Fig. 2.16. If they are connected in series, determine the maximum possible resistance of the combination.

Solution

(a) The first band is red so the first digit is 2; the second band is red so the second digit is 2; the third band is brown so there is one zero. There is no fourth band so that the tolerance is 20 per cent. The nominal value of this resistor is therefore 220 Q and its tolerance is 20 per cent so that its resistance should lie between 220 − 44 = 176 *Cl* and 220 + 44 = 264 *SI*.

(b) The first band is orange so the first digit is 3; the second band is white so the second digit is 9; the third band is red so there are two noughts; the fourth band (silver) means that the tolerance is 10 per cent. The nominal value of this resistor is therefore 3900 O (3.9 kfl) and its value lies between 3510 IT (−10 per cent) and 4290 *SI* (+10 per cent).

(c) The bands on this resistor represent 5 (first digit), 6 (second digit) and red (two zeros) so its nominal value is 5600 *SI* (5.6 kfl). The fourth band (gold) means that its tolerance is ±5 per cent and so its value must be within the range 5320 *SI* (5.32 kfl) to 5880 *SI* (5.88 kO).

If these resistors were to be connected in series the equivalent resistance of the combination would lie between 9006 fl (9.006 kfl) and 10 434 *SI* (10.434 kfl).

Non-linear resistors

A resistor which does not obey Ohm's law, that is one for which the graph of voltage across it to a base of current through it is not a straight line, is said to be non-linear. Most resistors are non-linear to a certain degree because as we have seen the resistance tends to vary with temperature which itself varies with current. So the term non-linear is reserved for those cases where the variation of resistance with current is appreciable. For example, a filament light bulb has a resistance which is very much lower when cold than when at normal operating temperature.

Capacitance

If we take two uncharged conductors of any shape whatever and move Q coulombs of charge from one to the other an electric potential difference will be set up between them (say V volts). It is found that this potential difference is proportional to the charge moved, so we can write V « Q or Q « V. Introducing a constant we have

$$Q = CV \qquad (2.18)$$

where C is the constant of proportionality and is called the capacitance of the conductor arrangement. It is a measure of the capacity for storing charge.

An arrangement of conductors having capacitance between them is called a capacitor and the conductors are called plates. The circuit symbol for a capacitor is always as shown in Fig. 2.17 whether the plates themselves are parallel plates, concentric cylinders, concentric spheres or any other configuration of conducting surfaces. The unit of capacitance is the farad (F) named in honour of Michael Faraday (1791–1867), an English scientist.

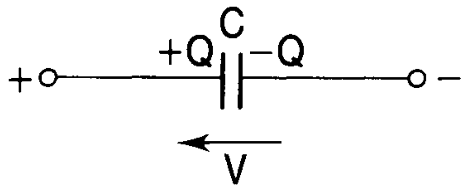

Figure 2.17

It is found that the capacitance of a capacitor depends upon the geometry of its plates and the material in the space between them, which Faraday called the dielectric. For a given arrangement of the plates the capacitance is greater with a dielectric between the plates than it is with a vacuum between them by a factor which is constant for the dielectric. This constant is called the relative permittivity of the dielectric, symbol ϵ_r and is dimensionless. The absolute permittivity (ϵ) of a dielectric is then ϵ_r multiplied by the permittivity of free space (ϵ_0) so that

$$\epsilon = \epsilon_0 \epsilon_r \tag{2.19}$$

For a vacuum, by definition, $\epsilon_r = 1$.

Permittivity is a very important constant in electromagnetic field theory and relates electric field strength (E) to electric flux density or displacement (D). In fact

$$D = \epsilon E \tag{2.20}$$

The capacitance of some commonly encountered conductor configurations is given below.

- Parallel plates of cross-sectional area A and separation d:

  $$C = A\epsilon/d \quad \text{farad} \tag{2.21}$$

- Concentric cylinders of radii a (inner cylinder) and b (outer cylinder) of which a coaxial cable is an important example:

  $$C = 2\pi\epsilon/\ln(b/a) \quad \text{farad per metre} \tag{2.22}$$

- Parallel cylinders of radii r and separation d of which overhead transmission lines are an important example:

$C = \pi\epsilon/\ln(d/r)$ farad per metre (2.23)

Example 2.14

Two parallel plates each of area $100\ \text{cm}^2$ are separated by a sheet of mica 0.1 mm thick and having a relative permittivity of 4.

(1) Given that the permittivity of free space $(\epsilon_0) = 8.854 \times 10^{-12}$ F/m, calculate the capacitance of the capacitor formed by this arrangement.

(2) Determine the charge on the plates when a potential difference of 400 V is maintained between them.

Solution

From Equation (2.21) the capacitance is given by $C = A\epsilon_0\epsilon_r/d$. In this case $A = 100 \times 10^{-4}\ \text{m}^2$; $d = 0.1 \times 10^{-3}$ m; $\epsilon_r = 4$ and $\epsilon_0 = 8.854 \times 10^{-12}$ F/m. Therefore

$$C = 100 \times 10^{-4} \times 8.854 \times 10^{-12} \times 4/(0.1 \times 10^{-3}) = 3.54\ \text{nF}$$

From Equation (2.18) $Q = CV = 3.54 \times 10^{-9} \times 400 = 1.4\ \mu\text{C}$.

Capacitors in series

Capacitors connected as shown in Fig. 2.18 are said to be in series. Applying a voltage V will cause a charge $+Q$ to appear on the left-hand plate of C_1 which will attract electrons amounting to $-Q$ coulombs to the right-hand plate. Similarly, a charge of $-Q$ appears on the right-hand plate of C_2 which will repel electrons from its left-hand plate, leaving it positively charged at $+Q$. Thus the charge throughout this series combination is of the same magnitude (Q). Remember that electric current is charge in motion and that the current at every point in a series circuit is the same. We have seen that $Q = CV$ so that $V_1 = Q/C_1$ and $V_2 = Q/C_2$.

A single capacitor which is equivalent to the series combination would have to have a charge of Q coulombs on its plates and a potential difference of $(V_1 + V_2)$ volts between them. The capacitance of this equivalent capacitor is therefore given by $C_{eq} = Q/V$ and so $V = Q/C_{eq}$. Since $V = V_1 + V_2$ then $Q/C_{eq} = Q/C_1 + Q/C_2$ and

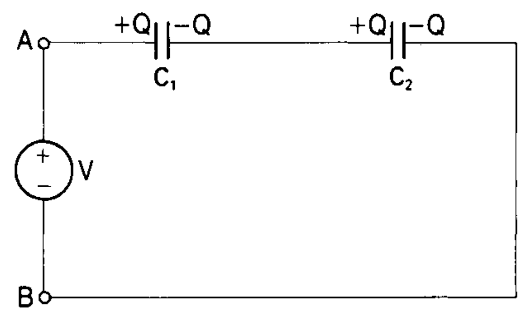

Figure 2.18

$1/C_{eq} = 1/C_1 + 1/C_2$

In general for n capacitors in series we have, for the equivalