The rotor contains the field coil arranged in six sections around the shaft. Each section forms a pole piece that is supplied via slip-rings and brushes. The alternator has no residual magnetism; its field has to be excited by a DC supply (e.g. the battery). When energised, the rotor’s pole pieces produce north and south poles. As these poles are rotated they induce currents in the stator windings; these are wound at 120° and this produces three phase AC. The AC output is fed to a diode rectifier pack comprising six high-current diodes; see Fig. 2.20 which produces a DC output. This has to be regulated before connecting to the various aircraft systems. Voltage regulators used with alternators on general aviation aircraft can be electromechanical or electronic. There are two types of electromechanical regulators: sensing coil with contacts and carbon-pile. Modern solid-state electronic regulators are more reliable as they use no mechanical parts.

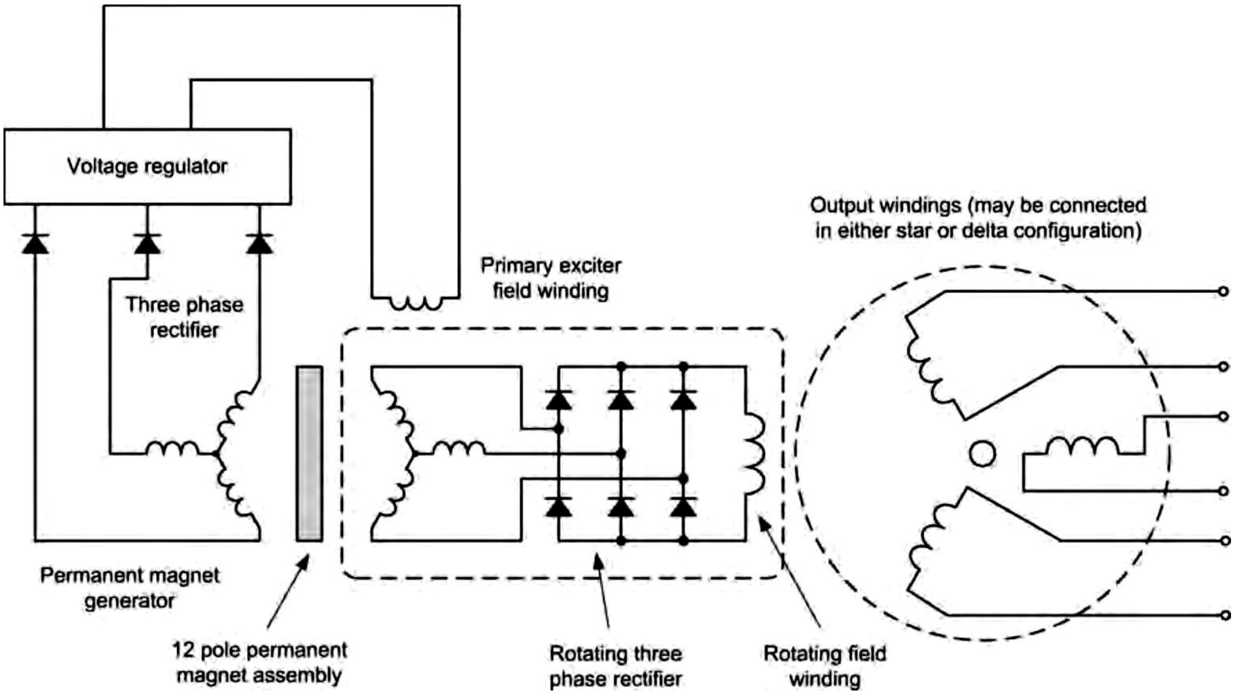

Figure 2.20 A practical brushless AC generator arrangement

The alternators previously described rely on sliprings and brushes, albeit with reduced current loading. Slip-rings and brushes require maintenance in the workshop thereby incurring an associated cost burden. The brushless generator is a more complex device but has significantly increased reliability coupled with reduced maintenance requirements. A schematic diagram for the brushless generator is shown in Fig. 2.20; the device can be divided into three main sections

- permanent magnet generator
- rotating field
- three-phase output.

The AC generator uses a brushless arrangement based on a rotating rectifier and **permanent magnet generator** (PMG). The output of the PMG rectifier is fed to the voltage regulator which provides current for the primary exciter field winding. The primary exciter field induces current into a three-phase rotor winding. The output of this winding is fed to the shaft-mounted rectifier diodes which produce a pulsating DC output which is fed to the rotating field winding. It is important to note that the excitation system is an integral part of the rotor and that there is no direct electrical connection between the stator and rotor.

The output of the main three-phase generator is supplied via current transformers (one for each phase) that monitor the load current in each line. An additional current transformer can also be present in the neutral line to detect an out-of-balance condition (when the load is unbalanced an appreciable current will flow in the generator's neutral connection).

The generator output is fed to the various aircraft systems and a solid-state regulator. This rectifies the output and sends a regulated direct current to the stator exciter field of the PMG. The regulator maintains the output of the generator at 115 V AC and is normally contained within a generator control unit (GCU);

Although the regulator controls the output voltage of the generator, its frequency will vary depending on the speed of shaft rotation. Variable frequency power supplies (sometimes called frequency wild) are acceptable for resistive loads, e.g. de-icing, but they are not suitable for many induction motor loads that need to run at constant speed, e.g. fuel pumps and gyroscopic instruments. Furthermore, certain loads are designed for optimum efficiency at the specified frequency of 400Hz, e.g. cooling fans. Some larger multi-engine aircraft operate the generators in parallel; it is essential that each generator is operating at the same frequency. Constant frequency can be achieved in one of two ways: controlling the shaft speed by electromechanical methods using a constant speed drive (CSD) or by controlling the generator output frequency electronically (variable speed constant frequency : VSCF) .

Key point

A three-phase AC generator can be made brushless by incorporating an integral excitation system in which the field current is derived from a rotor-mounted rectifier arrangement. In this type of generator the coupling is entirely magnetic and no brushes and slip-rings are required.

2.5.3 Constant speed drive/integrated drive generator

The CSD is an electromechanical device installed on each engine. The input shaft is connected to the engine gearbox; the output shaft is connected to the generator. The CSD is based on a variable ratio drive employing a series of hydraulic pumps and differential gears. CSDs can be disconnected from the engine via a clutch, either manually or automatically. Note that it is only possible to reconnect the clutch on the ground. Modern commercial aircraft employ a combined CSD and brushless AC generator, in one item – the integrated drive generator (IDG). Typical characteristics are a variable input speed of 4500/9000 r.p.m. and a constant output speed of $12{,}000 \pm 150 r.p.m.$ The IDG on a large commercial aircraft is oil-cooled and produces a 115/200V 400Hz three-phase..

VSCF systems are more reliable compared with constant speed drive and integrated drive generators since there are fewer moving parts. The VSCF system's moving parts consist of the generator's rotor and an oil pump used for cooling. The VSCF can be used for both primary and secondary power supplies; outputs of 110 kVA are achievable. Enabling technology for VSCF are the power transistors and diodes capable of handling currents in excess of 500 A. These diodes and transistors form the core of the rectifier and conversion circuits of the

GCCU. The VSCF contains an oil pump mounted on the generator shaft that circulates oil through the system; this oil is passed through a heat exchanger. Oil temperatures and pressures are closely monitored; warnings are given to the crew in the event of malfunctions. Oil level can be checked during ground servicing through a sight glass.

2.6 Multiple choice questions

1. The slip-rings in an AC generator provide a means of:
   (a) connecting an external circuit to a rotating armature winding
   (b) supporting a rotating armature without the need for bearings
   (c) periodically reversing the current produced by an armature winding.

2. Decreasing the current in the field coil of a DC generator will:
   (a) decrease the output voltage
   (b) increase the output voltage
   (c) increase the output frequency.

3. The rotor of an AC induction motor consists of:
   (a) a laminated iron core inside a ‘ squirrel cage ’ made from copper or aluminum
   (b) a series of coil windings on a laminated iron core with connections via slip-rings
   (c) a single copper loop which rotates inside the field created by a permanent magnet.

4. The slip speed of an AC induction motor is the difference between:
   (a) the synchronous speed and the rotor speed
   (b) the frequency of the supply and the rotor speed
   (c) the maximum speed and the minimum speed.
5. When compared with three-phase induction motors, single-phase induction motors:
   (a) are not inherently ‘ self-starting ’
   (b) have more complicated stator windings
   (c) are significantly more efficient.

6. A three-phase induction motor has three pairs of poles and is operated from a 60 Hz supply. Which one of the following gives the motor’s synchronous speed?
   (a) 1200r.p.m.

(b) 1800r.p.m.
(c) 3600r.p.m.

7. In a star-connected three-phase system, the line voltage is found to be 200V. Which one of the following gives the approximate value of phase voltage?
(a) 67 V
(b) 115 V
(c) 346 V.

8. A single-phase AC generator has twelve poles and it runs at 600r.p.m. Which one of the following gives the output frequency of the generator?
(a) 50 Hz
(b) 60 Hz
(c) 120 Hz.

9. In a balanced star-connected three-phase system the line current is 2 A and the line voltage is 200 V. If the power factor is 0.75 which one of the following gives the total power in the load?
(a) 300 W
(b) 520 W
(c) 900 W.

10. The commutator in a DC generator is used to:
(a) provide a means of connecting an external field current supply
(b) periodically reverse the connections to the rotating coil winding
(c) disconnect the coil winding when the induced current reaches a maximum value.

11. The brushes fitted to a DC motor/generator should have:
(a) low coefficient of friction and low contact resistance
(b) high coefficient of friction and low contact resistance
(c) low coefficient of friction and high content resistance.

12. Self-excited generators derive their field current from:
(a) the current produced by the armature
(b) a separate field current supply
(c) an external power source.

13. In a shunt-wound generator:
(a) none of the armature current flows through the field
(b) some of the armature current flows through the field
(c) all of the armature current flows through the field.

14. When combined with a CSD, a brushless threephase AC generator is often referred to as:
(a) a compound generator
(b) a ‘ frequency wild ’ generator
(c) an IDG.

15. An out-of-balance condition in an AC threephase system can be detected by means of:
(a) voltage sensors connected across each output line
(b) a dedicated field coil monitoring circuit
(c) a current transformer connected in the neutral line.

Chapter 3 : Power supplies

Lecture 6

Topics

3.1 Regulators

3.2 External power

3.3 Inverters

3.4 Transformer rectifier units

3.5 Transformers

3.6 Auxiliary power unit (APU)

3.7 Emergency power

3.8 Multiple choice questions

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Aircraft electrical power can be derived from a variety of sources; these are categorized as either primary or secondary sources. Batteries and generators are primary sources of electrical power; inverters and transformer rectifier units (TRU) are secondary sources of power. This power is either in the form of direct or alternating current depending on system requirements. In addition to onboard equipment, most aircraft have the facility to be connected to an external power source during servicing or maintenance. The basic power source found on most aircraft is the battery, delivering direct current (DC). Generators can supply either direct or alternating current; the outputs of generators need to be regulated. Alternating current generators are also referred to as alternators.

Inverters are used to convert DC (usually from the battery) into alternating current (AC). Transformer rectifier units (TRU) convert AC into DC; these are often used to charge batteries from AC generators. In some installations transformers are used to convert AC into AC, typically for stepping down from 115 to 26 V AC. An auxiliary power unit (APU) is normally used for starting the aircraft's main engines via the air distribution system. While the aircraft is on the ground, the APU can also provide electrical power. In the event of generator failure(s), continuous power can be provided by a ram air turbine (RAT). In this lecture, we review the various sources of electrical power used on aircraft and their typical applications.

3.1 Regulators

We know from basic theory that a generator's output will vary depending on the input shaft speed. A means of regulating the generator's output is therefore required.

3.1.1 Vibrating contact regulator

This device comprises voltage and current regulators as shown in Fig. 3.1 . They are used on small general aviation (GA) aircraft that have relatively low generator power outputs. When the engine starts, the alternator output voltage builds up rapidly to the nominal aircraft level (either 14 or 28 V DC). Contacts of both regulators remain closed to allow current to flow into the field windings. When the generator output voltage increases beyond 14/28 V, the voltage coil contacts open and this introduces the resistor into the field windings, thereby reducing the field excitation current, and subsequently reduces the generator output. Once the output voltage drops to below 14/28 V, the contacts close (by a spring mechanism) and the resistor is bypassed, allowing full excitation current back into the field. The on/off cycle repeats between 50 and 200 times per second, or 50–200 Hz. This process regulates the generator output to a mean level, typically $14 \pm\ 0.5\, V\ (or\ 28 \pm\ 1\ volt)$.

Current regulation is achieved in a similar way, i.e. by controlling the field current. When loads are high, the voltage output may be insufficient to open the contacts. The result is that the output will continue to increase until the maximum rated current is reached. At this point, the current regulator contacts open and the resistor are connected into the field windings.

The accuracy of this type of regulation depends on the resistor value and spring tensions. In the event of high rotor speed and low electrical load on the generator, the output could exceed the specified system voltage despite the field being supplied via the resistor. In this event, the contact is pulled to ground, thereby reducing the output to below the regulated mean level. Although simple, this type of regulator has the disadvantages of contact wear; a typical vibrating contact regulator product is shown in Fig. 3.2.

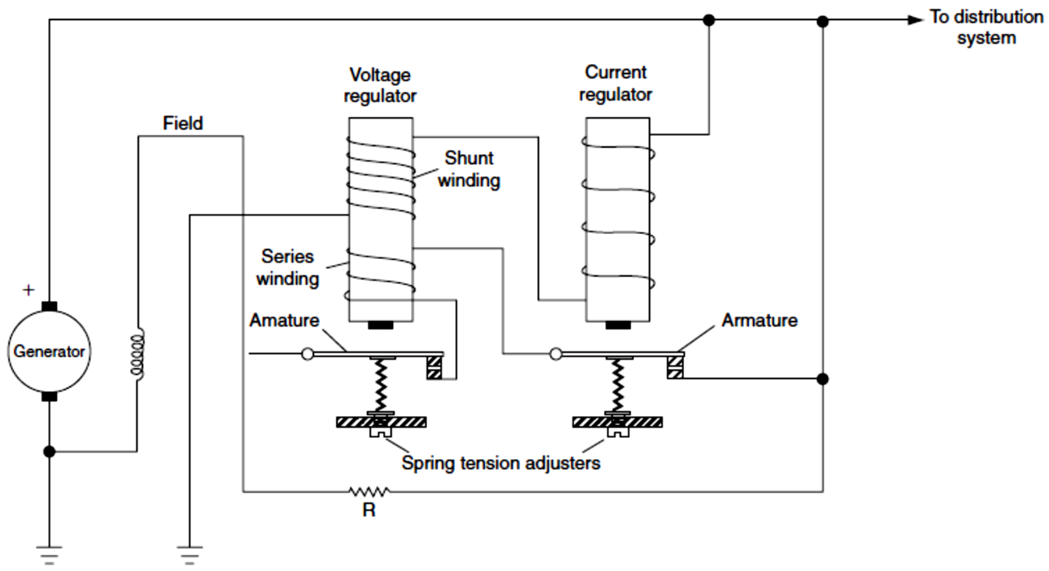


Figure 3.1 Vibrating contact regulator schematic

Key maintenance point

The accuracy of the vibrating contact regular to depends on the resistor value and spring tension.

Figure 3.2 Vibrating contact regulator overview

3.1.2 Carbon-pile regulator

Another type of electromechanical regulator is the carbon-pile device. This type of regulator is used in generator systems with outputs in excess of 50A and provides smoother regulation compared with the vibrating contact regulator. Carbon-pile regulators consists of a variable resistance in series with the generator's shunt wound field coil. The variable resistance is achieved with a stack (or pile) of carbon discs (washers). These are retained by a ceramic rube that keeps the discs aligned. Figure 3.3 shows the main features of the regulator in cross-section. The surface of each disc is relatively rough; applying pressure to the discs creates more surface contact, thereby reducing the resistance of the pile. When pressure is reduced, the reverse process happens, and the resistance through the pile increases. Pressure is applied to the pile by a spring plate. This compression is opposed by the action of an electromagnet connected to the generator output; the strength of the electromagnet's flux varies in proportion with generator output voltage.

Higher generator output increases the current in the electromagnet; this attracts the steel centre of the spring, which reduces compression on the pile, thereby increasing its resistance. Less field current reduces the generator output voltage; the current in the voltage coil reduces electromagnetic effect and the spring compresses the pile, reducing its resistance. The varying force applied by the electromagnet and spring thereby controls the pile's resistance to control field current and maintains a constant generator output voltage. The regulator is contained within a cylinder (typically three inches in diameter and six inches in length) with cooling fins. Functions of each component are as follows:

- Compression screw: the means of setting up compression on the pile and compensating for erosion of the pile during its life.
- Spring plate and armature: this compresses the pile to its minimum resistance position.
- Voltage coil: contains a large number of turns of copper wire and, with the core screw, forms an electromagnet when connected across the generator output.
- Magnet core: concentrates the coil flux; it is also used for voltage adjustment during servicing.
- Bi-metallic washers: providing temperature compensation.

Figure 3.4 shows the carbon-pile regulator connected into the generator's regulating circuit. The ballast resistor has a low-temperature coefficient and minimizes the effects of temperature on the voltage coil. The trimmer resistors (in series with the ballast resistor) allow the generator output voltage to be trimmed on the aircraft. The boost resistor is normally shorted out; if the switch is opened it allows a slight increase in generator output to meet short-term increases in loading. This is achieved by temporarily reducing the current through the voltage coil. The boost resistor can either be located in the regulator and/or at a remote location for easy access during maintenance.

Key point

Higher generator output increases the current in the carbon pile regulator, which reduces compression on the pile thereby increasing its resistance.

Test your understanding 3.1

Explain the purpose of the carbon pile regulator voltage coil.

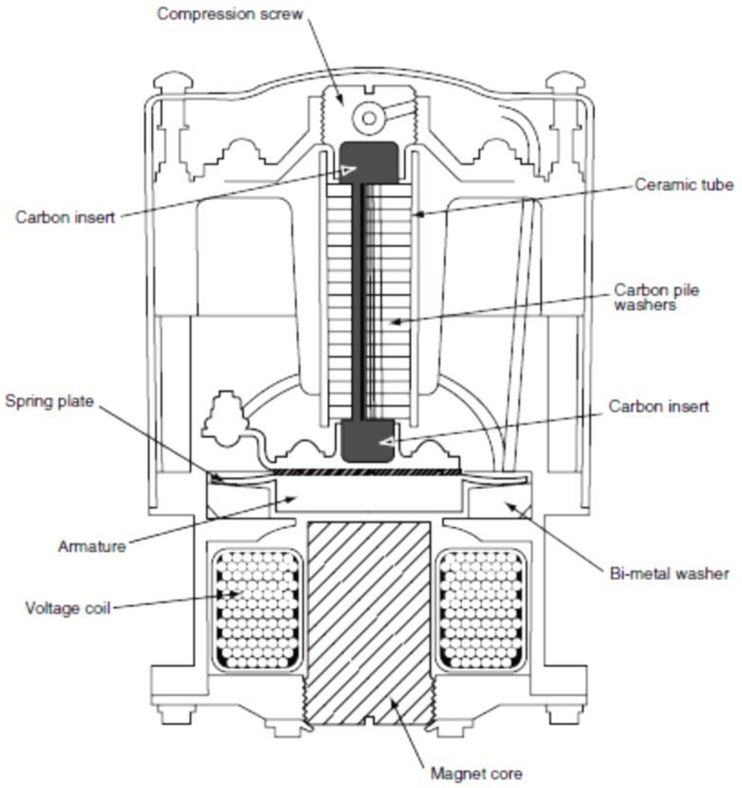


Figure 3.3 Carbon-pile regulator – cross section

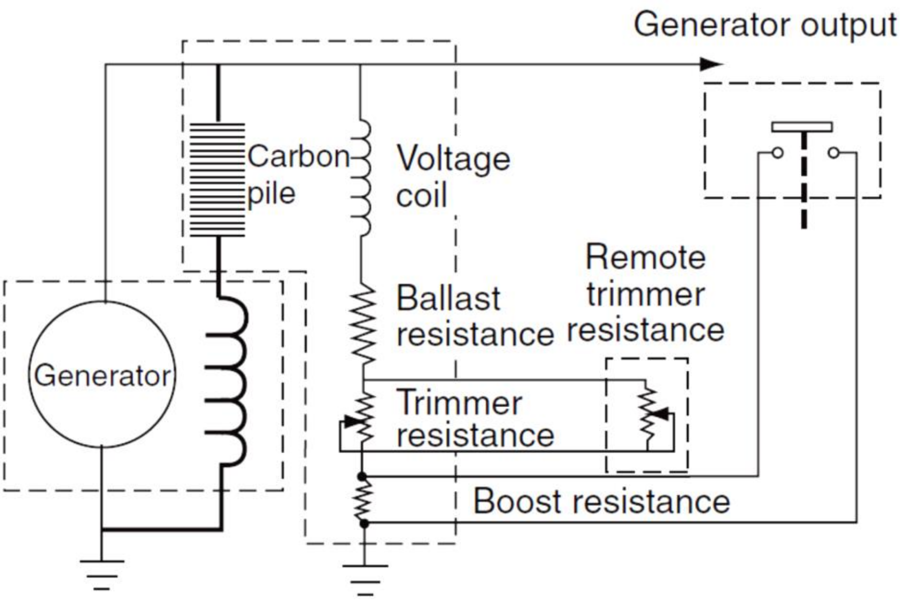


Figure 3.4 Carbon-pile regulator – schematic

3.1.3 Electronic voltage regulator

There are many types and configurations of electronic voltage regulators. A representative type is illustrated in Fig. 3.5. The alternator master switch used in AC systems energizes the field relay and applies current to the base of TR2 and the resistor network of R1, R2 , RV1 . This network, together with the Zener diode (Z) is used to establish the nominal operating voltage. Current flows through the alternator's field coil via transistors TR2 and TR3, allowing the generator's output to increase. When the output reaches its specified value (14 or 28 V DC depending on the installation) Zener diode Z conducts which turns on transistor TR1, shorting out transistor TR2 and TR3. The generator voltage falls and Zener diode Z stops conducting, thereby turning of transistor TR1. This turns transistors TR2 and TR3 back on, allowing the generator output to increase again. This operation is repeated many times per second as with the vibrating contact regulator; the difference being that electronic circuits have no moving parts and do not suffer from arcing across contacts. Diode D1 provides protection against the back e.m.f. induced in the field each time TR3 is switched. The trimming resistor RV1 can be used to adjust the nominal voltage output of the regulator.

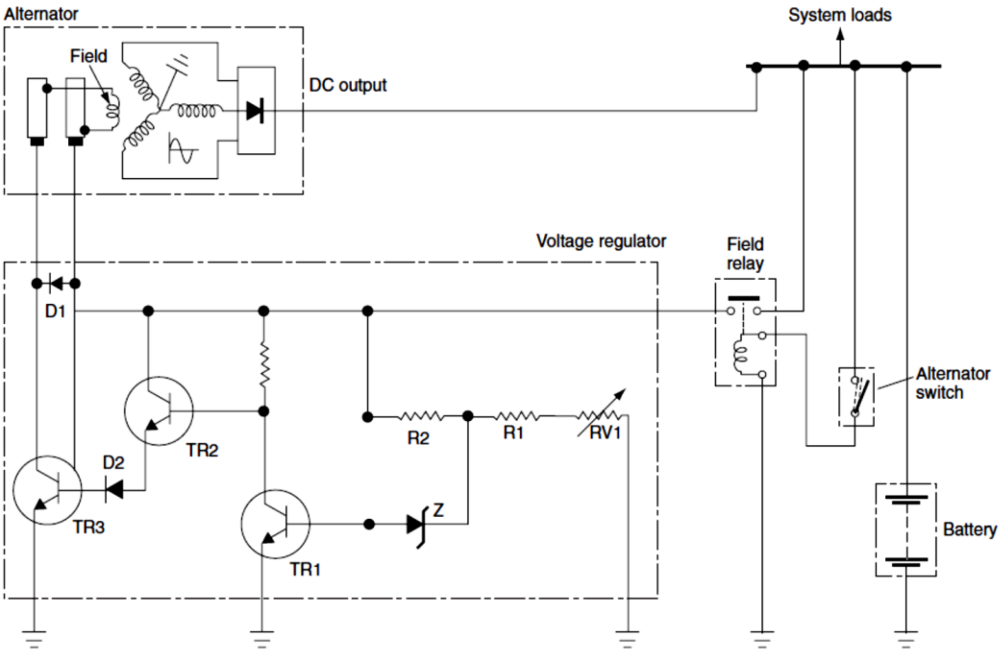


Figure 3.5 Electronic voltage regulator

3.2 External power

In addition to the onboard equipment that has been described, most aircraft have the facility to be connected to an external power source during servicing or maintenance. This allows systems to be operated without having to start the engines or use the battery. The external ground power can either be from a battery pack, a ground power unit (that has a diesel engine and generator) or from industrial power converters connected to the national grid. More details of external power and how it is used are given in the next lectures.

3.2.1 Power conversion

Equipment used on aircraft to provide secondary power supplies include:

- inverters
- transformer rectifier units (TRU)
- transformers.

3.3 Inverters

Inverters are used to convert direct current into alternating current. The input is typically from the battery; the output can be a low voltage (26 V AC) for use in instruments, or high voltage (115 V AC single or three phase) for driving loads such as pumps. Older rotary inverter technology uses a DC motor to drive an AC generator, see Fig. 3.6. A typical rotary inverter has a four-pole compound DC motor driving a star-wound AC generator. The outputs can be single- or threephase; 26 V AC, or 115 V AC. The desired output frequency of 400 Hz is determined by the DC input voltage. Various regulation methods are employed, e.g. a trimming resistor (Rv) connected in series with the DC motor field sets the correct speed when connected to the 14 or 28 V DC supply.

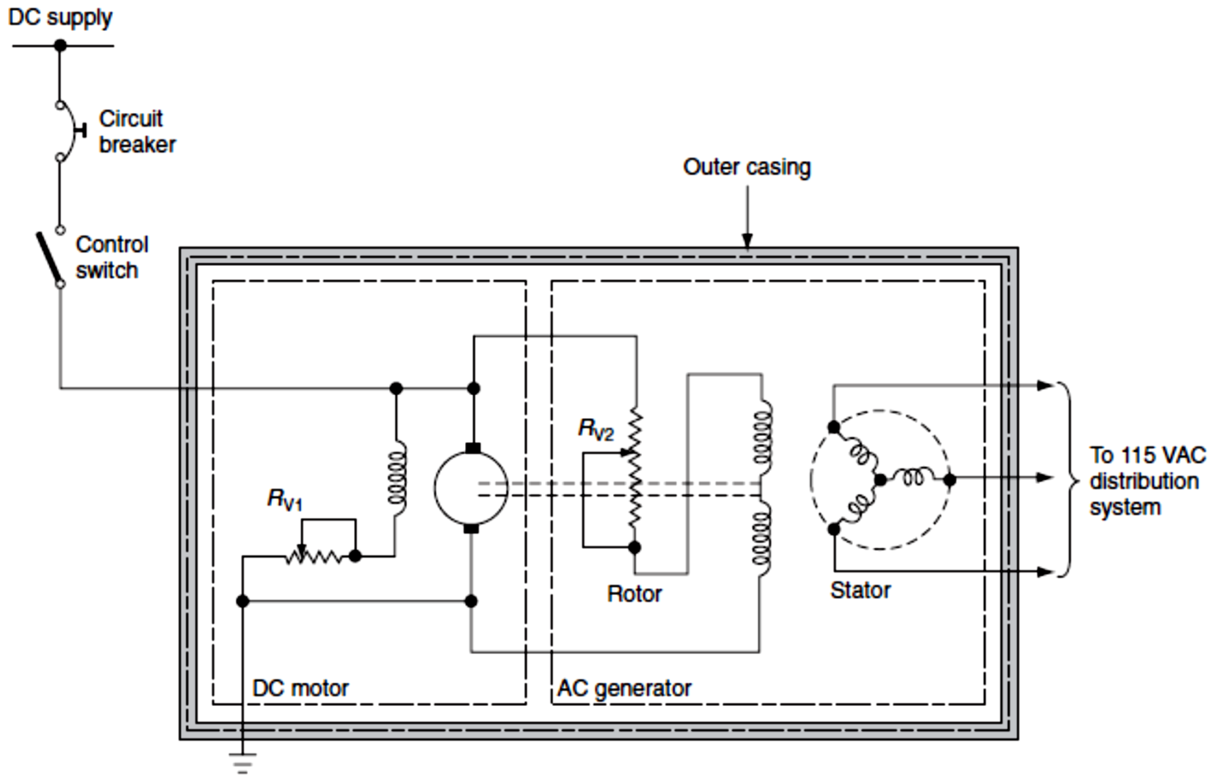


Figure 3.6 Rotary inverter schematic

Modern aircraft equipment is based on the static inverter; it is solid state, i.e. it has no moving parts (see Fig. 3.7). The DC power supply is connected to an oscillator; this produces a low-voltage 400 Hz output. This output is stepped up to the desired AC output voltage via a transformer.

The static inverter can either be used as the sole source of AC power or to supply specific equipment in the event that the main generator has failed. Alternatively they are used to provide power for passenger use, e.g. lap-top computers. The DC input voltage is applied to an oscillator that produces a sinusoidal output voltage. This output is connected to a transformer that provides the required output voltage. Frequency and voltage controls are usually integrated within the static inverter; it therefore has no external means of adjustment.

A typical inverter used on a large commercial aircraft can produce 1 kVA. Static inverters are located in an electrical equipment bay; a remote on/off switch in the flight compartment is used to isolate the inverter if required. Figure 3.8

shows an inverter installation in a general aviation aircraft. This particular inverter has the following features:

Input:	28 V DC	39 A
Outputs:	115 V AC	6.5 A
	26 V AC	5.8 A
	400 Hz 750 VA continuous	
Power factor:	0.8 to 0.95	
Weight:	15.6 lb	
Dimensions:	270 × 220 × 100 mm	

Key point

The desired output frequency of a rotary inverter is determined by the DC input voltage.

Key point

Inverters are used to convert direct current into alternating current.

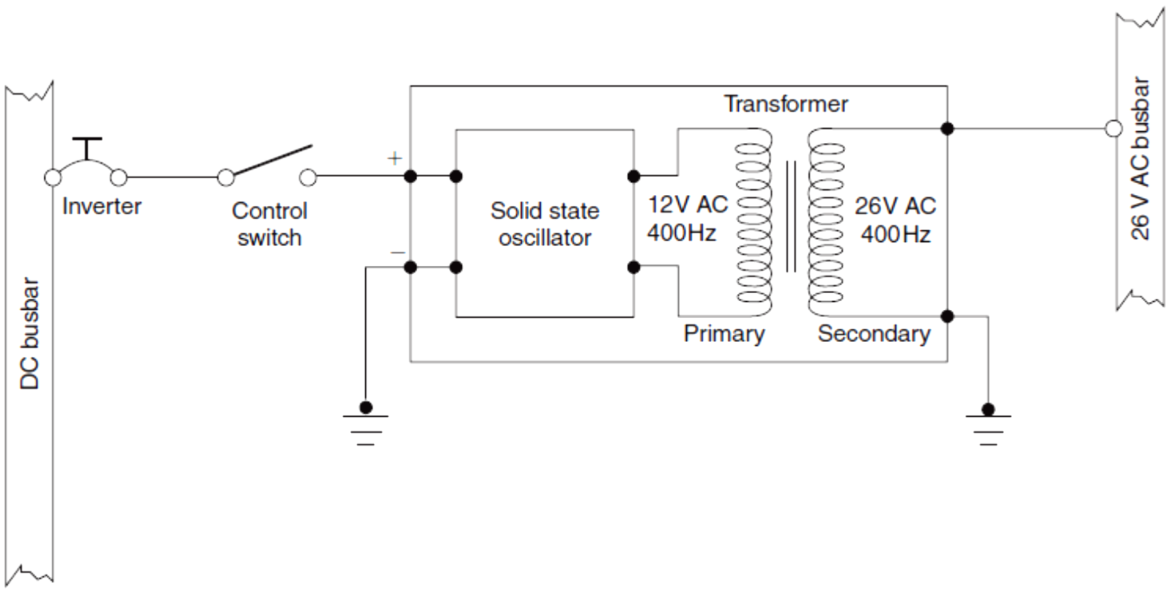


Figure 3.7 Static inverter schematic

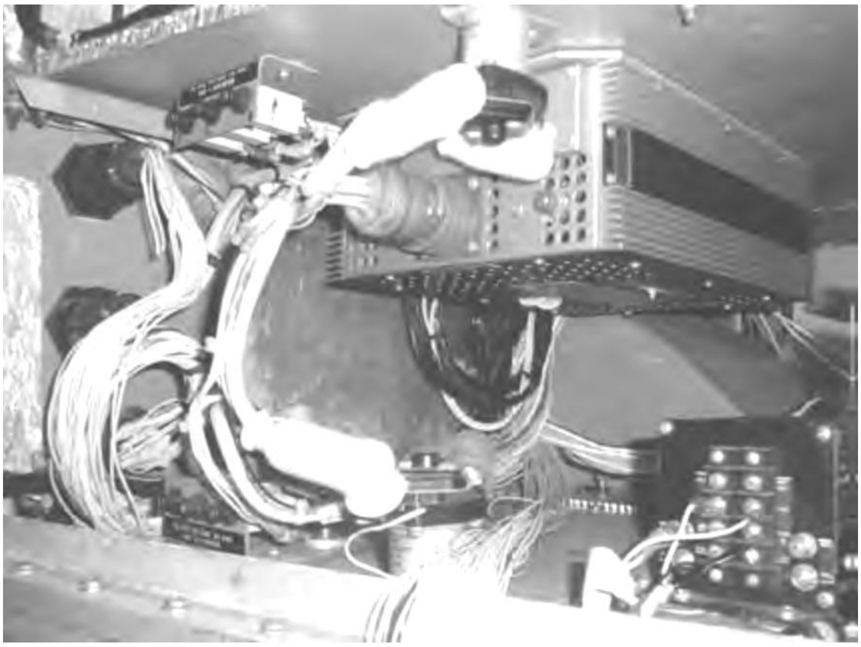


Figure 3.8 Static inverter installation

3.4 Transformer rectifier units

Transformer rectifier units (TRU) convert AC into DC; these are often used to charge batteries from AC generators. A schematic diagram for a TRU is shown in Fig. 3.9. The three-phase 115/200 V 400 Hz input is connected to star-wound primary windings of a transformer. The dual secondary windings are wound in star and delta configuration. Outputs from each of the secondary windings are rectified and connected to the main output terminals. A series (shunt) resistor is used to derive the current output of the TRU. Overheat warnings are provided by locating thermal switches at key points within the TRU.

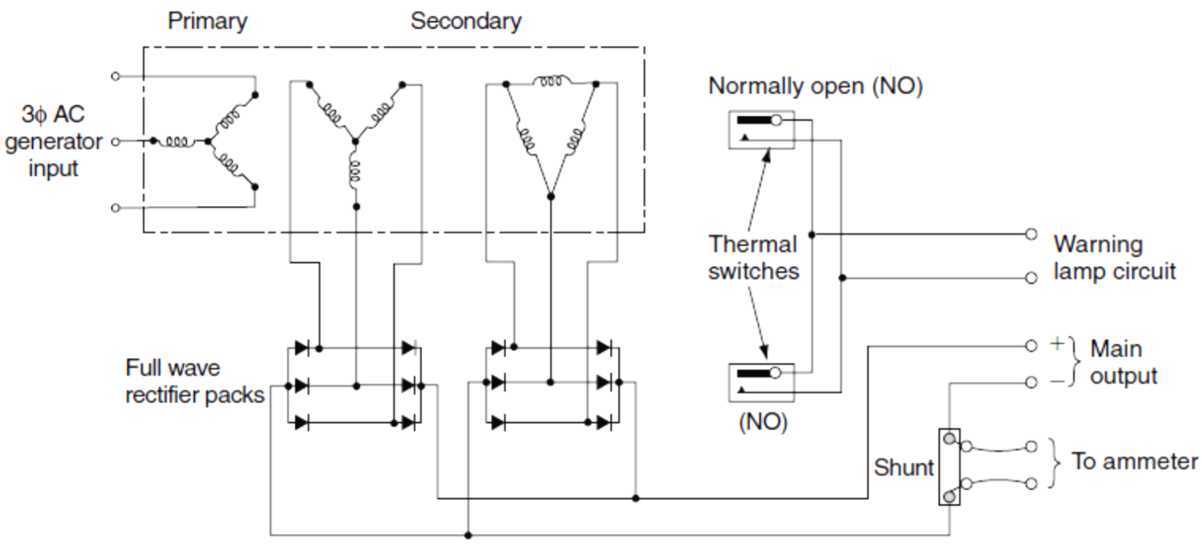


Figure 3.9 Transformer rectifier unit (TRU) schematic

Test your understanding 3.2

Explain the applications of inverters and transformer rectifier units (TRUs).

3.5 Transformers

Transformers are devices that convert (or transfer) electrical energy from one circuit to another through inductively coupled electrical conductors. The transformer used as a power supply source can be considered as having an input (the primary conductors, or windings) and output (the secondary conductors, or windings). A changing current in the primary windings creates a changing magnetic field; this magnetic field induces a changing voltage in the secondary windings. By connecting a load in series with the secondary windings, current flows in the transformer. The output voltage of the transformer (secondary windings) is determined by the input voltage on the primary and ratio of turns on the primary and secondary windings. In practical applications, we convert high voltages into low voltages or vice versa; this conversion is termed step down or step up. (More transformer theory is given in Chapter 1.)

Circuits needing only small step-up/down ratios employ auto-transformers. These are formed from single winding, tapped in a specific way to form primary and secondary windings. Referring to Fig. 3.10(a), when an alternating voltage is applied to the primary (P1 –P2) the magnetic field produces links with all turns on the windings and an EMF is induced in each turn. The output voltage is developed across the secondary turns (S1 –S2) which can be connected for either step-up or step-down ratios. In practice, auto-transformers are smaller in size and weight than conventional transformers. Their disadvantage is that, since the primary and secondary windings are physically connected, a breakdown in insulation places the full primary e.m.f. onto the secondary winding.

The arrangement for a three-phase auto-transformer is shown in Fig. 3.10(b). This is a star - connected step-up configuration. Primary input voltage is the 200 V AC from the aircraft alternator; multiple outputs are derived from the secondary tappings: 270, 320, 410 and 480 V AC. Applications for this type of arrangement include windscreen heating.

Test your understanding 3.3

Explain the difference between conventional and auto-transformers.

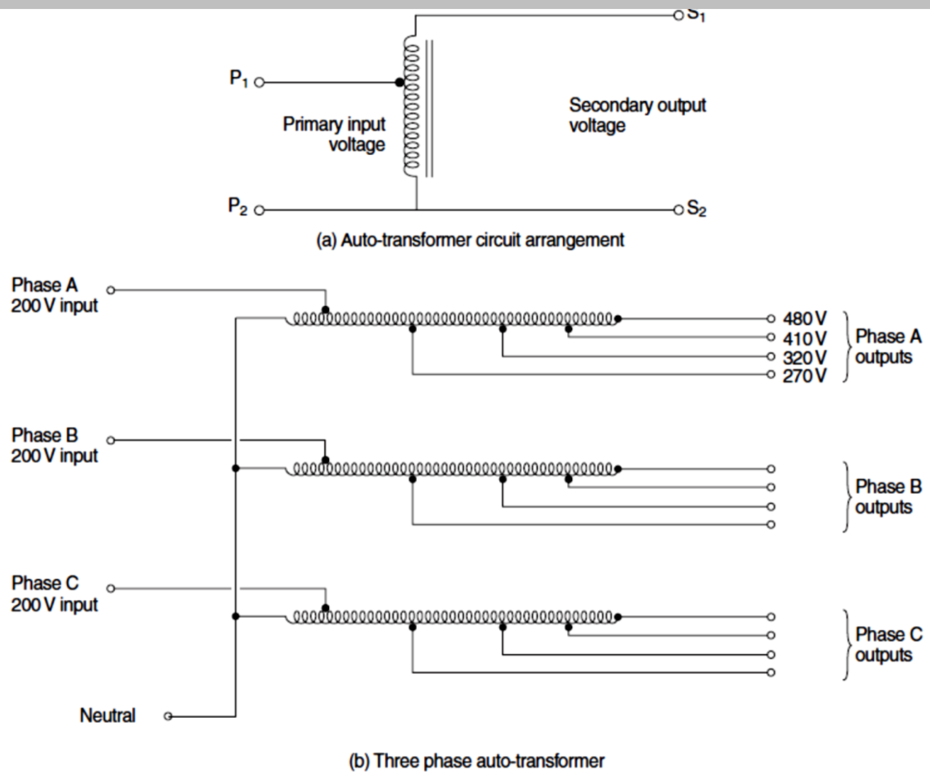


Figure 3.10 (a) Autotransformer principles; (b) three-phase autotransformer

3.6 Auxiliary power unit (APU)

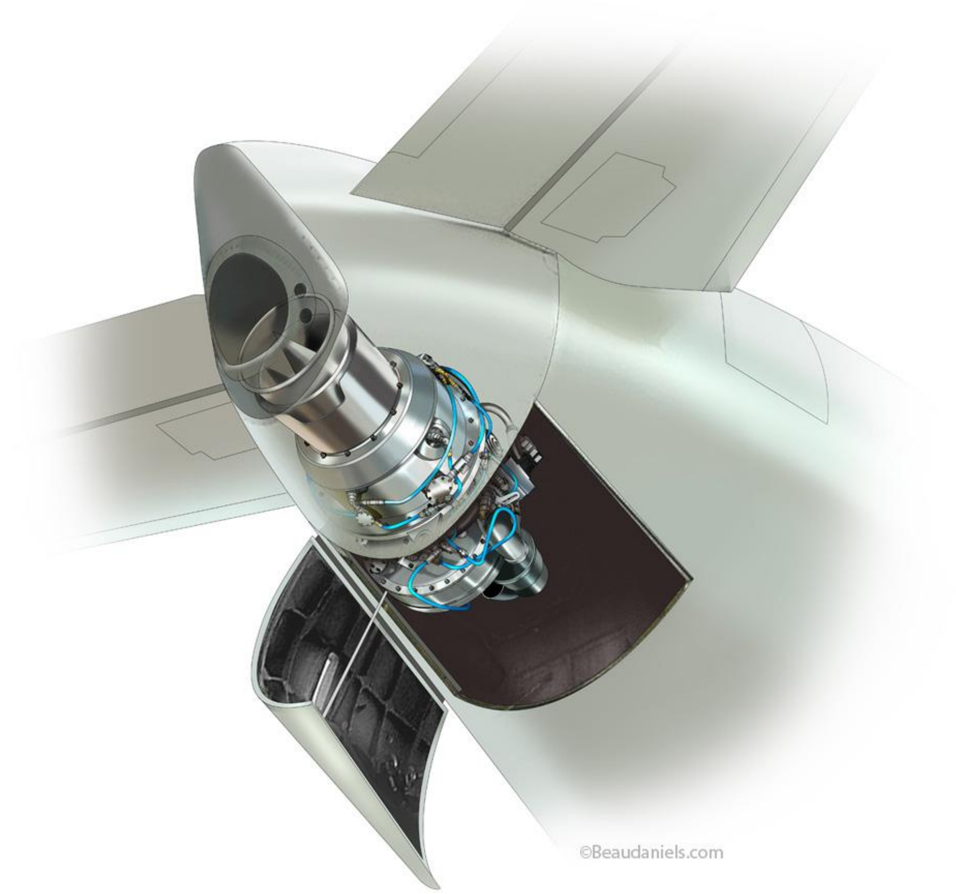
An APU is a relatively small gas turbine engine, typically located in the tail cone of the aircraft. The APU is a two-stage centrifugal compressor with a single turbine. Bleed air is tapped from the compressor and connected into the aircraft's air distribution system. Once started the APU runs at constant speed, i.e. there is no throttle control. The APU shuts down automatically in the event of malfunction.

APUs are used for starting the aircraft's main engines via the air distribution system. While the aircraft is on the ground, the APU can also provide:

- electrical power
- hydraulic pressure
- air conditioning.

The APU itself is started from the main aircraft battery. In some aircraft, the APU can also provide electrical power in the air in the event of main generator failure. The Boeing 787 aircraft has more electrical systems and less pneumatic systems than aircraft it is replacing. In this case the APU delivers only electrical power.

APUs fitted to extended-range twin-engine operations aircraft (ETOPS) are critical to the continued safe flight of the aircraft since they supply electrical power, hydraulic pressure and an air supply in the event of a failed main engine generator or engine. Some APUs on larger four-engined aircraft are not certified for use while the aircraft is in flight.



Key maintenance point

It is essential to remove electrical power from the relevant busbar (or in some cases the entire aircraft) before removing or installing electrical components. Failure to observe this precaution can result in electric shock as well as damage to components and equipment.

Key maintenance point

It is essential that electrical power is removed from an external power cable before connecting the cable to the aircraft. Failure to observe this precaution can result in electric shock as well as damage to components and equipment.

3.7 Emergency power

In the event of generator failure, continuous power can be provided by a ram air turbine (RAT). Also referred to as an air-driven generator, this is an emergency source of power that can be called upon when normal power sources are not available. The RAT is an air-driven device that is stowed in the wing or fuselage and deployed in the event that the aircraft loses normal power. When deployed, it derives energy from the airflow, see Fig. 3.11 . RATs typically comprises a two-bladed fan, or propeller that drives the generator shaft via a governor unit and gearbox; the gear ratios increase the generator shaft speed. The RAT can be deployed between aircraft speeds of 120 to 430 knots; some RATs feature variable pitch blades operated by a hydraulic motor to maintain the device at typical speeds of 4,800 r.p.m. Typical RAT generators produces an AC output of 7.5 kVA to a TRU. Heaters are installed in the RAT generator to prevent ice formation. RATs can weigh up to 400 lbs on very large transport aircraft, with blade diameters of between 40 and 60 inches depending on power requirements.

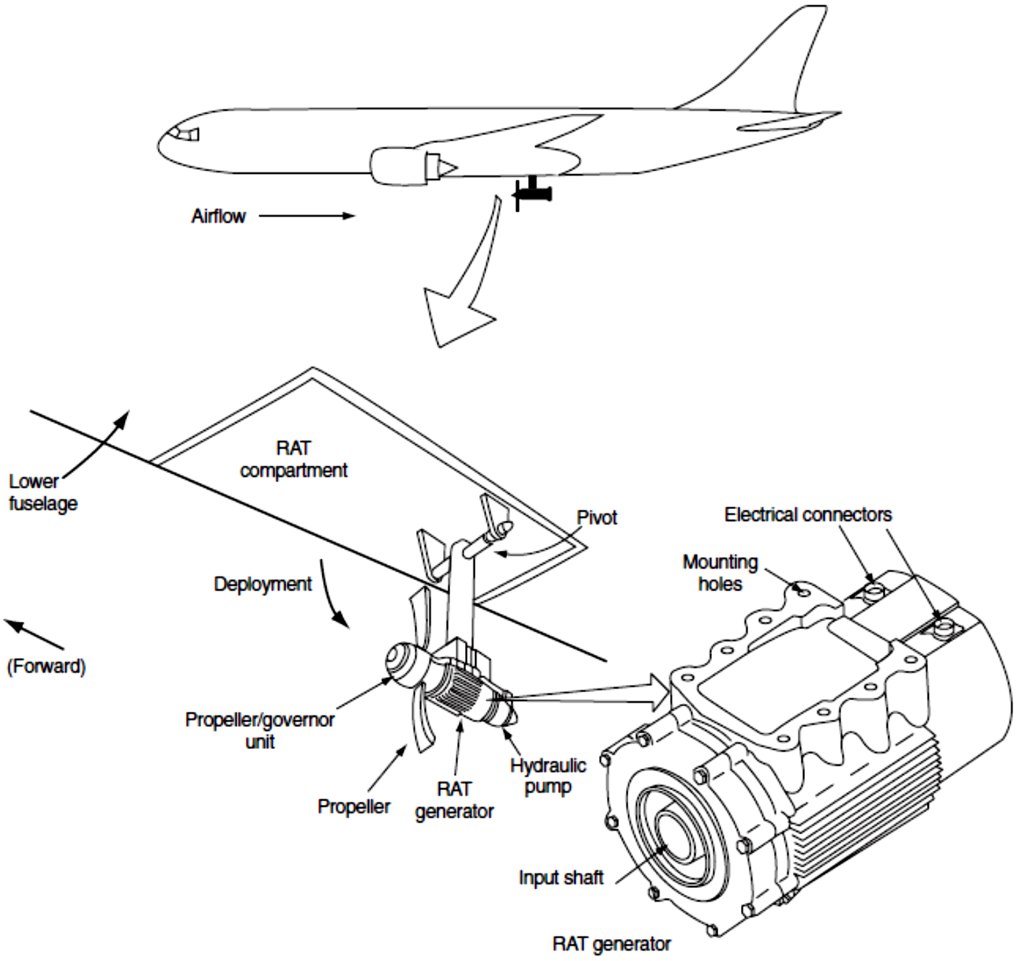


Figure 3.11 Ram air turbine

3.8 Multiple choice questions

1. Circuits needing only small step-up/down ratios employ:

(a) auto-transformers

(b) transformer rectifier units

(c) inverters.

2. Inverters are used to convert what forms of electrical power?

(a) AC into DC

(b) AC into AC

(c) DC into AC.

3. The accuracy of the vibrating contact regulator depends on the:

(a) input voltage

(b) generator output current

(c) resistor value and spring tension.

4. The voltage coil of a carbon pile regulator contains a:

(a) large number of copper wire turns connected across the generator output

(b) low number of copper wire turns connected across the generator output

(c) large number of copper wire turns connected in series with the generator output.

5. Transformer rectifier units (TRU) are often used to:

(a) convert battery power into AC power

(b) charge batteries from AC generators

(c) connect batteries in series.

6. Stepping a power supply down from 115 to 26 V AC would normally be achieved by a:

(a) transformer rectifier unit

(b) inverter

(c) transformer.

7. The desired output frequency of a rotary inverter is determined by the:

(a) AC input voltage

(b) input frequency

(c) DC input voltage.

8. Inverters and transformer rectifier units (TRU) are sources of:

(a) emergency power

(b) secondary power

(c) primary power.

9. Higher generator output increases the current in the carbon pile regulator, this:

(a) reduces compression on the pile thereby increasing its resistance

(b) increases compression on the pile thereby increasing its resistance

(c) reduces compression on the pile thereby decreasing its resistance.

10. TRUs are used to convert what forms of electrical power:

(a) AC into DC

(b) AC into AC

(c) DC into AC.

Chapter 4 : Batteries

Lectures 7 & 8

Topics

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Aircraft electrical power can be derived from a variety of sources; these are categorized as either primary or secondary. Batteries are primary sources of electrical power found on most aircraft delivering direct current. (Secondary sources of power are described in Chapter 3.) There are several types of battery used on aircraft, defined by the types of materials used in their construction; these include lead-acid and nickelcadmium batteries. The choice of battery type depends mainly on performance and cost. Other types of battery are being considered for primary power on aircraft; these include lithium and nickel-metal hydride. Electrical power delivered by batteries is used for a variety of applications, e.g. lights, radios, instruments, and motors. This chapter reviews the battery types used on aircraft, typical applications and how they are installed and maintained.

4.1 Overview

The main aircraft battery is a primary source of electrical power; its use can be controlled by the pilot or by automatic means. The main battery provides autonomous starting for the engine(s) or auxiliary power unit (APU) when external ground power is not available. Typical current requirement during APU starting is 1000A, albeit for a short period of time. Batteries also supply essential loads in the event of generator failure. It is an airworthiness[1] requirement that the main battery(s) supplies essential services for a specified period of time. Other aircraft systems are supplied with their own dedicated batteries, e.g. aircraft emergency lights. Individual computers use their own battery sources to provide non-volatile memory. Battery type and maintenance requirements have to be understood by the aircraft engineer to ensure safe and reliable operation and availability. The battery is constructed from a number of individual cells; generic cell features consist of two electrodes (the anode and cathode) and electrolyte contained within a casing. Cell materials vary depending on the type of battery performance required for a given cost. The simple primary cell (Fig. 4.1) causes an electron flow from the cathode (negative) through the external load to the anode (positive). The materials used refer to the two types of battery cell in widespread use on aircraft for the primary source of power: lead-acid or nickel-cadmium. These are maintained on the aircraft and treated as line-replaceable units; a full description of these two battery types is provided in this chapter. Cells used within other aircraft equipment or systems are typically made from lithium or nickel-metal hydride materials. These are not maintained as individual items on the aircraft, they are installed/removed as part of the equipment that they are fitted into; in this case only a brief description is provided.

[1] صلاحية الطائرات للطيران

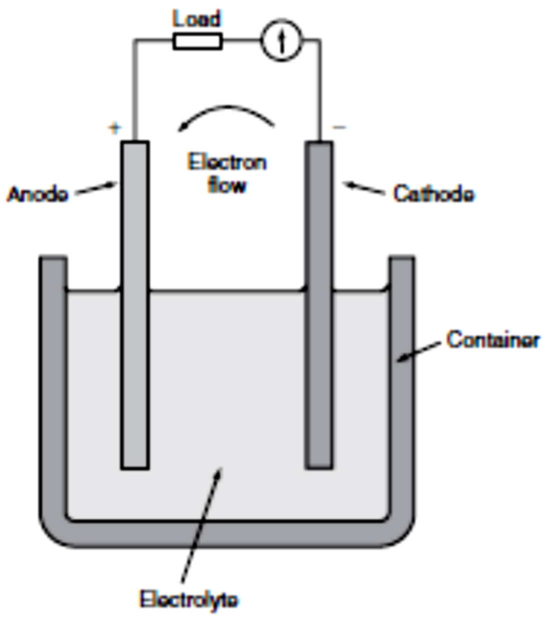

Figure 4.1 Electrical storage cell

Key point

The main aircraft battery is a primary source of electrical power; its use can be controlled by the pilot or by automatic means

4.2 Storage cells

The basic function of any electrical cell is the conversion of chemical energy into electrical energy. The cells can be considered as a chemical means of storing electrical energy. Electrons are removed from the (positive) cathode and deposited on the (negative) anode. The electrolyte is the physical means of migration between the cathode/anode. The attraction of electrons between cathode/anode creates a potential difference across the cell; the cathode/anode are attached to external terminals for connection to the equipment or system. Material types used for the cathode/anode and electrolyte will determine the cell voltage.

Key maintenance point

Different battery types possess different characteristics both in terms of what they are used for, and in terms of how they should be maintained; always refer to maintenance manual instructions for servicing.

Cells are categorized as either primary (where they can only be used once) or secondary (where they can be recharged). In the primary cell, the chemical activity occurs only once, i.e. during discharge. By applying current through a secondary cell in the opposite direction to that of discharging, the chemical reaction is reversed and the cell can be used again. The cathode/anode are returned to their original charged form; the cell therefore becomes a chemical means of storing electrical energy.

Key maintenance point

It can be dangerous to attempt charging a primary cell. In the secondary cell, the chemical activity is reversible.

The energy storage capacity of a cell is determined by the amount of material available for chemical reaction. To maximize the storage capacity, the physical areas of the cathode and anode are made as large as possible, normally by constructing them as plates. Capacity is stated in ampere-hours; batteries are rated with low or high discharge rates, either 10 hours or 1 hour. The battery's capacity will gradually deteriorate over time depending on usage, in particular the charge and discharge rates. For aircraft maintenance purposes, we need to define the acceptable capacity of the main battery(s); this is the ratio of actual capacity and rated capacity, expressed as a percentage. Actual capacity must not fall below 80% of the rated capacity; therefore testing is required on a periodic basis. Memory effect is observed in some secondary cells that cause them to hold less charge; cells gradually lose their maximum capacity if they are repeatedly recharged before being fully discharged. The net result is the cell appears to retain less charge than specified.

All secondary cells have a finite life and will gradually lose their capacity over time due to secondary chemical reactions; this occurs whether the cell is used or not. They also have a finite number of charge and discharge cycles since they lose a very small amount of storage capacity during each cycle. Secondary cells can be damaged by repeated deep discharge or repeated over-charging.

Storage cells have internal resistance; this is usually very small but it has the effect of limiting the amount of current that the cell can supply and also reducing the amount of electromotive force (e.m.f.) available when connected to a load. Internal resistance varies significantly with the distance between plates. For this reason, the gap is made as small as practicably possible. This internal resistance is sometimes shown as a series resistor within the cell for design purposes, but it is normally omitted in circuit diagrams used in maintenance and wiring diagram manuals. Internal resistance is affected by temperature and this leads to practical issues for certain cell types.

Test your understanding 4.1

Describe the process whereby secondary cells gradually lose their maximum capacity (memory effect).

A number of cells are linked together in series to form a battery . The total battery terminal voltage is the sum of individual cell voltages, see Fig. 4.2(a) . In this illustration, six cells are connected in series to for a 12 V battery. The circuit symbols for individual cells and a battery are shown in Fig. 4.2(b) . All of the individual cells are contained within a battery case, see Fig. 4.2(c) .

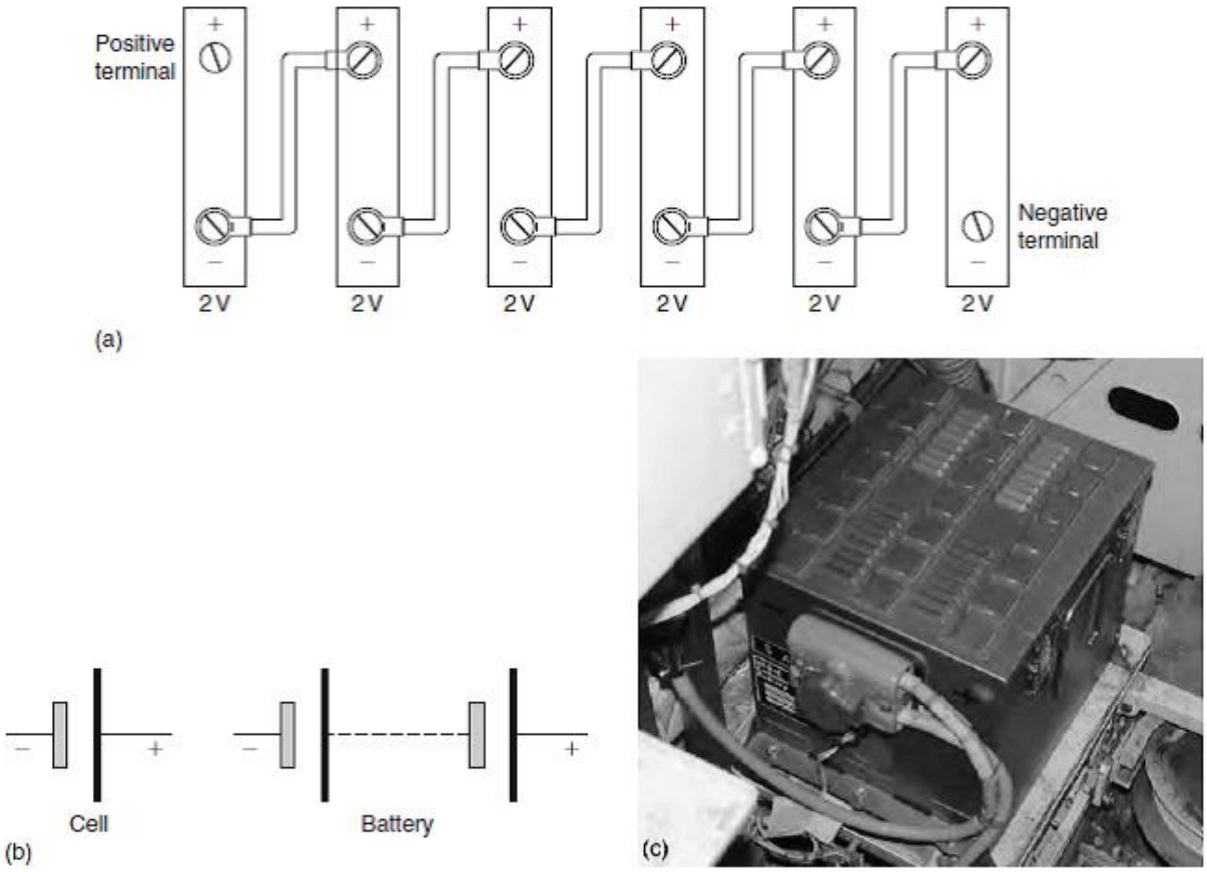

Figure 4.2 Cells and batteries: (a) connection of cells to form a battery; (b) symbols for cells and a battery; (c) typical battery casing

4.3 Lead-acid batteries

Developed in 1859, this is the oldest secondary cell technology in aircraft use today. Despite advances in alternative technologies, lead-acid batteries have retained market share (particularly in general aviation) due to the relatively low cost and mature technology. This type of battery has widespread applications on general aviation fixed and rotary wing aircraft due to the high current available for engine start and relatively low manufacturing cost (compared with nickelcadmium batteries). The surface area of the plates strength of the electrolyte the actual capacity of a lead-acid cell. There are two types of lead-acid battery used in aircraft: flooded (wet-cell) and sealed. The disadvantages of flooded batteries are that they require regular maintenance, they liberate gas during charging and the electrolyte can be spilt or leak. Spillage and/or leakage of the electrolyte requires immediate clean-up to avoid corrosion. These problems are overcome with sealed leadacid batteries. Although lead-acid batteries remain popular with GA aircraft, this battery technology will eventually be phased out due to environmental issues.

4.3.1 Construction

Flooded cells are housed within an impact- and acid resistant casing made from polystyrene-based materials. The casing retains the two terminals and includes a vent cap to prevent gas pressure build-up whilst not allowing the electrolyte to escape. A single battery cell contains a number of positive and negative plate groups constructed as illustrated in Fig. 4.3 . The individual plates are separated by a porous material to prevent short circuit through physical contact; there is space below the plates to allow any material shed from the plates to accumulate without shorting the plates. Flooded cells can be accessed on an individual basis for checking the content and condition of the electrolyte.

Key point

Since each positive plate is always positioned between two negative plates, there is actually one more negative plate than the positives.

Each positive plate is a cast lead/antimony frame formed as a grid; this is impregnated with a paste of lead dioxide (PbO_2). The negative plate is a similar frame containing lead (Pb); this is sometimes referred to as ‘spongy lead’. In practice, a typical cell is constructed with several plates in order to get the required current output. Positive plates distort when chemical reactions take place on only one side; for this reason, there are always an even number of positive plates sandwiched between an odd numbers of negative plates. All positive plates are connected together as are all the negatives. The plates are interlaced and separated by a porous separator that allows free circulation of the electrolyte at the plate surfaces; the plates are all stacked within the cell container. The electrolyte is sulphuric acid diluted with distilled (pure) water ($H_2 SO_4$).

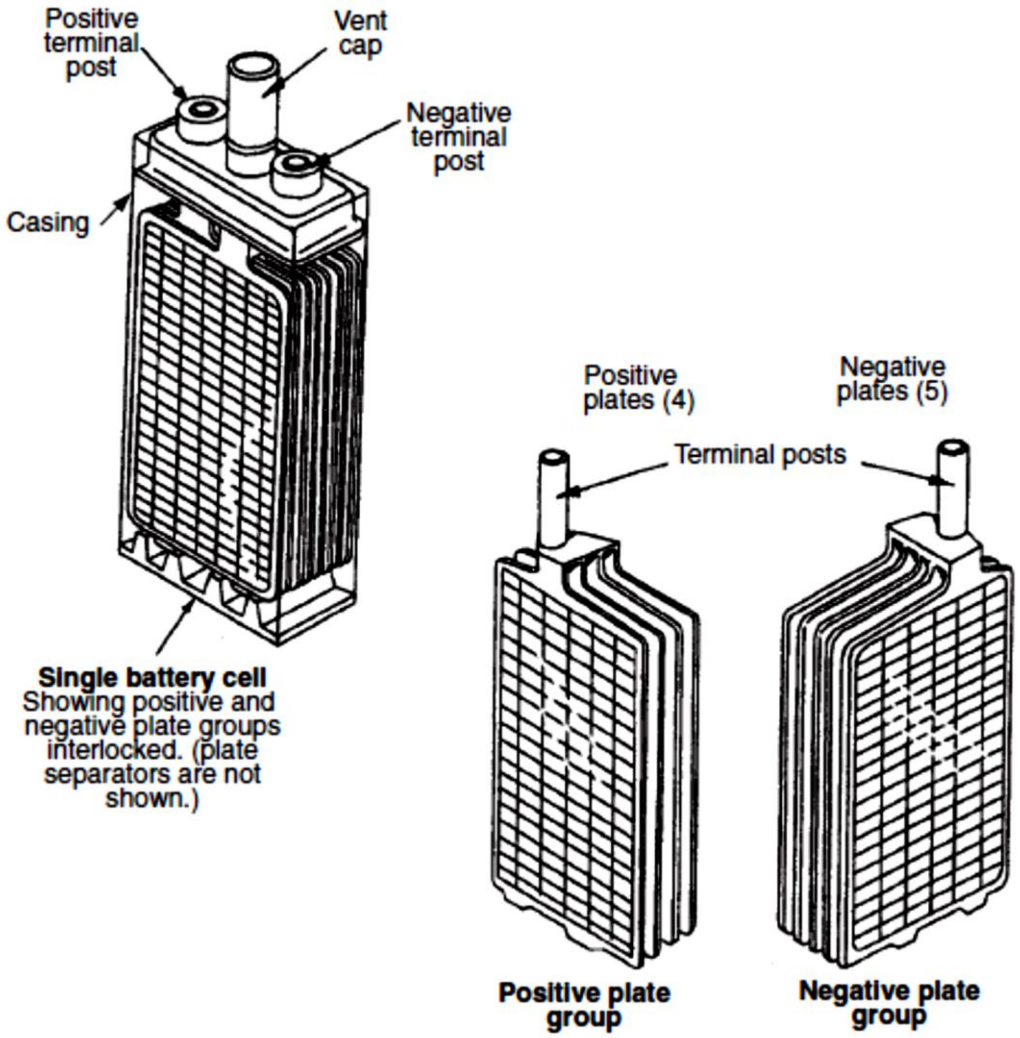

Figure 4.3 Lead-acid cell construction

Test your understanding 4.2

What are the advantages and disadvantages of flooded (wet-cell) batteries?

4.3.2 Charging/discharging

When fully charged, each cell has a potential difference of 2.5 V (falling to 2.2 V after a period of approximately one hour) at its terminals; when discharged, this potential difference is 1.8 V. A six-cell battery would produce 13.2 V fully charged, and 10.8 V DC when discharged. A twelve-cell battery would produce 26.4 V DC fully charged, and 21.6 V DC when discharged. During normal use of lead-acid cells, the terminal voltage stays at around 2 V for a long period of cell life, this is referred to as the cell's nominal voltage. When fully charged, the positive plate is lead dioxide (PbO_2) and the negative plate is lead (Pb).

Connecting an external load to the battery completes the electrical circuit, electrons are transferred from the negative plate and the battery starts to discharge. The chemical reaction that takes place during discharge changes each of the plates into lead sulphate ($PbSO_4$). Molecules of water are formed, thereby diluting the electrolyte. For a given battery capacity, a steady discharge rating forms part of the battery specification, e.g. a 20 hour rate produces a constant current for 20 hours until the cell is discharged. Figure 4.4 illustrates typical lead-acid battery characteristics at different discharge currents. The discharge current, in amps (A), is expressed as a fraction of the numerical value of C. For example, 0.1 C means C/10 A, and discharging will take approximately 10 hours. If the battery capacity was 35 Ah, a discharge current of 3.5 A can be expressed as 0.1 C (or C/10). This means that batteries of different sizes can be compared by a single set of graphs. Since a battery may be rated for different discharge times, its rated capacity will normally be an indication of current used. With a 20-hour discharge capacity, the chart shows that C/20 will discharge the battery at 1 A current in 20 hours.

The condition of each cell can be determined by the specific gravity (SG) of its electrolyte. When the battery is charged, the above process is reversed. The lead sulphate on the positive plate is returned to lead peroxide. The negative plate is returned to lead, and the electrolyte is restored to its original specific gravity; SG ranges will be from 1.25–1.3 (charged) down to 1.15–1.2 when discharged. is -62^{o}C. Although this guards against freezing, the consequence of maintaining a battery in this condition is that it will gradually self-discharge.

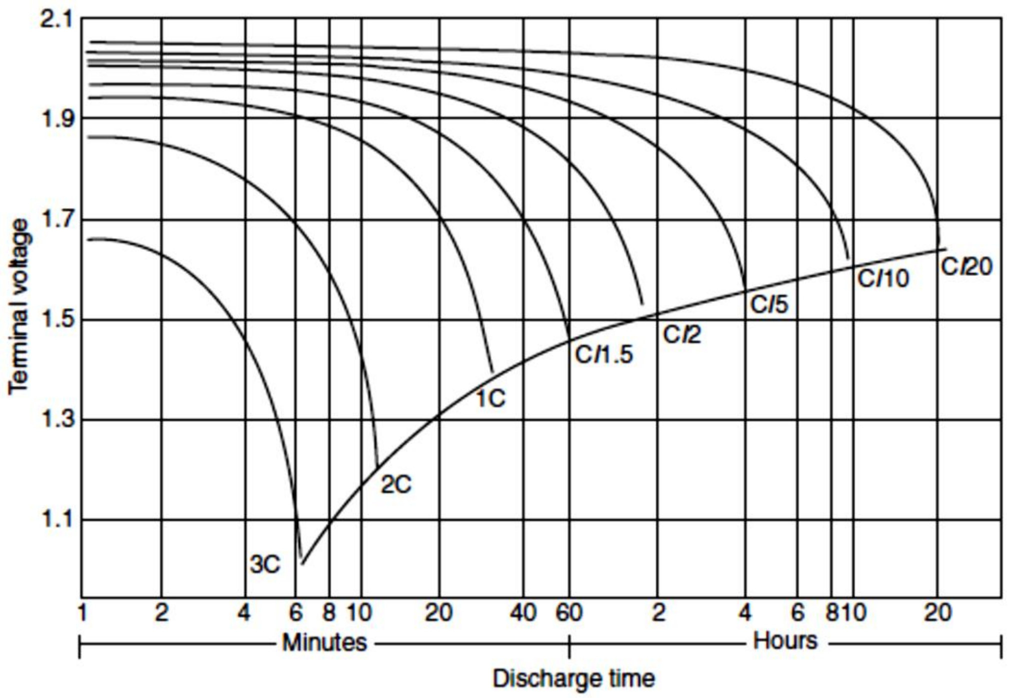

Figure 4.4 Lead-acid cell discharge characteristics

Lead-acid batteries require a three-month capacity check , and have approximately 18–24 months ' life. The condition of a fully charged lead-acid battery can be confirmed by three factors:

- The terminal voltage remains at its maximum level
- There is a free discharge of gas
- The SG is in the range 1.25–1.3.

The specific gravity of the electrolyte provides the definitive means of checking the charged condition of a lead-acid cell; this must be checked with a hydrometer on a periodic basis. (Specific gravity of a fluid is the relative density, or ratio of fluid's weight compared to pure water.) The electrolyte must always cover the plates; it can be topped up with distilled water. Differences of specific gravity readings between cells indicates that the battery is reaching the end of its useful life.

Key maintenance point

Specific gravity is temperature-dependent, and correction factors must be applied when taking measurements (refer to maintenance manual instructions).

Key maintenance point

When taking specific gravity readings from lead acid cells, the acid sample should always be returned into the same cell.

Charging of lead-acid batteries should be from a constant voltage source. Excessive charging rates can lead to boiling of the electrolyte; fumes containing droplets of electrolyte can escape the battery. These fumes can become noxious unless the battery is properly ventilated. The voltage per cell during charging should not exceed 2.35 V.

Sulphation occurs when an excess of lead sulphate builds up on the plates. This happens with a fully charged battery over a period of several weeks when the battery self-discharges. To prevent this, the battery should be re-charged in accordance with the maintenance manual instructions. Sulphation can eventually occur on a permanent basis and the sulphate will not go back into solution when charged. Over time, the lead sulphate gradually occupies more space on the plates thereby reducing capacity. This can be removed by drawing a heavy charge current causing particles to be removed from the plates and subsequently accumulated at the bottom of the cell. Eventually the plates become uneven in cross-section and distorted, leading to cracks being formed. Particles will accumulate at the bottom of the cell and this can lead to shorting of the plates. Sulphating is accelerated by small (trickle) discharging/charging together with incorrect electrolyte strength and levels.

In the event of electrolyte spillage/leaks , (always refer to the aircraft maintenance manual for any specific requirements) the following generic actions should be taken:

1. Report the incident.
2. Mop-up the electrolyte with a damp rag or sponge.
3. Brush the affected area with a dilute solution of sodium bicarbonate.
4. Sponge the area with clean water; dry thoroughly.
5. Press a moist piece of blue litmus paper on the affected area; a change of colour to red indicates the presence of acid (repeat steps 3–4 until the acid is removed).
6. Leave for 24 hours, and then check for any evidence of corrosion.
7. Restore any protective finish to the aircraft structure.

4.3.4 Sealed batteries

Maintenance and servicing costs associated with flooded cells can be overcome with sealed lead-acid batteries. This technology was developed in the 1970s and has been in place since the 1980s and is known as valve-regulated lead-acid (VRLA); the sealed lead-acid (SLA) effectively provides maintenance free lead-acid batteries.

Cell plates are made from lead calcium; the electrolyte is sulphuric acid diluted with distilled water. Plates are separated by an absorbent glass mat (AGM) that absorbs gasses liberated from the plates during charging. The lead plates are purer (99.99%) than flooded cell materials since they do not have to support their own weight. The electrolyte is absorbed between the plates and immobilized by a very fine fibreglass mat. This glass mat absorbs and immobilizes the acid while keeping the electrolyte in contact with the plates. This allows a fast reaction between and electrolyte and plate material during charge/discharge. There is no disintegration of the active materials leading to a short-circuit.

Key maintenance point

It is not possible to check the SG of the electrolyte; the battery can only be checked by measuring the terminal voltage.

The internal resistance of sealed lead-acid cells is lower than flooded cells, they can handle higher temperatures, and self-discharge more slowly. They are also more tolerant to the attitude of the aircraft. The product is inherently safer than the flooded cell due to reduced risk of spillage, leakage and gassing. Maintenance requirements are for a capacity check only. The overall capacity-to-weight ratio of sealed lead-acid batteries is superior to flooded lead-acid batteries. Since they are sealed, they can be shipped as non-hazardous material via ground or air.

Multiple choice questions

1. In a simple cell, electrons are:

(a) removed from the (positive) cathode and deposited on the (negative) anode

(b) removed from the (negative) cathode and deposited on the (positive) anode

(c) removed from the (negative) anode and deposited on the (positive) cathode.

2. The energy storage capacity of a cell is determined by the:

(a) terminal voltage

(b) electrolyte specific gravity

(c) amount of material available for chemical reaction.

3. When mixing electrolyte:

(a) acid is always added to the water

(b) water is always added to the acid

(c) it is not important how water and acid are mixed.

4. Battery capacity is measured in:

(a) volts

(b) amperes

(c) ampere-hours.

5. Lead acid batteries are recharged by constant:
(a) voltage
(b) current
(c) ampere-hours.

6. A cell that can only be charged once is called a:
(a) secondary cell
(b) metal-hydride cell
(c) primary cell.

7. The only accurate and practical way to determine the condition of the lead-acid battery is with a:
(a) specific gravity check of the electrolyte
(b) measured discharge in the workshop
(c) check of the terminal voltage.

8. Referring to Fig. 4.5 , the reason for having an even number of positive plates in a lead-acid battery is because:
(a) positive plates distort when chemical reactions take place on both sides
(b) positive plates distort when chemical reactions take place on one side
(c) negative plates distort when chemical reactions take place on both sides.

9. Referring to Fig. 4.6 , a 20 Ah battery, when discharging at 2A, will be fully discharged in approximately:
(a) two hours
(b) 15 minutes
(c) ten hours.

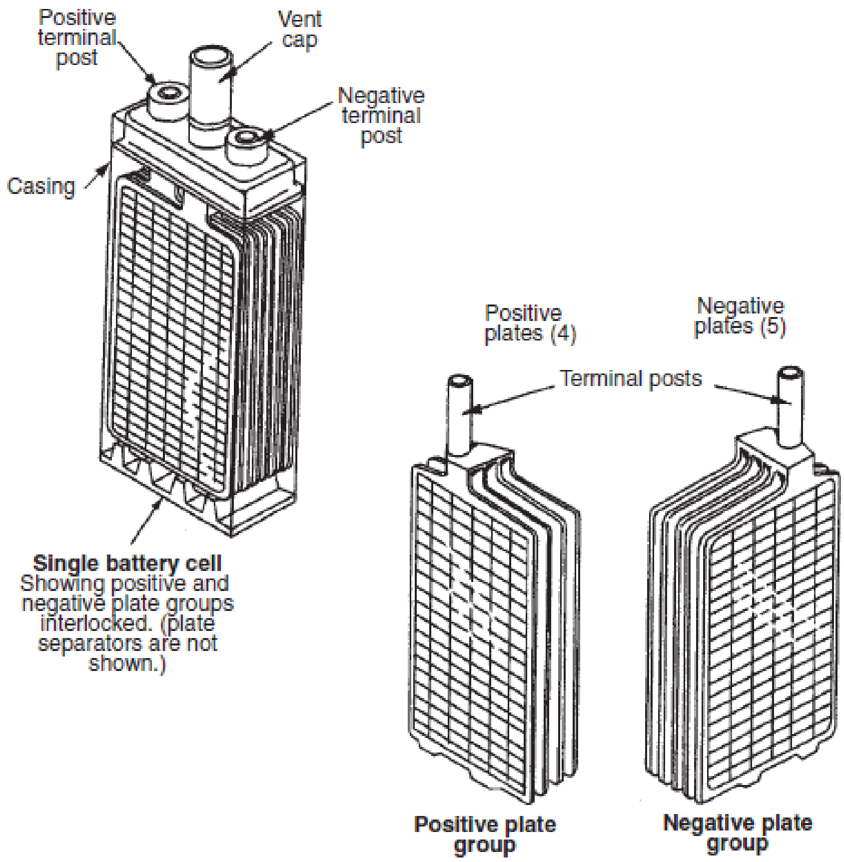

Figure 4.5 See Question 8

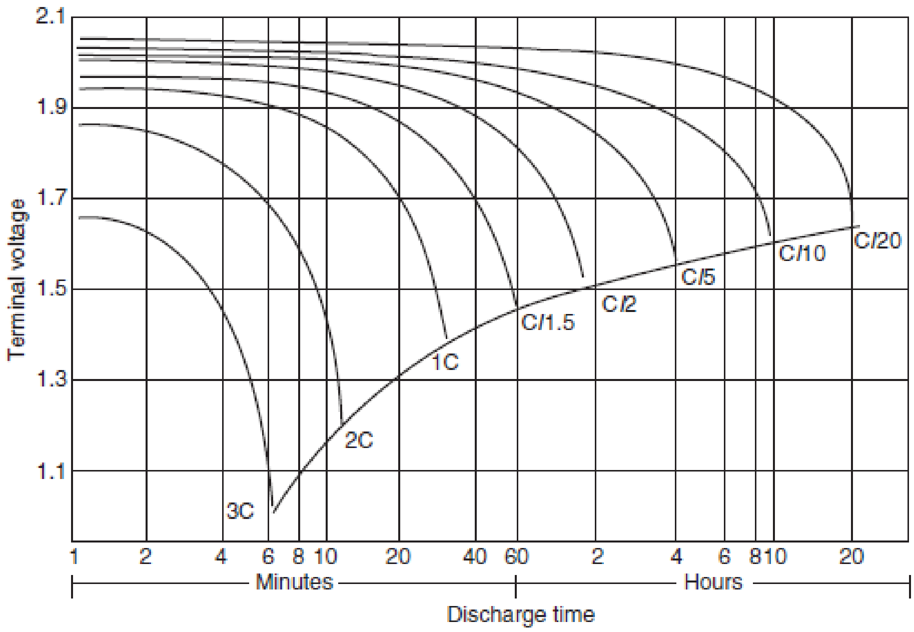

Figure 4.6 See Question 9

4.4 Nickel-cadmium batteries

Nickel-cadmium battery technology became commercially available for aircraft applications in the 1950s. At that time the major sources of batteries for aircraft were either vented lead-acid or silver-zinc technology. The nickel-cadmium (Ni-Cd) battery (pronounced 'nye-cad') eventually became the preferred battery type for larger aircraft since it can withstand higher charge/discharge rates and has a longer life. Ni-Cd cells are able to maintain a relatively steady voltage during high discharge conditions. The disadvantages of nickel-cadmium batteries are that they are more expensive (than lead-acid batteries) and have a lower voltage output per cell (hence their physical volume is larger than a lead-acid battery).

4.4.1 Construction

Plates are formed from a nickel mesh on which a nickel powder is sintered. The sintering process (where powdered material is formed into a solid) is used to form the porous base-plates (called plaques). This process maximizes the available quantity of active material. The plaques are vacuum impregnated with nickel or cadmium salts, electrochemically deposited with the pores of the plaques. Nickel tabs are spot-welded onto the plates and formed into the terminals; these plates are then stacked and separated by a porous plastic in a similar fashion to the lead-acid battery. The electrolyte is potassium hydroxide (KOH) diluted in distilled water giving a specific gravity of between 1.24 and 1.3. Both the plates and electrolyte are sealed in a plastic container.

4.4.2 Charging

During charging, there is an exchange of ions between plates. Oxygen is removed from the negative plate, and transferred to the positive plate. This transfer takes place for as long as charging current exists, until all the oxygen is driven out of the negative plate (leaving metallic cadmium) and the positive plate becomes nickel oxide. The electrolyte acts as an ionized conductor and it does not react with the plates in any way. There is virtually no chemical change taking place in the electrolyte during charging or discharging, therefore its condition does not provide an indication of cell condition. Towards the end of charging, gassing occurs as a result of electrolysis and the water content of the electrolyte is reduced. Gas emitted by decomposition of water molecules is converted into hydrogen at the negative plate and oxygen at the positive plate. This gassing leads to the loss of some water; the amount of gas released is a function of electrolyte temperature and charging voltage. When fully charged, each cell has a potential difference of between 1.2 and 1.3 V across its terminals. This reduces to 1.1 V when discharged. An aircraft battery containing 19 cells at 1.3 V therefore produces a battery of 24.7 V. Charging voltage depends on the design and construction, but will be in the order of 1.4/1.5 V per cell.

4.4.3 Discharging

This is a reverse chemical activity of the charging process; the positive plate gradually loses oxygen and the negative plate gradually regains oxygen. No gassing takes place during a normal discharge; the electrolyte is absorbed into the plates and may not be visible over the plates. When fully charged, the volume of electrolyte is high; this is the only time that water should be added to a Ni-Cd battery. Ni-Cd battery electrolyte freezes at approximately –60ºC and is therefore less susceptible to freezing compared to lead-acid. The formation of white crystals of potassium carbonate indicates the possibility that overcharging has occurred.

Referring to Fig. 4.7 , the nickel-cadmium cell voltage remains relatively constant at approximately 1.2 V through to the end of discharge, at which point there is a steep voltage drop. The discharge characteristics of a cell are affected by the:

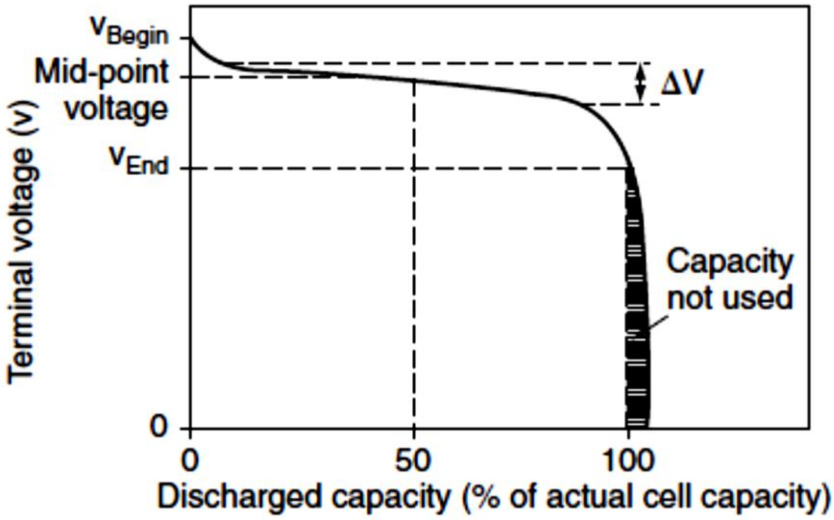

Figure 4.7 Nickel-cadmium cell discharge characteristics

- discharge rate
- discharge time
- depth of discharge
- cell temperature
- charge rate and overcharge rate
- charge time, and rest period after charge
- previous cycling history.

Every nickel-cadmium cell (and hence a battery) has a specific:

- rated capacity
- discharge voltage
- effective resistance.

Individual cells are rated at a nominal 1.2V, and voltage for battery voltages are multiples of the individual cell nominal voltage. Five cells connected in series would therefore result in a 6V battery. It can be seen from Fig. 5.8 that the discharge voltage will exceed 1.2 V for some portion of the discharge period. Cell capacity is normally rated by stating a conservative estimate of the amount of capacity that can be discharged from a relatively new, fully charged cell. The cell rating in ampere-hours (or milliamperehours) is therefore quoted by most manufacturers to a voltage of 0.9 V at 5 hour discharge rate

Figure 4.8 shows that when rates of discharge are reduced, the available capacity becomes less dependent on the discharge rate. When rates of discharge rates increase, the available capacity decreases.

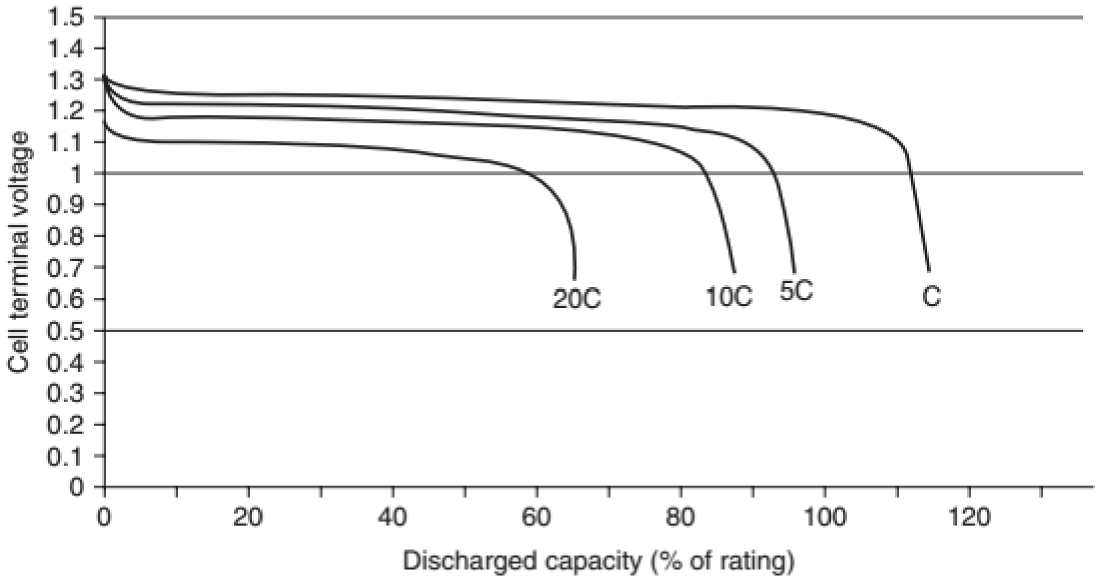

Figure 4.8 Nickel-cadmium cell discharge profiles and capacity

Charging of nickel-cadmium batteries needs specific methods since they can suffer from an effect called thermal runaway. This occurs at high temperatures and if the battery is connected to a constant charging voltage that can deliver high currents. Thermal runaway causes an increase in temperature and lower internal resistance, causing more current to flow into the battery. In extreme cases suffi cient heat may be generated to destroy the battery. Dedicated battery charges (either on the aircraft or in the workshop) is designed to take this into account by regulating the charging current. Temperature sensors are installed in the batteries to detect if a runaway condition is occurring.

4.4.4 Maintenance

Since there is virtually no chemical change taking place during nickel-cadmium cell charging or discharging, the condition of the electrolyte does not provide an indication of the battery's condition. Cell terminal voltage does not provide an indication of charge since it remains relatively constant. The only accurate and practical way to determine the condition of the nickelcadmium battery is with a measured discharge in the workshop. The fully charged battery is tested after a two hour 'resting' period, after which the electrolyte is topped up using distilled or demineralized water. Note that since the electrolyte level depends on the state of charge, water should never be added to the battery on the aircraft. This could lead to the electrolyte overflowing when the battery discharges, leading to corrosion and self-discharging (both of which could lead to premature failure of the battery). Ni-Cd batteries emit gas near the end of the charging process and during overcharging. This is an explosive mixture and must be prevented from accumulating; maintenance of the venting system is essential.

In the event of electrolyte spillage/leaks (always refer to the aircraft maintenance manual for specific details):

- report incident
- mop electrolyte with damp rag or sponge
- cover the area with a dilute solution of acetic acid, 5% solution of chromic acid, or 10% solution of
boric acid
- press moist piece of red litmus paper on affected area; change of colour to blue indicates presence of alkaline
- leave for a minimum of 24 hours, check for corrosion
- restore protective finish.

In addition to providing primary power, Ni-Cd batteries are also used in aircraft for emergency equipment, e.g. lighting. This type of cell is sealed and the electrolyte cannot be topped up. Extreme care must be taken with how these batteries are charged.

Key maintenance point

Servicing equipment used for lead-acid batteries must not be used for nickel-cadmium batteries; sulphuric acid is detrimental to the operation of nickelcadmium batteries.

Key maintenance point

If Ni-Cd batteries are replacing lead-acid batteries, always neutralize the battery compartment.

Key maintenance point

Electrolyte used in lead-acid and nickel cadmium batteries is actively corrosive.

Key maintenance point

Main batteries need to be kept upright in the aircraft to avoid spilling any of the electrolyte

4.5 Lithium batteries

Lithium batteries include a family of over 20 different products with many types of anodes, cathodes and electrolytes. The type of materials selected depends on many factors, e.g. cost, capacity, temperature, life etc.; these are all driven by what the application requirements are.

Applications range from consumer products (accounting for the largest market requirement) through to specialist applications including communications and medical equipment. Aircraft are often equipped with systems requiring an autonomous source of energy, e.g. emergency locator beacons, life rafts and life jackets. Lithium (Li) is one of the alkali group of reactive metals; it is one of the lightest elements, giving it an immediate advantage for aircraft applications. It has a single valence electron with low combining power, therefore readily becoming a positive ion. The materials used in these cells are:

- electrolyte: lithium-ion
- cathode: cobalt
- anode: graphite.

Lithium-ion is a fast-growing and promising battery technology. This type of battery is often found in consumer products (mobile phones and laptop computers) because they have very high energy-to-weight ratios, no memory effect, and a slow discharge charge rate when not in use. They are being introduced for aircraft applications (e.g. in smoke detectors) on a cautious basis because they are significantly more susceptible to thermal runaway. Applications on aircraft now include engine start and emergency back-up power, the first such application of the devices in the business aviation sector. In the longer term, they are being developed for main battery applications. They offer several advantages compared to lead-acid and nickel-cadmium products, including:

- longer life
- less weight
- low maintenance
- reduced charging time.

Disadvantages are the higher product cost and the fact that the electrolyte is extremely flammable. They can lose up to 10% of their storage capacity every year from when they are manufactured, irrespective of usage. The rate at which the ageing process occurs is subject to temperature; higher temperatures results in faster ageing.

The lithium-ion main aircraft battery will not be a ‘ drop-in ’ replacement for main battery applications. Safety features are required within the aircraft as well as in the battery. These features include protection circuits and hardware to maintain voltage and current within safe limits. The nominal cell voltage is 3.6V, charging requires a constant voltage of 4.2V with associated current limiting.

When the cell voltage reaches 4.2 V, and the current drops to approximately 7% of the initial charging current, the cell is fully recharged. Figure 4.9 illustrates the typical discharge curve of a lithium-ion cell when discharged at the 0.2 C rate. Lithium-ion cells have a very flat discharge curve, and cell voltage cannot be used to determine the state of charge. The effective capacity of the lithium-ion cell is increased with low discharge rates and reduced if the cell is discharged at higher rates.

Software-based monitoring and alarms are needed for safe operation during charging. Specific design and maintenance considerations for these batteries in aircraft include:

- maintaining safe cell temperatures and pressures
- mitigating against explosion
- preventing the electrolyte escaping from the battery
- disconnecting the charging source in the event of over-temperature
- providing a low battery charge warning.

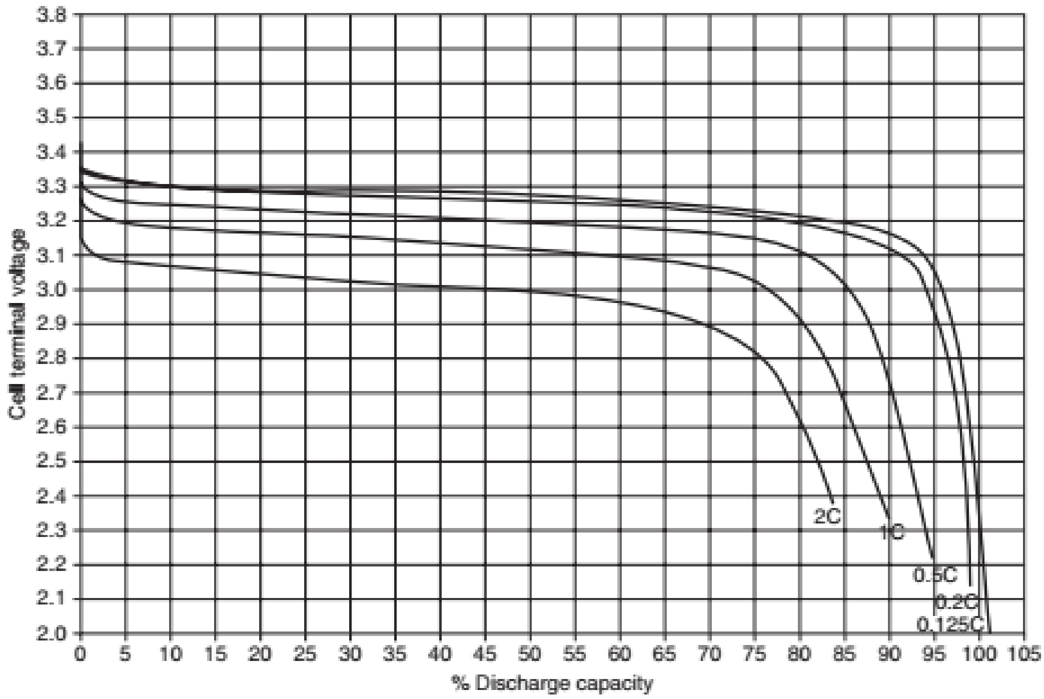

Figure 4.9 Lithium-ion cell discharge characteristics

4.6 Nickel-metal hydride batteries

Nickel-metal hydride (Ni-MH) is a secondary battery technology, similar to the sealed nickel-cadmium product. Ni-MH batteries provide a constant voltage during discharge, excellent long-term storage and long cycle life (over 500 charge– ischarge cycles). No maintenance is required on this type of battery; however, care must be taken in charging and discharging. The evolution of Ni-MH technology is being driven by the need for environmentally friendly materials and higher energy efficiency. The materials used in the Ni-MH battery technology are:

- anode: nickel and lanthanum
- cathode: nickel hydroxide
- electrolyte: potassium hydroxide.

The charging voltage is in the range of 1.4/1.6V per cell. A fully charged cell measures between 1.35 and 1.4 V (unloaded), and supplies a nominal 1.2V per cell during use, reducing to approximately 1 volt per cell (further discharge may cause permanent damage). The Ni-MH cell requires a complex charging algorithm, and hence dedicated charger equipment.

Figure 4.10 illustrates the voltage profile of a metalhydride cell, discharged at the 5-hour rate (0.2 C rate). This profi le is affected by temperature and discharge rate; however under most conditions, the cell voltage retains a fl at plateau that is ideal for electronics applications. As with nickel-cadmium cells, the nickel-metal hydride cell exhibits a sharp ‘knee’ at the end of the discharge where the voltage drops rapidly

A new generation of nickel-metal hydride 12 V batteries has been designed by Advanced Technological Systems International Limited (ATSI) as a direct replacement for the conventional sealed lead-acid battery typically used in gliders. It delivers more than twice the power of its lead acid counterpart whilst having the same base footprint and lower weight. The integral advance electronics guarantees that it will always deliver maximum output up to the point of total discharge. Unlike sealed lead-acid batteries, it does not suffer any loss of performance even after many deep discharge cycles, or storage in a discharged state, making it one of the most advanced batteries in the world today. The new battery type will be longer lasting than the equivalent sealed lead-acid battery and requires a purpose-designed charging unit

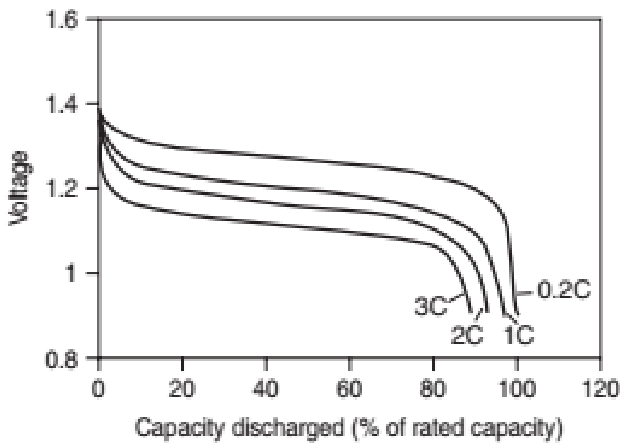

Figure 4.10 Metal-hydride cell discharge characteristics

Key maintenance point

A Ni-Cad charger should not be used as a substitute for a Ni-MH charger.

4.7 Battery locations

An aircraft is fitted with one or two main batteries depending on its size and role. The battery is located as close as possible to its point of distribution; this is to reduce IR losses through heavy-duty cables. In smaller general aviation (GA) aircraft, the battery can be located in the engine compartment, alternatively behind the luggage compartment in the rear fuselage, see Fig. 4.11(a). On some larger GA aircraft the battery is located in the leading edge of the wing, see Fig. 4.11(b). Other locations include the nose equipment bay on medium size helicopters (Fig. 4.11(c)) or attached to the external airframe, see Fig. 4.11(d) . For larger aircraft, e.g. the Boeing 747, one battery is located in the flight compartment; the other is located in the auxiliary power unit (APU) bay at the rear of the aircraft. Batteries are installed in a dedicated box or compartment designed to retain it in position and provide ventilation. The battery compartment is usually fitted with a tray to collect any spilt electrolyte and protect the airframe. Tray material will be resistant to corrosion and non-absorbent. The structure around the battery compartment will be treated to reduce any damage from corrosion resulting from any spilt electrolyte or fumes given off during charging. Batteries must be secured to prevent them from becoming detached during aircraft maneuvers; they are a fire risk if they become detached from their tray.

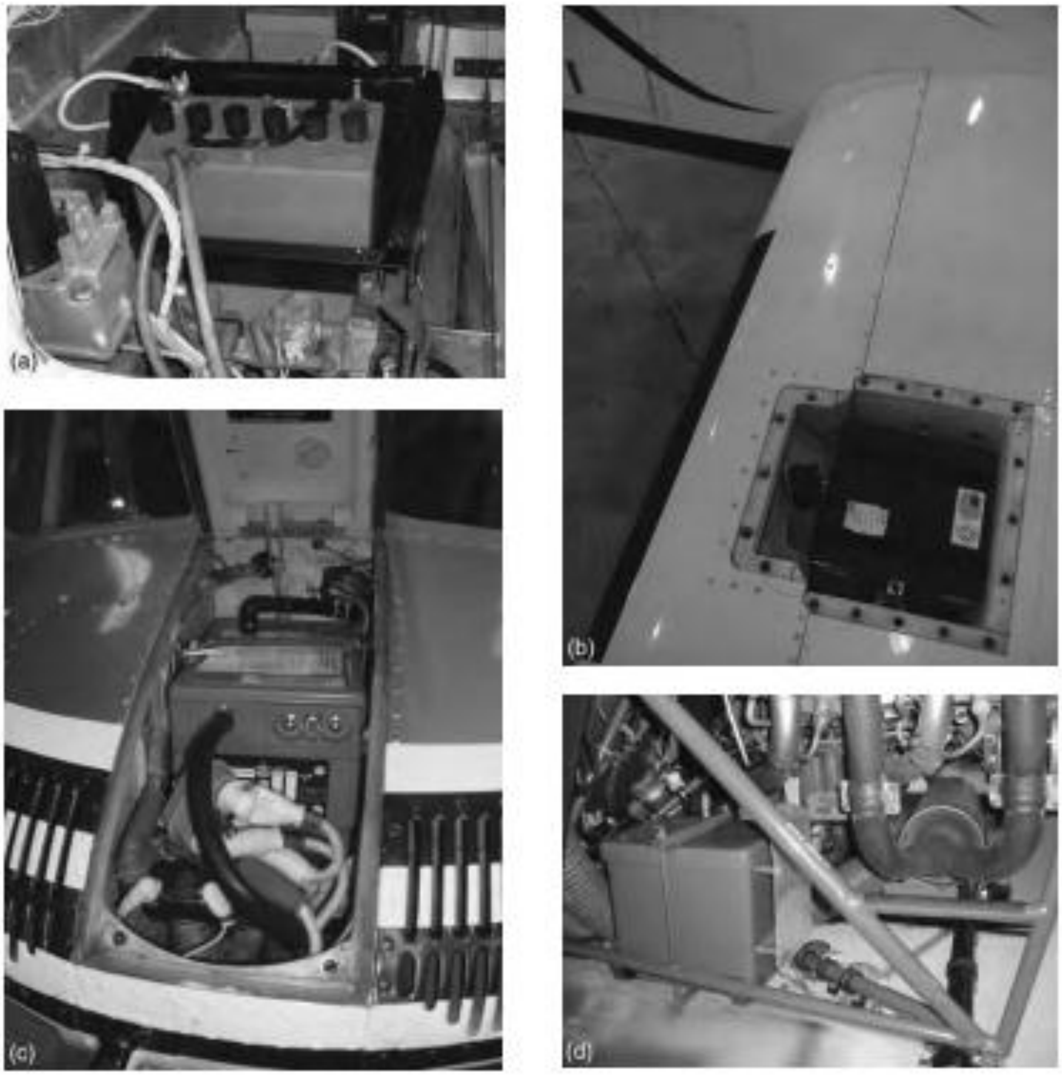

Figure 4.11 Typical battery locations: (a) battery compartment (GA aircraft); (b) wing leading edge (Beech King Air); (c) nose equipment bay (medium helicopter); (d) externally mounted (small helicopter)

Key maintenance point

When installing batteries in the aircraft, extreme care must be taken not to directly connect (or 'short circuit') the terminals. This could lead to a high discharge of electrical energy causing personal harm and/or damage to the aircraft.

Key maintenance point

The battery must be secured without causing any deformation of the casing which could lead to plate buckling and internal shorting.

4.8 Battery venting

Main battery installations must be vented to allow gases to escape, and accommodate electrolyte spillage. Rubber or other non-corroding pipes are used as ventilation lines which direct the gases overboard, usually terminating at the fuselage skin. On pressurized aircraft the differential pressures between cabin and atmosphere are used to draw air through the venting system. Some installations contain traps to retain harmful gases and vapours. Figure 4.12 illustrates battery venting, acid traps and how pressurized cabin air is used to ventilate the battery

Key maintenance points

• Avoid personal contact with battery electrolyte (fluid and fumes).

• Observe safety precautions for the protection of hands and eyes.

• Always use personal protective equipment (goggles, rubber gloves, aprons) when handling electrolyte to prevent serious burns.

• Seek first aid in the event of electrolyte contact.

• When mixing electrolyte, acid is always added to the water. (Adding water to acid is very dangerous.)

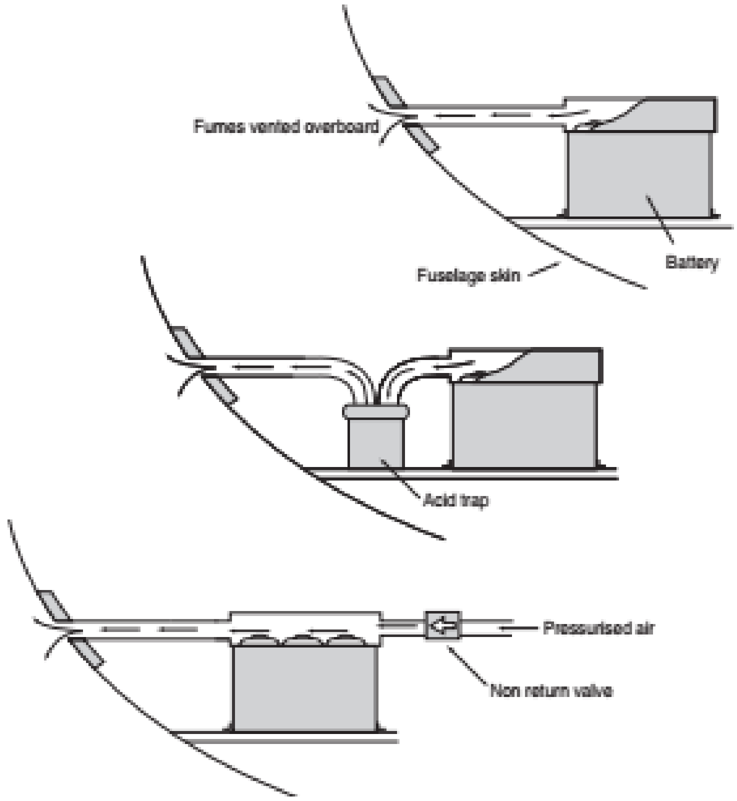

Figure 4.14 Battery venting

4.9 Battery connections

These depend on the type of battery and aircraft installation. On smaller aircraft the cable connections simply fit over the terminal lugs and are secured with a nut, bolt and washers. On larger aircraft, the main batteries have quick-release connectors, see Fig. 4.13 . These provide protection for the terminals and cable connections, the aircraft connector is a plastic housing with two shrouded spring-loaded terminals (for connecting the battery cables) and a hand-wheel with lead-screw. The battery connection is a plastic housing integrated into the casing; it contains two shrouded pins and a female lead screw. When the two halves are engaged, the lead screws are pulled together and eventually form a lock. This mechanism provides good contact pressure and a low resistance connection. The main battery(s) is connected into the aircraft distribution system.

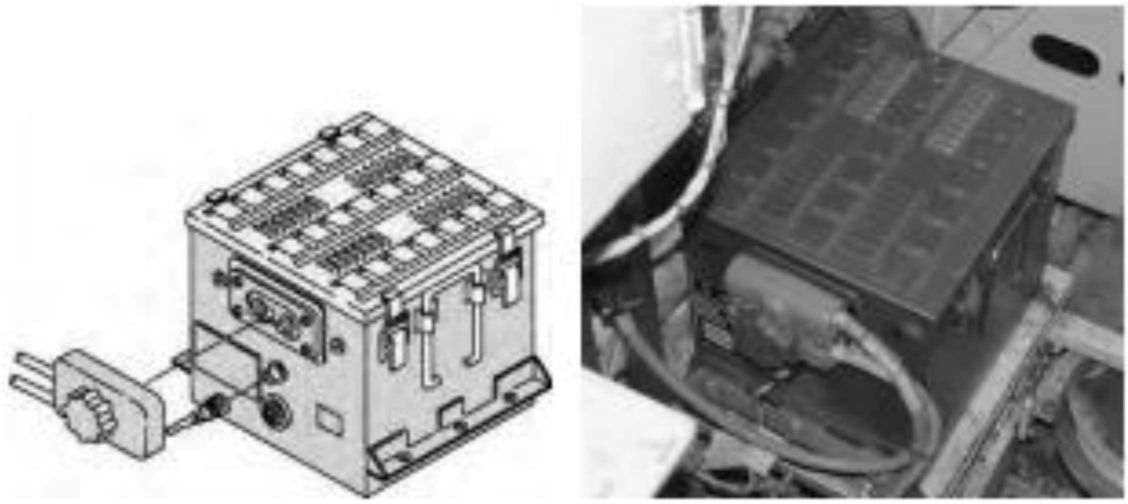

Figure 4.13 Battery connections

Key maintenance point

Batteries must not be exposed to temperatures or charging currents in excess of their specified values. This will result in the electrolyte boiling, rapid deterioration of the cell(s) eventually leading to battery failure.

Key maintenance point

Removal of the aircraft battery can result in loss of power to any clocks that are electrically. It will usually be necessary to check and reset the clocks on the flight deck when battery power is eventually restored.

Key maintenance point

Some aircraft main batteries are heavy and may require a hoist for removal/installation into the aircraft.

4. 10 Multiple choice questions

1. Servicing equipment used for lead-acid batteries:

(a) can also be used for nickel-cadmium batteries

(b) must not be used for nickel-cadmium batteries

(c) must be disposed of after use.

2. The only accurate and practical way to determine the condition of the nickel-cadmium battery is with a:

(a) specific gravity check of the electrolyte

(b) measured discharge in the workshop

(c) check of the terminal voltage.

3. The only accurate and practical way to determine the condition of the lead-acid battery is with a:

(a) specific gravity check of the electrolyte

(b) measured discharge in the workshop

(c) check of the terminal voltage.

PART II: Aircraft Instrument Systems

Chapter 5 : Introduction to Aircraft Instrument

Lecture 9

Topics

5.1 Introduction

5.2 Requirements

5.3 Standards

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5.1. Introduction

The complexity of modern aircraft and all allied equipment, and the nature of the environmental conditions under which they must operate, require conformity of design, development and subsequent operation with established requirements and standards. This is, of course, in keeping with other branches of mechanical and transport engineering, but in aviation requirements and standards are unique and by far the most stringent.

The formulation and control of airworthiness requirements as they are called, and the recommended standards to which raw materials, instruments and other equipment should be designed and manufactured, are established in the countries of design origin, manufacture and registration, by government departments and/or other legally constituted bodies. The international operation of civil aircraft necessitates international recognition that aircraft do, in fact, comply with their respective national airworthiness requirements. As a result, international standards of airworthiness are also laid down by the International Civil Aviation Organization[1] (ICAO). These standards do not replace national regulations, but serve to define the complete minimum international basis for the recognition by countries of airworthiness certification.

[1] منظمة الطيران المدني الدولية

It is not intended to go into all the requirements - these take up volumes in themselves- but rather to extract those related essentially to instruments; **by** so doing a useful foundation can blaid on which to study operating principles and how they are applied in meeting the requirements.

5.2. Requirements

Location, Visibility and Grouping of Instruments

1. AI1 instruments shall be located so that they can be read easily by the appropriate member of the flight crew.
2. When illumination of instruments is provided there shall be sufficient illumination to make them easily readable and discernible by night. Instrument lights shall be installed in such a manner that the pilot's eyes are shielded from their direct rays and that no objectionable reflections are visible to him.
3. Flight, navigation and power-plant instruments for use by a pilot shall be plainly visible to him from his station with the minimum practicable deviation from his normal position and line of vision when he is looking out and forward along the flight path of the aircraft.
4. All flight instruments shall be grouped on the instrument panel and, as far as practicable, symmetrically disposed about the vertical plane of the pilot's forward vision.
5. All the required power-plant instruments shall be conveniently grouped on instrument panels and in such a manner that they may be readily seen by the appropriate crew member.
6. In multi-engine aircraft, identical power-plant instruments for the several engines shall be located so as to prevent any misleading impression as to the engines, to which they relate,

Instrument Panels

The vibration characteristics of instrument panels shall be such as not to impair seriously the accuracy of the instruments or to damage them. The minimum acceptable vibration insulation characteristics are established by standards formulated by the appropriate national organization.

Instruments to be installed

Right and Navigation Instruments

1. Altimeter adjustable for changes in barometric pressure
2. Airspeed indicator
3. Vertical speed indicator
4. Gyroscopic bank-and-pitch attitude indicator
5. Gyroscopic rate-of-turn indicator (with bank indicator)
6. Gyroscopic direction indicator
7. Magnetic compass
8. Outside air temperature indicator
9. Clock

Pitot-static System

Instruments 1, 2 and 3 above form part of an aircraft's pitot-static system, which must also conform to certain requirements. These are summarized as follows:

a. The system shall be air-tight, except for the vents to atmosphere, and shall be arranged so that the accuracy of the instruments cannot be seriously affected by the aircraft's speed, attitude, or configuration; by moisture, or other foreign matter.

b. The system shall be provided with a heated pitot-pressure probe to prevent malfunctioning due to icing.

c. Sufficient moisture traps shall be installed to ensure positive drainage throughout the whole of the system.

d. In aircraft in which an alternate or emergency system is to be installed, the system must be as reliable as the primary one and any selector valve must be clearly marked to indicate which system is in use.

e. Pipelines shall be of such an internal diameter that pressure lag and possibility of moisture blockage is kept to an acceptable minimum.

f. Where static vents are used, to obviate yawing errors they shall be situated on opposite sides of the aircraft and connected together as one system. Where duplicate systems are prescribed, a second similar system shall be provided.

Gyroscopic Instruments

Gyroscopic instruments may be of the vacuum-operated or electrically operated type, but in all cases the instruments shall be provided with two independent sources of power, a means of selecting both power source, and a means of indicating that the power supply is working satisfactorily.

The installation and power supply system shall be such that failure of one instrument, or of the supply from one source, or a fault in any part of the supply system, will not interfere with the proper supply of power from the other source.

Duplicate Instruments

In aircraft involving two-pilot operation it is necessary for each pilot to have his own pilot-static and gyroscopic instruments. Therefore two independent operating systems must be provided and must be so arranged that no fault which might impair the operation of one is likely to impair the operation of both,

Magnetic Compass

The magnetic compass shall be installed so that its accuracy will not be excessively affected by the aircraft vibration or magnetic fields of a permanent or transient nature.

Power Plant Instruments

1. Tachometer to measure the rotational speed of a crankshaft or a compressor as appropriate to the type of power plant.
2. Cylinder-head temperature indicator for an air-cooled engine to indicate the temperature of the hottest cylinder.
3. Carburetor-intake air temperature indicator.
4. Oil temperature indicator to show the oil inlet and/or outlet temperature.
5. For turbojet and turbo propeller engines a temperature indicator to indicate whether the turbine or exhaust gas temperature is maintained within its limitations.
6. Fuel-pressure indicator to indicate pressure at which fuel is being supplied and a means for warning of low pressure.
7. Oil-pressure indicator to indicate pressure at which oil is being supplied to a lubricating system and a means for warning of low pressure.
8. Manifold pressure gauge for a supercharged engine.
9. Fuel-quantity indicator to indicate in gallons or equivalent units the quantity of usable fuel in each tank during flight. Indicators shall be calibrated to read zero during cruising level flight, when the quantity of fuel remaining is equal to the unusable fuel, i.e. the amount of fuel remaining when, under the most adverse conditions, the first evidence of malfunctioning of an engine occurs.
10. Fuel-flow indicator for turbojet and turbopropeller engines. For piston engines not equipped with an automatic mixture control a fuel flowmeter or fuellair ratio indicator.
11. Thrust indicator for a turbojet engine.
12. Torque indicator for a turbopropeller engine.

5.3 Standards

In the design and manufacture of any product, it is the practice to comply with some form of specification the purpose of which is to ensure conformity with the required production processes, and to set an overall standard for quality of the product and reliability when ultimately performing its intended function. Specifications, or standards as they are commonly known, are formulated at both national and international levels by specialized organizations. For example, in the United Kingdom, the British Standards Institution . is the recognized body for the preparation and promulgation of national standards and codes of practice, and it represents the United Kingdom in the International Organization for Standardization (ISO), in the International Electrotechnical Commission (IEC) and in West European organizations performing comparable functions.

Standards relate to all aspects of engineering and as 'a result vast numbers are produced and issued in series form corresponding to these aspects. As far as aircraft instruments and associated equipment are concerned, British Standards come within the Aerospace G100 and G200 series; they give definitions, constructional requirements, dimensions, calibration data, accuracy required under varying environmental conditions, and methods of testing. Also in connection with instruments and associated electronic equipment, frequent reference is made to what are termed ARINC specifications. This is an acronym for Aeronautical Radio Incorporated, an organization in the United States which operates under the aegis of the airline operators, and in close collaboration with manufacturers.

One notable specification of the many which ARINC formulate is that which sets out a standard set of form factors for the items colloquially termed 'black boxes'. In the main, these factors cover case dimensions, mounting racks, location of plugs and sockets, and a system of indexing fouling pins to ensure that only the correct equipment can be fitted in its appropriate rack position. The size of box is based on a standard width dimension called 'one ATR' (yet another abbreviation meaning Air Transport Rack) and variations in simple multiples of this provide a range of case widths. Two case lengths are provided for, and are termed long and short, and the height is standard.

Test your understanding

1. **What are the requirements should be available in instruments panel?**
2. **Number six navigation instruments to be installed in navigation panel.**
3. **Number the navigation instruments that used pitot tube.**
4. **Number eight power plant Instruments of aircrafts.**

Chapter 6 : Instrument displays, panels and layouts

Lecture 10

Topics

6.1 Quantitative Displays

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In flight, an airplane and its operating crew form a 'man-machine' system loop, which, depending on the size and type of aircraft, may be fairly simple or very complex. The function of the crew within the loop is that of controller, and the extent of the control function is governed by the simplicity or otherwise of the machine as an integrated whole. For example, in manually flying an airplane, and manually initiating adjustments to essential systems, the controller's function is said to be a fully active one. If, on the other hand, the flight of an aeroplane and adjustments to essential systems are automatic in operation, then the controller's function becomes one of monitoring, with the possibility of reverting to the active function in the event of failure of systems.

Instruments, of course, play an extremely vital role in the control loop as they are the means of communicating data between systems and controller. Therefore, in order that a controller may obtain a maximum of control quality, and also to minimize the mental effort in interpreting data, it is necessary to pay the utmost regard to the content and form of the data display.

The most common forms of data display applied to aircraft instruments are:

(a) **quantitative,** in which the variable quantity being measured is presented in terms of a numerical value and by the relative position of a pointer or index, and

(b) **qualitative**, in which the information is presented in symbolic or pictorial form.

6.1 Quantitative Displays

There are three principal methods by which information may be displayed:

(i) The circular scale, or more familiarly, the 'clock' type of scale,

(ii) Straight scale, and

(iii) digital, or counter.

Let us now consider these three methods in detail

6.1.1 Circular Scale

This may be considered as the classical method of displaying information in quantitative form and is illustrated in Fig 6.1

The scale base, or graduation circle, refers to the line, which may be actual or implied, running from end to end of the scale and from which the scale marks and line of travel of the pointer are defined.

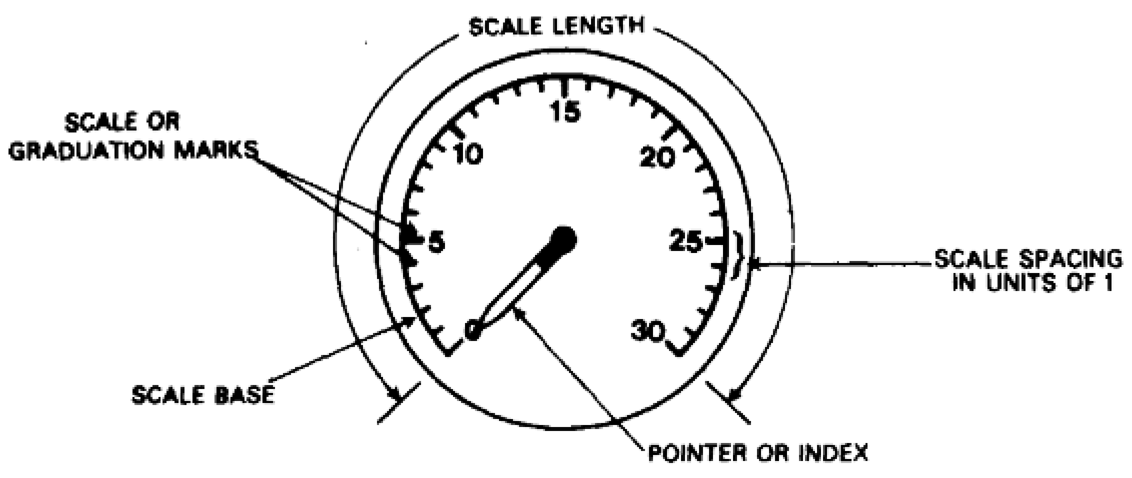


Figure 6.1 Circular scale quantitative display

Scale marks, or graduation marks, are the marks which constitute the scale of the instrument. For quantitative displays it is of extreme importance that the number of marks be chosen carefully in order to obtain quick and accurate interpretations of readings. If there are too few marks dividing the scale, vital information may be lost and reading errors may occur. If, on the other hand, there are too many marks, time will be wasted since speed of reading decreases as the number of markings increases. Moreover, an observer may get a spurious sense of accuracy if the number of scale marks makes it possible to read the scale accurately to, say, one unit (the smallest unit marked) when in actual fact the instrument has an inherent error causing it to be accurate to, say, two units. As far as quantitative-display aircraft instruments are concerned, a simple rule followed by manufacturers is to divide scales so that the marks represent units of 1, 2 or 5 or decimal multiples thereof. The sizes of the marks are also important and the general principle adopted is that the marks which are to be numbered are the largest while those in between are shorter and usually all of the same length.

Spacing of the marks is also of great importance, but since it is governed by physical laws related to the quantity to be measured, there cannot be complete uniformity between all quantitative displays. In general, however, we do find that they fall into two distinct groups, linear and non-linear; in other words, scales with marks evenly and non-evenly spaced. Typical examples are illustrated in Fig6.2, from which it will also be noted that nonlinear displays may be of the square-law or logarithmic-law type, the physical laws in this instance being related to airspeed and rate of altitude change respectively.

The sequence of numbering always increases in a clockwise direction, thus conforming to what is termed the 'visual expectation' of the observer. In an instrument having a center zero, this rule would, of course, only apply to the positive scale, As in the case of marks, numbering is always in steps of 1 , 2, or 5 or decimal multiples thereof. The numbers may be marked on the dial either inside or outside the scale base; the latter method is p referable since the numbers are not covered by the pointer during its travel over the scale.

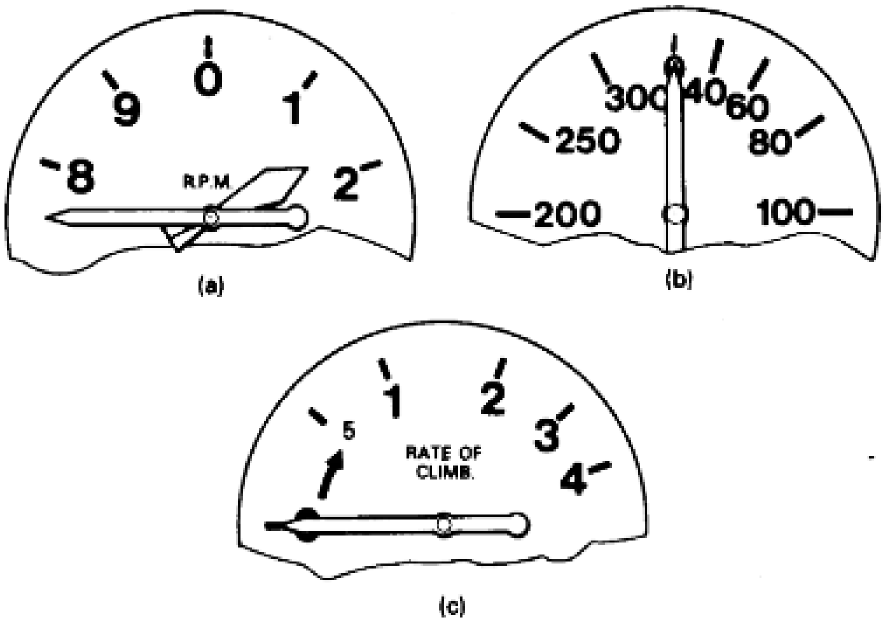


Figure 6.2 Linear and nonlinear scales. (a) Linear; (b) square-law;(c) logarithmic

The distance between the centers of the marks indicating the minimum and maximum values of the chosen range of measurement, and measured along the scale base, is called the scale length. Governing factors in the choice of scale length for a particular range are the size of the instrument, the accuracy with which it needs to be read, and the conditions under which it is to be observed. Under ideal conditions and purely from theoretical considerations, it has been calculated that the length of a scale designed for observing at a distance of 30 in and capable of being read to **1%** of the total indicated quantity, should be about 2 in (regardless of its shape), This means that for a circular-scale instrument a 1 in diameter case would be sufficient. However, aircraft instruments must retain their legibility in conditions which at times may be far from ideal - conditions of changing light, vibrations imparted to the instrument panel, etc. In consequence, some degree of standardization of instrument case sizes was evolved, the utilization of such cases being dictated by the reading accuracy and the frequency at which observations are required. Instruments displaying information which is to be read accurately and at frequent intervals have scales about 7 in in length fitting into standard **3%**in cases, while those requiring only occasional observation, or from which only approximate readings are required, have shorter scales and fit into smaller cases.

6.1.2 High-Range Long-Scale Displays

For the measurement of some quantities, for example, turbine-engine rev./min., airspeed, and altitude, high measuring ranges are involved with the result that very long scales are required. This makes it difficult to display such quantities on single circular scales in standard-size cases, particularly in connection with the number and spacing of the marks. If a large number of marks are required their spacing might be too close to permit rapid reading, while, on the other hand, a reduction in the number of marks in order to open up the spacing will also give rise to errors when interpreting values at points between scale marks.

Some of the displays developed as practical solutions to the difficulties encountered are illustrated in Fig 6.3.

(a) Concentric scales;

(b) fined and rotating scales;

(c) common scale, triple pointers;

(d) split pointer

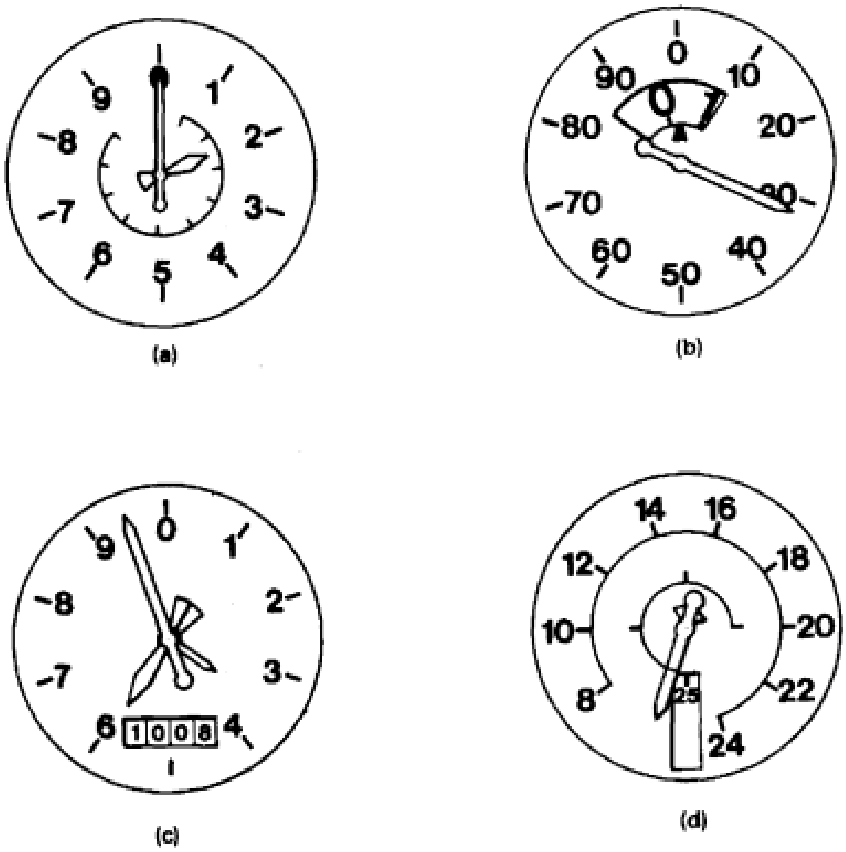


Figure 6.3 High-range long scale displays. (a) Concentric scales; (b) fined and rotating scales; (c) common scale, triple pointers; (d) split pointer.

6.1.2 Angle of Observation

Another factor which has an important bearing on the choice of the correct scale length and case size is the angle at which an instrument is to be observed. It is important because, even though it would be possible to utilize longer scales in the same relevant case sizes, the scale would be positioned so close to the outer edge of the dial plate that it would be obscured when observed at an angle. For thisreason, a standard is also laid down that no part of an instrument should be obscured by the instrument case when observed at angles up to 30° from the normal. A method adopted by some manufacturers, which conforms to this standard, is the fitting of instrument mechanisms inside square cases.

6.1.3 Scale Range and Operating Range

A point quite often raised in connection with instrument scale lengths and ranges is that they usually exceed that actually required for the operating range of the system with which the instrument is associated thus leaving part of the scale unused. At first sight this does appear to be somewhat wasteful, but an example will show that it helps in improving the accuracy with which readings may be observed.

Let us consider a fluid system in which the operating pressure range is say 0-30 lbf/in2. It would be no problem to design a scale for the required pressure indicator which would be of a length equivalent to the system's operating range, also divided into a convenient number of parts as shown in Fig 6.4 (a). However, under certain operating conditions of the system concerned, it may be essential to monitor pressures having such values as 17 or 29 lbf/in2 and to do this accurately in the shortest possible time is not very easy, as a second glance at the diagram will show. Let us now redesign the scale so that its length and range exceed the system's operating range and set out the scale marks according to the rule given on page 2. The result shown at (b) clearly indicates how much easier it is to interpret the values we have considered it essential to monitor.

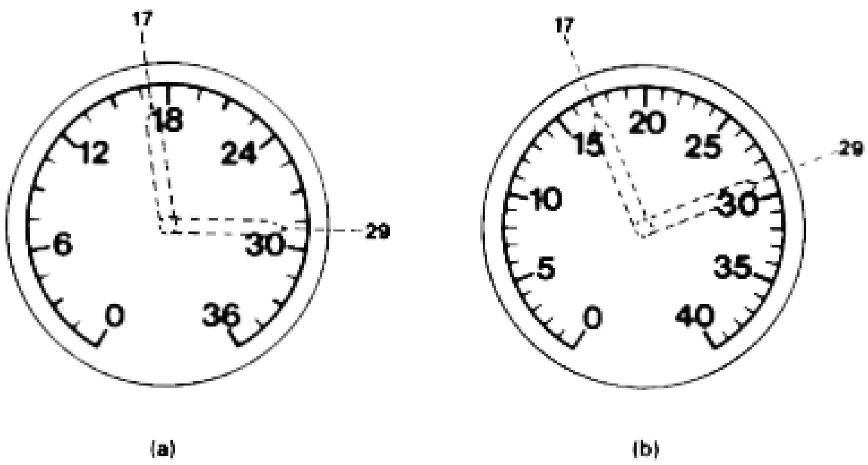


Figure 6.4 Reading accuracy. (a) Equal scale length and operating range; (b)scale range exceeding operating range.

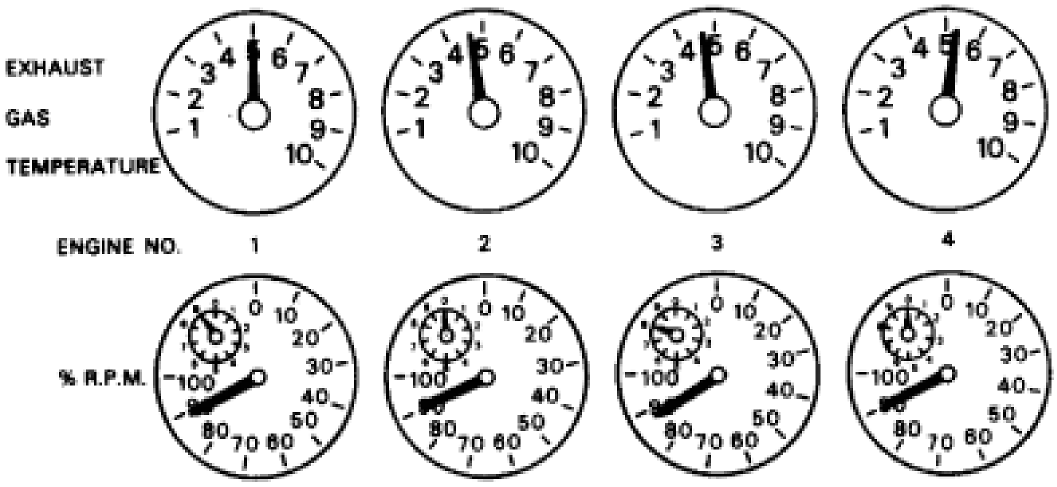
6.1.4 Straight Scale

In addition to the circular scale presentation, a quantitative display may also be of the straight scale (vertical or horizontal) type. For the same reason that the sequence of numbering is given in a clockwise direction on a circular scale, so on a straight scale the sequence is from bottom to top or from left to right

In the field of aircraft instruments there are very few applications of the straight scale and pointer displays, as they are not suitable for the monitoring of the majority of quantities to be measured. However, they do possess characteristics which can contribute to the saving of panel space and improved observational accuracy, particularly where the problems of grouping and monitoring a large number of engine instruments is concerned.

The development of these characteristics, and investigations into grouping and monitoring problems, has resulted in the practical application of another variation of the straight scale display. This is known as the moving-tape or 'thermometer' display and is illustrated in Fig 6.5 as it would be applied to the measurement of two parameters vital to the operation of an aircraft powered by four turbojet engines.

Each display unit contains a servo-driven white tape in place of a pointer, which moves in a vertical plane and registers against a scale in a similar manner to the mercury column of a thermometer. As will be noted there is one display unit for each parameter, the scales being common to all four engines. By scanning across the ends of the tapes, or columns, a much quicker and more accurate evaluation of changes in engine performance can be obtained than from the classical circular scale and pointer display. This fact, and the.fact that panel space can be considerably reduced, are also clearly evident from Fig 6.5.



Engine No.	E.G.T. °C	% R.P.M.
1	500	89
2	470	90
3	480	88
4	520	90

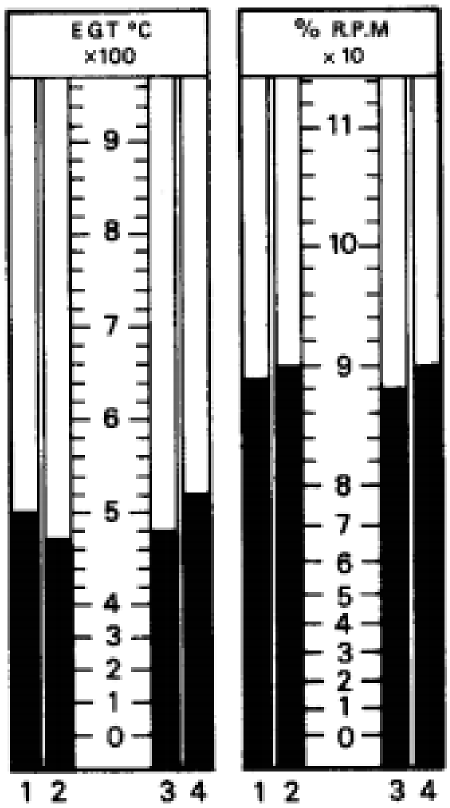


Figure 6.5 Comparison between moving-tape and circular scale displays.

6.1.5 Digital Display

A digital or veeder-counter type of display is one in which data are presented in the form of letters or numbers-alpha-numeric display, as it is technically termed. In aircraft instrument practice, the latter presentation is the most common and a counter is generally to be found, operating in combination with the circular type of display. Typical examples are shown in Fig 6.6. In the application to the altimeter there are two counters; one presents a fixed pressure value which can be set mechanically by the pilot as and when required, and is known-asa static counter display; the other is geared to the altimeter mechanism and automatically presents changes in altitude, and is therefore known as a dynamic counter display. It is of interest to note that the presentation of altitude data by means of a scale and counter is yet another method of solving the long-scale problem already discussed on page 5.

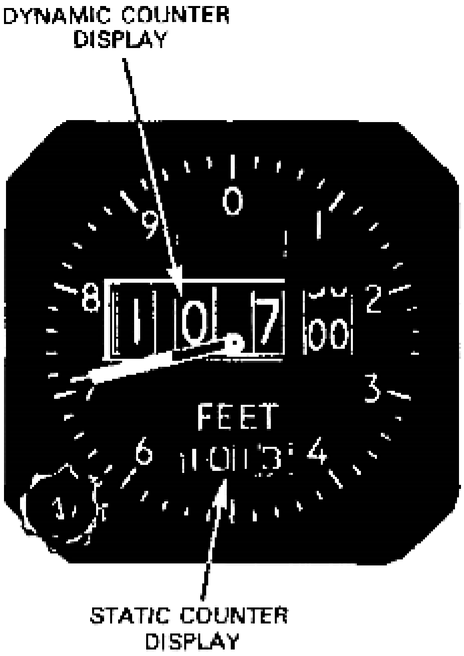


Figure 6.6 Application of digital display.

6.1.6 Dual-Indicator Displays

Dual-indicator displays are designed principally as a means of conserving panel space, particularly where the measurement of the various quantities related to engines is concerned. They are normally of two basic forms: one in which two separate indicators and scales are embodied in one case; and the other, also having two indicators in one case, but with the pointers registering against a common scale.

Typical examples of display combinations are illustrated in Fig 6.7.

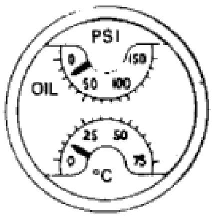
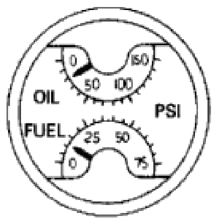
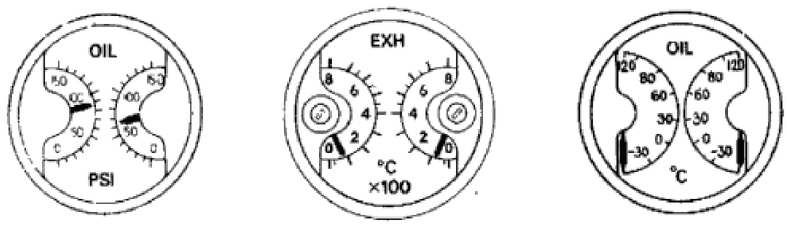
MEASUREMENT	PRESENTATION
A. TWO DIFFERENT QUANTITIES OF ONE SYSTEM	
B. SAME QUANTITY OF TWO DIFFERENT SYSTEMS	
C. SAME QUANTITIES OF TWO IDENTICAL SYSTEMS	

Figure 6.7 Examples of dual-indicator displays.

6.1.7 Colored Displays

The use of color in displays can add much to their value; not, of course from the artistic standpoint, but as a means of indicating specific operational ranges of the systems with which they are associated and to assist in making more rapid assessment of conditions prevailing when scanning the instruments.

Color may be applied to scales in the form of sectors and arcs which embrace the number of scale marks appropriate to the required part of the range, and in the form of radial lines coinciding with appropriate individual scale marks. A typical example is illustrated in Fig 6.8. It is usual to find that colored sectors are applied to those parts of a range in which it is sufficient to know that a certain condition has been reached rather than knowing actual quantitative values. The colors chosen may be red, yellow or green depending on the condition to be monitored. For example, in an aircraft oxygen system it may be necessary for the cylinders to be charged when the pressure has dropped to below, say, 500 Ibf/in2. The system pressure gauge would therefore have a red sector on its dial embracing the marks from 0 to 500; thus, if the pointer should register within this sector, this alone is sufficient indication that recharging is necessary and that it is only of secondary importance to know what the actual pressure is.

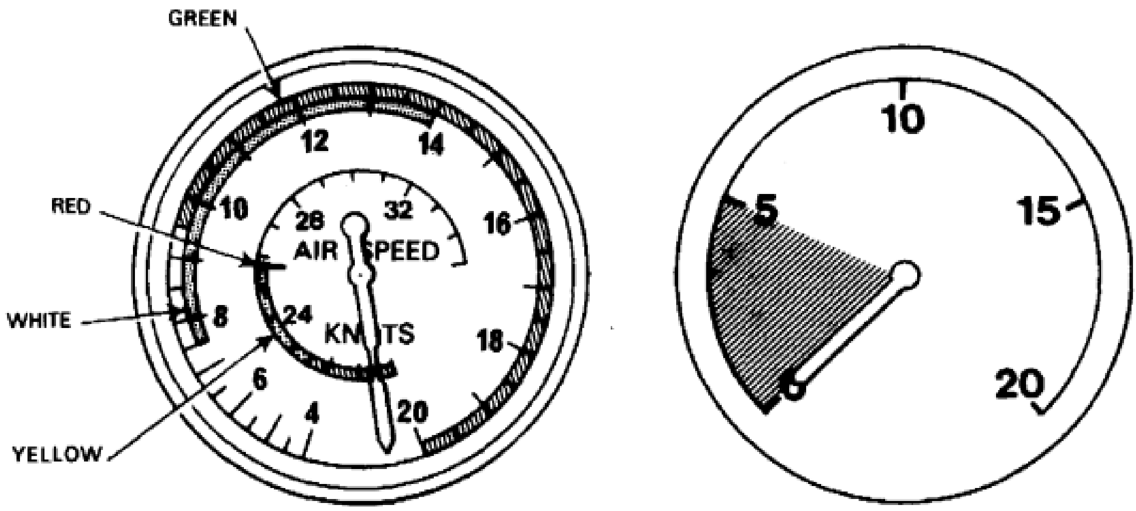


Figure 6.8 Use of color in instrument displays. White arc 75-140; Green arc 95-225; Yellow arc 225-255; Red radial line 255.

Arcs and radial lines are usually called range markings, their purpose being to define values at various points in the range of a scale which are related to specific operational ranges of an aircraft, its power plants and systems.

The definitions of these marks are as follows:

RED radial line : Maximum and minimum limits

YELLOW arc : Take-off and precautionary ranges

GREEN arc : Normal operating range

RED arc : Range in which operation is prohibited

Chapter 6 : Instrument displays, panels and layouts

Lecture 11

Topics

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6.2 Qualitative Displays

These are of a special type in which the information is presented in a symbolic or pictorial form to show the condition of a system, whether the value of an output is increasing or decreasing, the movement of a component and so on. Two typical examples are shown in Fig 6.9. The synchroscope at (a) is used in conjunction with a rev./min. indicating system of an aircraft having a multiple arrangement of propeller-type engines, and its pointers, which symbolize the propellers, only rotate to show the differences of speed between engines.

The display, shown at (b), is a good example of one indicating the movement of components; in this case, flight control surfaces, landing flaps, and air spoilers. The instrument contains seventeen separate electrical mechanisms, which on being actuated by transmitters, position symbolic indicating elements so as to appear at various angles behind apertures in the main dial.

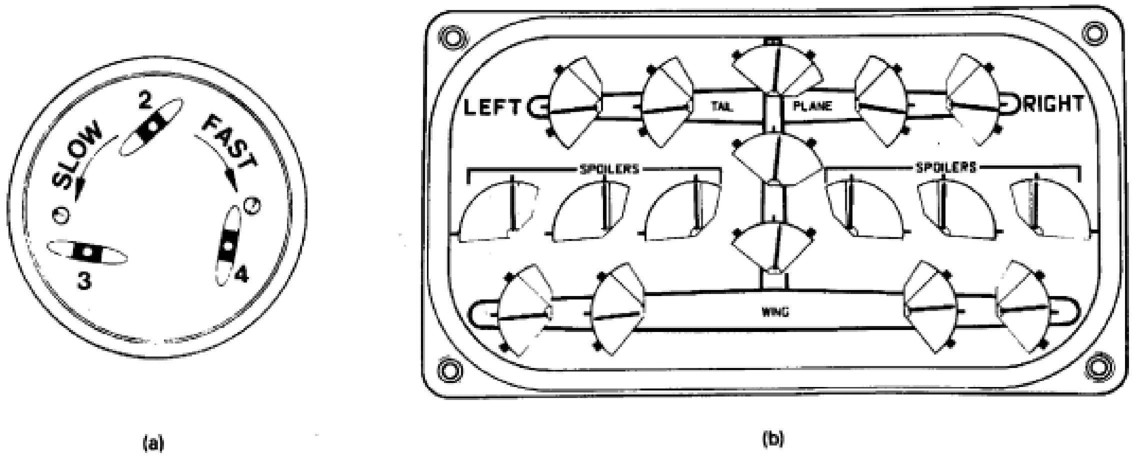


Figure 6.9 Qualitative displays. (a) Engine synchronizing; (b) position of flight control surfaces.

6.3 Director Displays

Director displays are those which are associated principally with flight attitude and navigational data, and presenting it in a manner which indicates to a pilot what control movements he must make either to correct any departure from a desired flight path, or to cause the aircraft to perform a specific manoeuvre. It is thus apparent that in the development of this type of display there must be a close relationship between the direction of control movements and the instrument pointer or symbolic-type indicating element; in other words, movements should be in the 'natural' sense in order that the pilot may obey the 'directives' or 'demands' of the display.

Although flight director displays are of comparatively recent origin as specialized integrated instrument systems of present-day aircraft, in concept they are not new. The gyro horizon which has been in use for many years utilizes in basic form a director display of an aircraft's pitch and bank attitude. In this instrument there are three elements making up the display: a pointer registering against a bank-angle scale, an element symbolizing the aircraft, and an element symbolizing the natural horizon. Both the bank pointer and natural horizon symbol are stabilized by a gyroscope. As the instrument is designed for the display of attitude angles, and as also one of the symbolic elements can move with respect to the other, then it has two reference axes, that of the case which is fixed with respect to the aircraft, and that of the moving element. Assuming that the aircraft's pitch attitude changes to bring the nose up, then the horizon display will be shown as in Fig 6.10 (a), thus directing or demanding the pilot to 'get the nose down'. Similarly, if the bank attitude should change whereby the left wing goes down, then the horizon display would be as shown at (b), directing or demanding the pilot to 'bank the aircraft to the right.' In both cases, the demands would be satisfied by the pilot moving his controls in the natural sense.

Another example of a director display is that utilized in an indicator used in conjunction with the Instrument Landing System (ILS); this is a radio navigation system which aids a pilot in maintaining the correct position of his aircraft during the approach to land on an airport runway. Two radio signal beams are transmitted from the ground; one beam is in the vertical plane and at an angle to the run way to establish the correct approach or glide slope angle; while the other, known as the **localizer**, is in the horizontal plane; both are lined up with the runway centre-line.

A receiver on board the aircraft receives the signals and transmits them to two meters contained within the indicator; one meter controls a glide slope pointer, and the other a localizer pointer. In the majority of current types of aircraft, the (Instrument Landing System)ILS directive display is always presented on two indicators comprising what is termed either an Integrated Instrument System or a Flight Director System. A typical presentation of one of these indicators (referred to as an attitude indicator) is also shown in Fig 6.10. As will be noted, it combines a gyro horizon directive display, and there by eliminates the need for a pilot having to monitor the indications of two separate instruments.

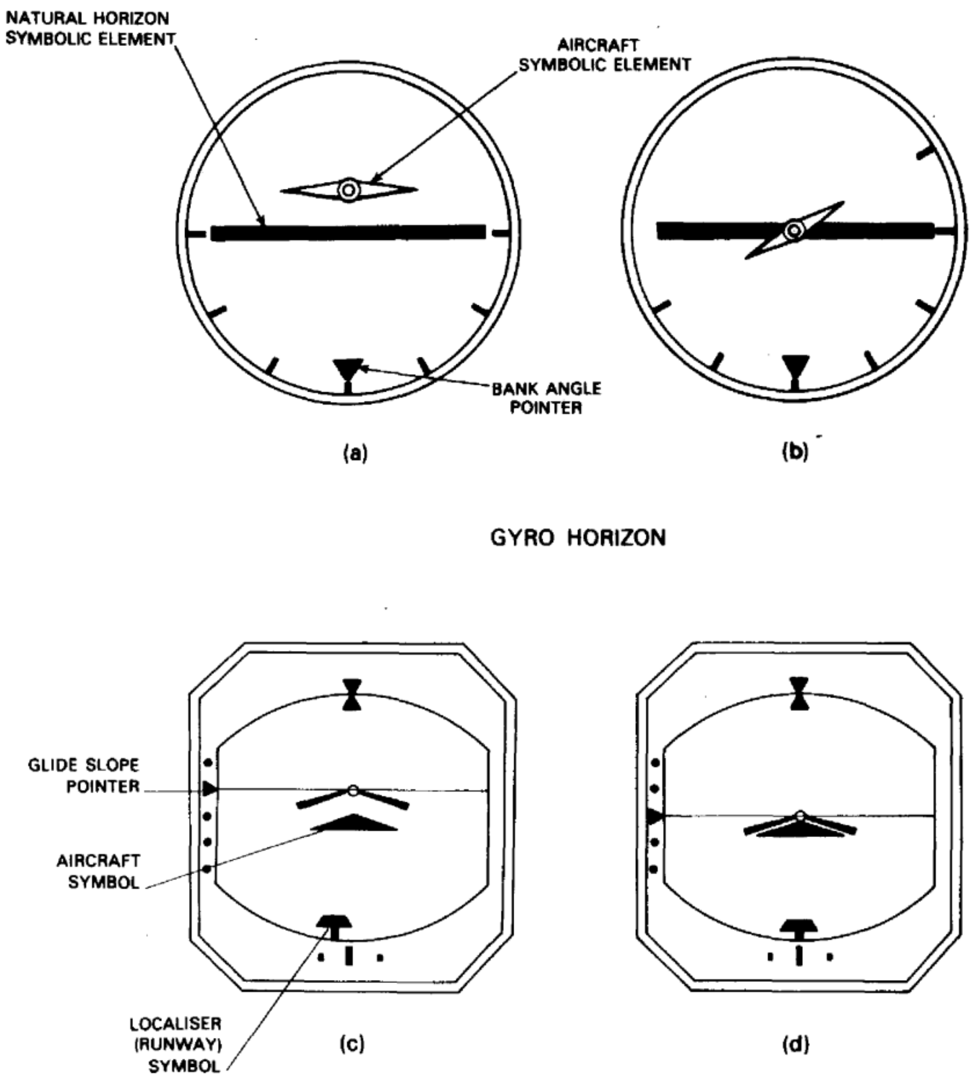


Figure 6.10 Examples of director display. (a) 'Fly down' directive ;(b) 'bank right' directive;(c) 'fly left' and 'fly up' directive; (d) response matches directive.

When the aircraft is on the approach to glide slope beam, the glide slope pointer of the instrument will be deflected upwards as shown in Fig 6.10 (c). Thus, the pilot is directed to 'fly the aircraft up' in order to intercept the beam. Similarly, if the aircraft is to the right of the localizer beam the localizer pointer will be deflected to the left thus directing the pilot to 'fly the aircraft left'. As the pilot responds to the instrument's directives the pointers move back to their centre positions indicating that the aircraft is in the correct approach position for landing. (Fig 6.10 (d)).

It will be apparent from the diagram that as the aircraft is manoeuvred in response to demands, the pointer movements are contrary to the 'natural' sense requirements; for example, in responding to the demand 'fly left' the localizer pointer will move to the right. However, in turning to the left the bank attitude of the aircraft will change into the direction of the turn, and as this will be indicated directly by the gyro horizon display, the response to the ILS demands can be readily cross-checked.

6.4 Head-Up Displays

From the descriptions thus far given of the various instrument displays, we have gained some idea of the development approach to the problem of presenting data which are to be quickly and accurately assimilated. The simplicity or otherwise of assimilation is dictated by the number of instruments involved, and by the amount of work and instrument monitoring sequences to be performed by a pilot during the various phases of flight. In the critical approach and landing phase, a pilot must transfer his attention more frequently from the instruments to references outside the aircraft, and back again; a transition process which is time-consuming and fatiguing as a result of constant re-focusing of the eyes.

A method of alleviating these problems has therefore been developed in which vital flight data are presented at the same level as the pilot's line-of-sight when viewing external references, i.e. when he is maintaining a 'head-up' position. The principle of the method is to display the data on the face of a special cathode-ray tube and to project them optically as a composite symbolic image on to a transparent reflector plate, or directly on the windscreen. The components of a typical head-up display system are shown in Fig 6.11. The amount of data required is governed by the requirements of the various flight phases and operational role of an aircraft, i.e. civil or military, but the four parameters shown are basic. The data are transmitted from a data computer unit to the cathode-ray tube the presentation of which is projected by the optical system to infinity. It will be noted that the attitude presentation resembles that of a normal gyro horizon, and also that airspeed and altitude are presented by markers which register against linear horizontal and vertical scales. The length, or range, of the scales is determined by operational requirements, but normally they only cover narrow bands of airspeed and altitude information. This helps to reduce irrelevant markings and the time taken to read and interpret the information presented.

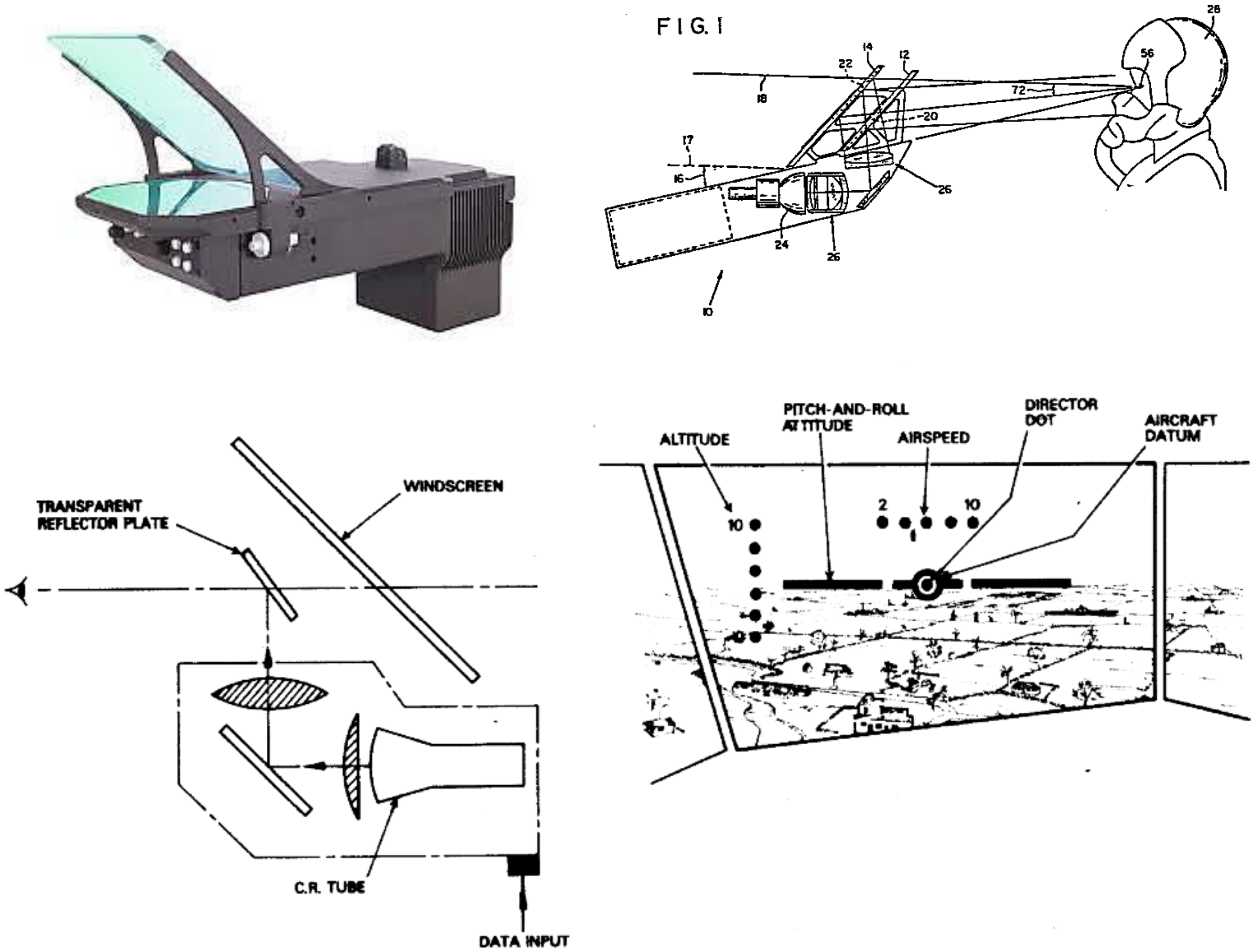


Figure 6.11 Head-up display systems.

Figure 6.12 illustrates the head-up display of a system known as a Visual Approach Monitor (VAM). The system is an airborne equivalent of the Visual

Approach Slope Indicator (VASI) and was evolved principally as an aid to pilots when approaching airfields not equipped with VASI, ILS, or other approach aids.

The display unit is mounted on a sliding tray located at a glare shield panel in front of the pilot, and when required, the tray is pulled out to automatically raise the lens through which the display is projected. The display provides the following cues: vertical approach angle, horizontal attitude, and speed error. Approach angle is displayed by two vertical scales, one each side of the lens, and graduated in degrees above and below the fixed bar symbolizing the aircraft. The required angle is selected on a control module to position the scales relative to the bar. During an approach, the pilot holds the bar symbol in his line pf sight and controls the aircraft so that the symbol is aligned with the runway threshold or touchdown zone, thereby ensuring the approach is at the selected flight path angle.

The speed error cue is in the form of three symbols which are coloured to indicate whether the aircraft approach speed is correct, too fast, or too slow (see Fig 6.12). The error between actual airspeed and that selected on the control module is indicated by variations in the light intensity of the three symbols. For example, if the approach airspeed drops to eight knots or more below the selected airspeed, this is displayed by the red symbol 'S' appearing at full intensity and flashing on and off continuously.

6.5 Light-Emitting Displays

In the continuing development of aircraft displays, the trend has been to exploit the techniques applied to those instruments which are taken so much for granted these days; namely, the pocket calculator and the digital watch. The displays adopted in both these instruments are of the 'light-emitting' type the basis of which, in its turn, has its origin in the well-known cathode-ray display.

There are several ways in which numerical data can be displayed by means of light-emission, but the ones which are of interest in this context are the liquid-crystal display and the light-emitting diode display.

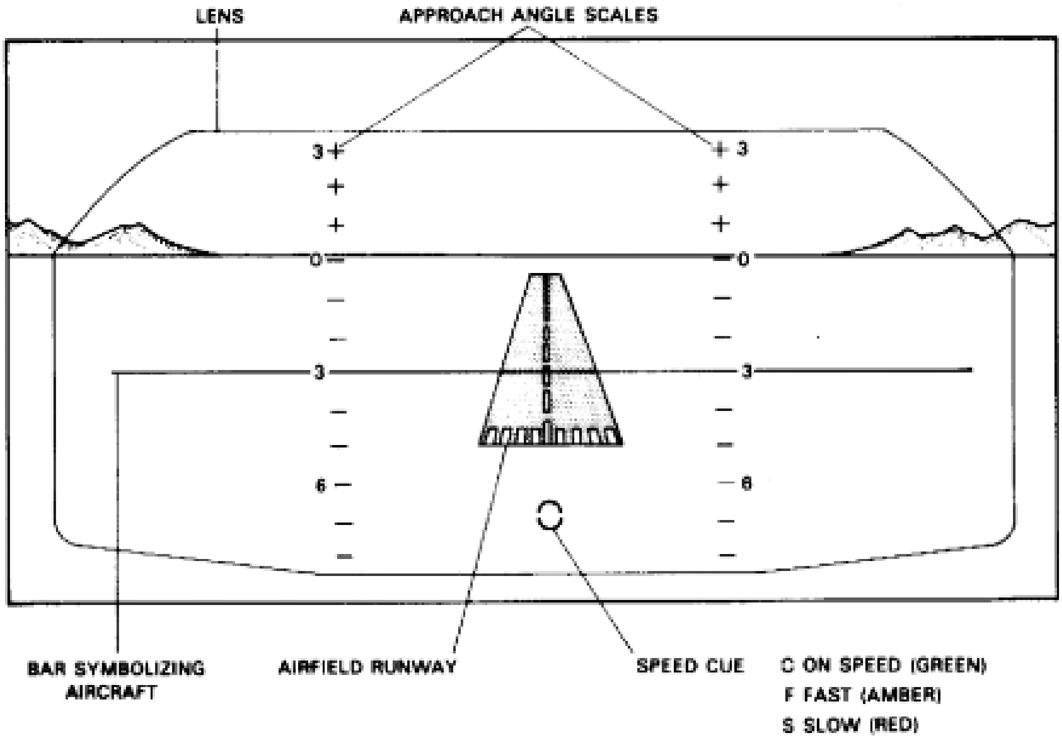


Figure 6.12 Visual approach monitor display.

6.5.1 Liquid-Crystal Display (LCD)

The basic structure of an LCD (see Fig 6.13) consists of two glass plates, coated on their inner surfaces with a thin transparent conductor such as indium oxide. The conductor on the front plate is etched into a standard display format of seven bars or segments each segment forming an electrode. Each bar is electrically separate and is selected by a logic driver circuit which causes the bars to illuminate in patterns forming the digit to be displayed (diagram (b)). A mirror image of the digits with its associated electrical contact is also etched into the oxide layer of the back glass plate, but this is not segmented since it constitutes a common return for all segments.

6.5.2 Light-Emitting Diode (LED)

An LED is essentially a transistor and so, unlike an LCD, it is classified as a solid-state display; the construction is shown in Fig 6.14. The heart of the display

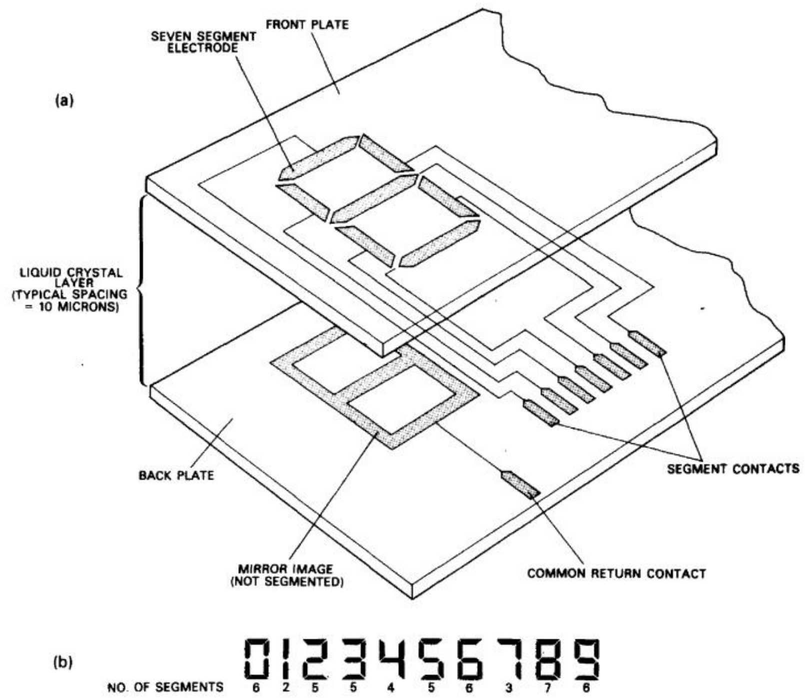
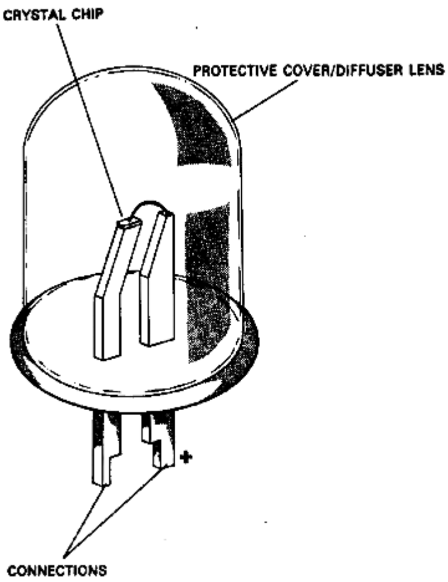


Figure 6.13 Liquid crystal display (LCD).

is a slice or chip of gallium arsenide phosphide (GaAsP) moulded into a transparent plastic covering which not only serves to protect the chip, but also as a diffuser lens. The diode leads are soldered to a printed circuit board to form the numerical display required, e.g. the digit segment already referred to. When current flows through the chip it produces light which is directly transmitted in proportion to the current flow. To provide different colours, the proportion of Gap and GaAs is varied during manufacture of the chip, and also the technique of 'doping' with other elements e.g. oxygen or nitrogen is applied.

In the normal 7-bar or segment display format, it is usual to employ. one LED per segment, but the number depends on the overall size of the digits required for display and its appearance.



LED vertical scale display.

Figure 6.14 Light-emitting diode (LED).

6.6 Instrument Panels and Layouts

All instruments essential to the operation of an aircraft are accommodated on special panels the number and distribution of which vary in accordance with the number of instruments, the size of aircraft and cockpit layout. A main instrument panel positioned in front of pilots is a feature common to all types of aircraft; since it is mandatory for the primary flight instruments to be installed within the pilots' normal line of vision (see Fig 6.15.) Typical positions of other panels are: overhead, at the side, and on a control pedestal located centrally between the pilots.

6.7 Instrument Grouping

6.7.1 Flight Instruments

Basically there are six flight instruments whose indications are so co-ordinated as to create a 'picture' of an aircraft's flight condition and required control movements; they are airspeed indicator, altimeter, gyro horizon, direction indicator, vertical speed indicator and turn-and-bank indicator. It is therefore most important for these instruments to be properly grouped to maintain co-ordination and to assist a pilot to observe them with the minimum of effort.

Figure 6.15 Location of instrument panels in a turbo jet airliner.

The first real attempt at establishing a standard method of grouping was the 'blind flying panel' or 'basic six' layout shown in Fig 3.18 (a).

With the development and introduction of new types of aircraft, flight instruments and integrated instrument systems, it became necessary to review the functions of certain instruments and their relative positions within the group. As a result a grouping known as the 'basic T' was introduced (Fig 3.18 (b)). The theory behind this method is that it constitutes a system by which various items of related flight information can be placed in certain standard locations in all instrument panels regardless of type or make of instrument used. In this manner, advantage can be taken of integrated instruments which display more than one item of flight information

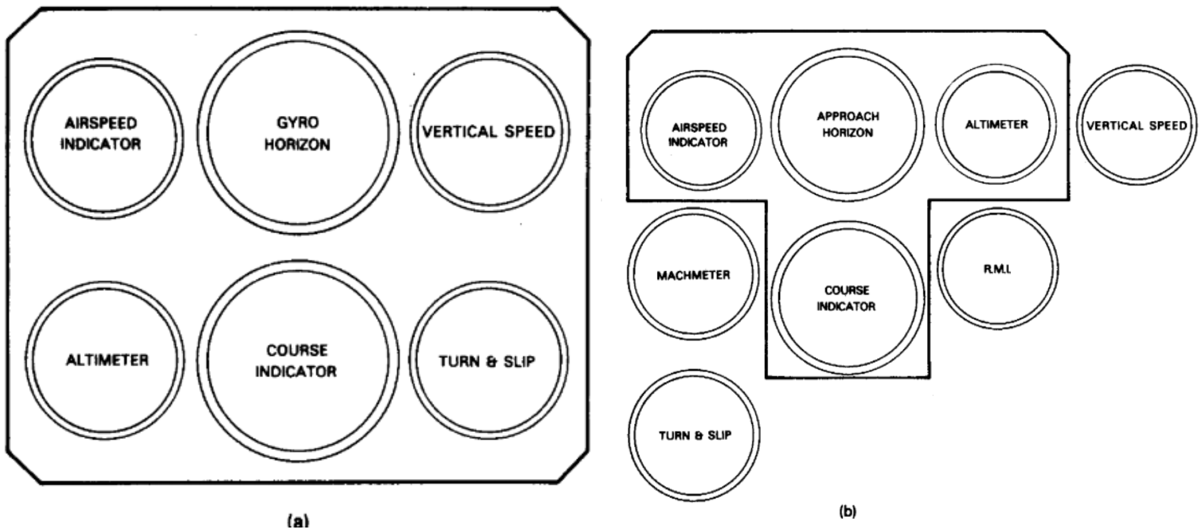


Figure 6.16 Flight instrument grouping. (a) 'Basic six'; (b) 'basic T'.

6.7.2 Power-Plant Instruments

The specific grouping of instruments required for the operation of power plants is governed primarily by the type of power plant, the size of the aircraft and therefore the space available. In a single engined aircraft, this does not present much of a problem since the small number of instruments may flank the pilot's flight instruments thus keeping them within a small 'scanning range'

The problem is more acute in multi-engined aircraft; duplication of power plants means duplication of their essential instruments. For twin-engined aircraft, and for certain medium-size four-engined aircraft, the practice is to group the instruments at the center of the main instrument panel and between the two groups of flight instruments.

In some large types of public transport aircraft, a flight engineer's station is provided in the crew compartment and all the power plant instruments are grouped on the control panels at this station (Fig 6.17). Those instruments measuring parameters required to be known by a pilot during take-off, cruising and landing, e.g. rev./min. and turbine temperature, are duplicated on the main instrument panel.

Figure 6.17 Instrument grouping at a flight engineer's station.

The positions of the instruments in the power plant group are arranged so that those relating to each power plant correspond to the power plant positions as seen in plan view. It will be apparent from the layout of Fig 6.18 that by scanning a row of instruments a pilot or engineer can easily compare the readings of a given parameter, and by scanning a column of instruments can assess the over-all performance pattern of a particular power plant. Another advantage of this grouping method is that all the instruments for one power plant are more easily associated with the controls for that power plant. A practical example of this method of grouping as adopted in the Boeing 747 is shown in Fig 6.18 (b).

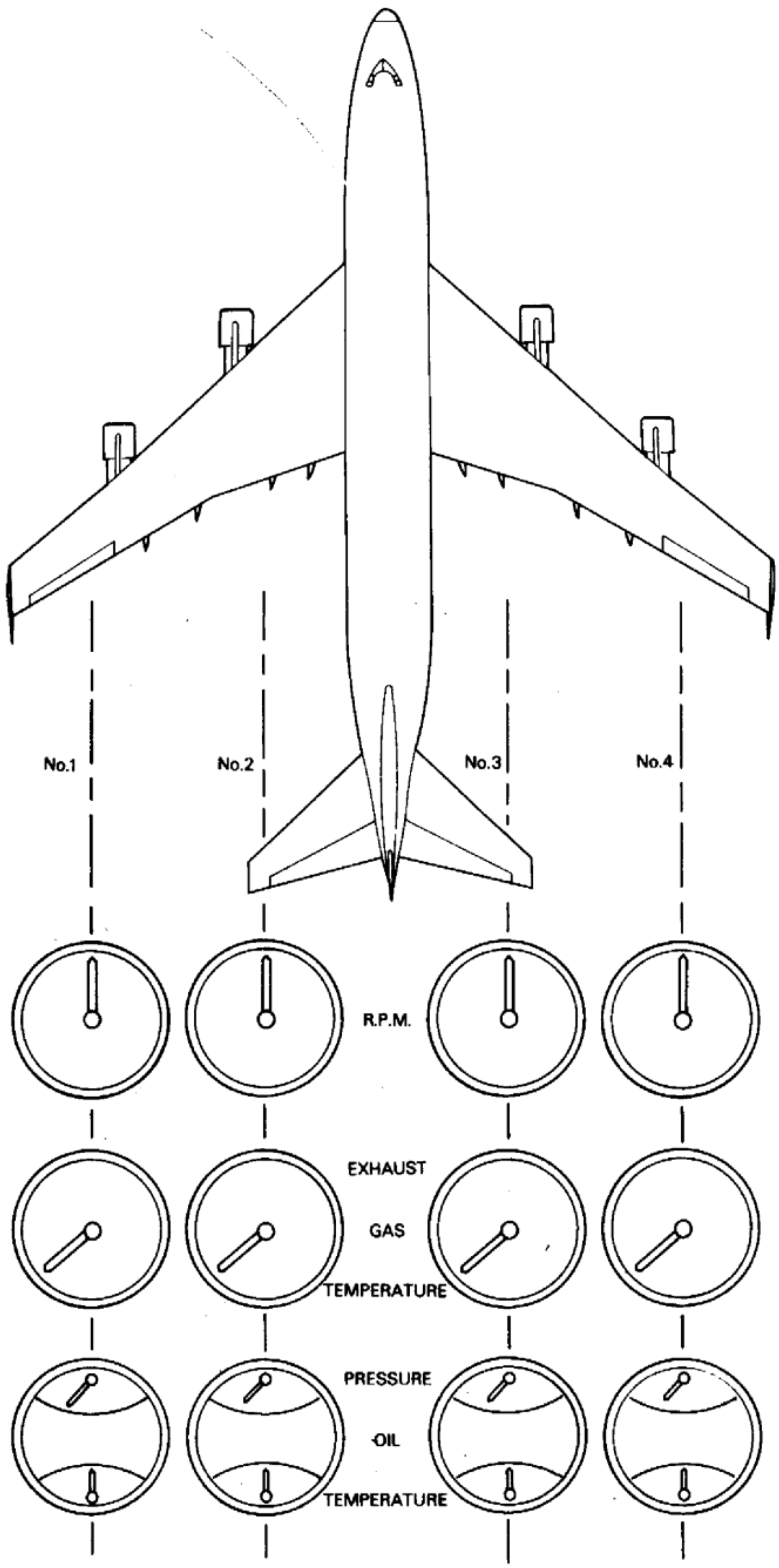


Figure 6.18(a) Power plant instrument grouping.

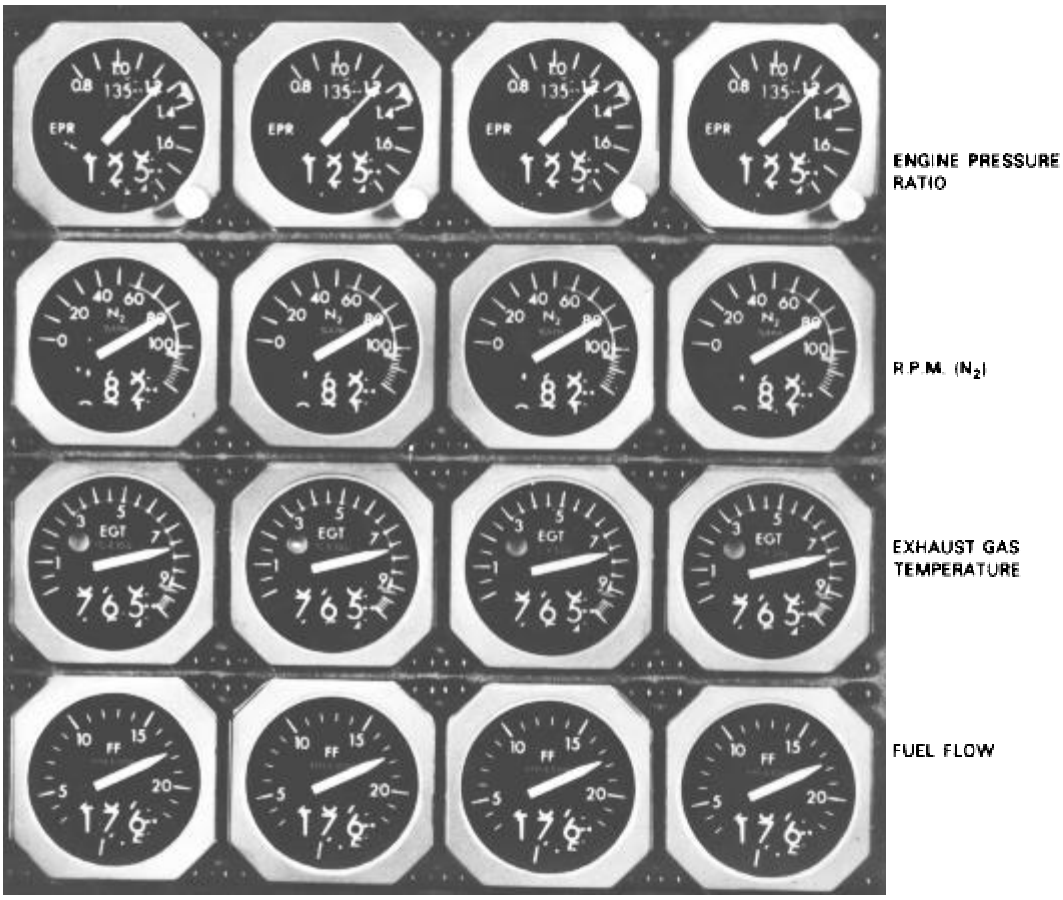


Figure 6.18 (b) Power plant instrument grouping- Boeing 747.

6.8 Illumination of Instruments and Instrument Panels

When flying an aircraft at night, or under adverse conditions of visibility, a pilot is dependent on instruments to a much greater extent than he is when flying in daylight under good visibility conditions, and so the ability to observe their readings accurately assumes greater importance. For example, at night, the pilot's attention is more frequently divided between the observation of instruments and objects outside the aircraft, and this of course results in additional ocular and general fatigue being imposed on him, Adequate illumination of instruments and the panels to which they are fitted is therefore an essential requirement.

The colour chosen for lighting systems has normally been red since this is considered to have the least effect on what is termed the 'darkness adaptation characteristic' of the eyes. As a result of subsequent investigations and tests, however, it would appear that white light has less effect, and this is now being used in some current types of aircraft.

6.8.1 Pillar and Bridge Lighting

Pillar lighting, so called from the method of construction and attachment of the lamp, provides illumination for individual instruments and controls on the various cockpit panels. A typical assembly, shown in Fig 6.19 (a), consists of a miniature centre- ontact filarnentlamp inside a housing, which is a push fit into the body of the assembly. The body is threaded externally for attachment to the panel and has a hole running through its length to accommodate a cable which connects the positive supply to the centre contact. The circuit through the lamp is completed by a ground tag to connect to the negative cable.

Light is distributed through a red filter and an aperture in the lamp housing. The shape of the aperture distributes a sector of light which extends downwards over an arc of approximately 90^{o} to a depth slightly less than 2 in from the mounting point.

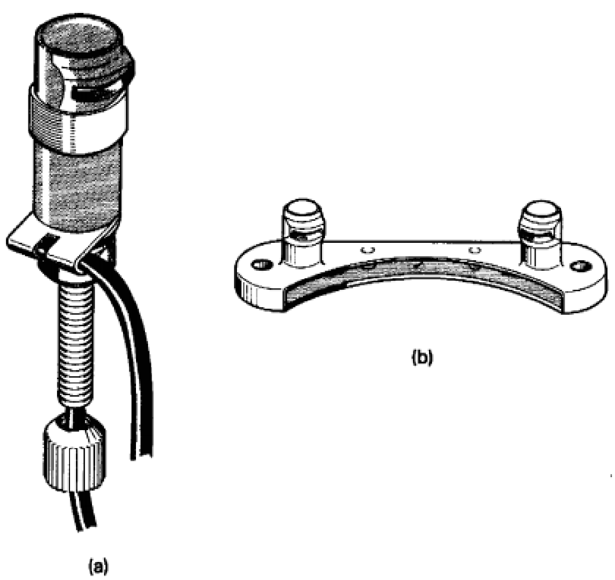


Figure 6.19 Pillar light assemblies.

The bridge type of lighting (Fig 3.19 (b)) i s a multi-lamp development of the individual pillar lamp already described. Two or four lamps are fitted to a bridge structure designed to fit over a variety of the standardized instrument cases. The bridge fitting is composed of two light-alloy pressings secured together by rivets and spacers, and carrying the requisite number of centre contact assemblies above which the lamp housings are mounted, Wiring arrangements provide for two separate supplies to the lamps thus ensuring that loss of illumination cannot occur as a result of failure of one circuit.

6.8.2 Wedge-Type Lighting

This method of instrument lighting derives its name from the shape of the two portions which together make up the instrument cover glass. It relies for its operation upon the physical law that the angle at which light leaves a reflecting surface equals the angle at which it strikes that surface.

The two wedges are mounted opposite to each other and with a narrow air-space separating them, as shown in Fig 6.20. Light is introduced into wedge A from two 6V lamps set into recesses in its wide end. A certain amount of light passes directly through this wedge and onto the face of the dial while the remainder is reflected back into the wedge by its polished surfaces. The angle at which the light rays strike the wedge surfaces governs the amount of light reflected; the lower the angle, the more light reflected.

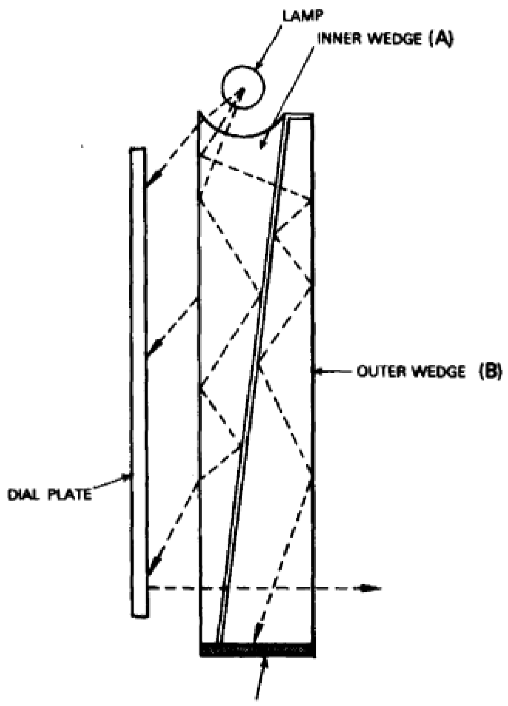


Figure 6.20 Wedge-type lighting.

6.9 Questions

1. Describe two of the methods adopted for the display of indications related to high-range measurements.
2. What is the purpose of a 'platform scale'? Describe its arrangement.
3. Name some of the aircraft instruments to which a digital counter display is applied.
4. What is the significance of coloured markings applied to the dials of certain instruments?
5. If it is necessary to apply coloured markings to the cover glass of an instrument, what precautions must be taken?
6. What types of display would you associate with the following instruments: (a) a synchroscope, (b) an altimeter, (c) a gyro horizon?
7. What do you understand by the term "head-up display"? With the aid of diagrams describe how required basic flight data is displayed to a pilot.
8. Describe the 'basic T' method of grouping flight instruments.
9. Briefly describe one form of light-emitting display. .
10. Describe one of the methods of illuminating instrument dials,
11. Why the engineering used Head-Up Displays in aircrafts?
12. Why the engineering put the instruments as croups in aircrafts**?**
13. Which colors are used for lighting systems of Instrument Panels? Why?
14. Number two types of lighting Instrument Panels.
15. What is the problem of multi - aircraft engines for Power-Plant Instruments?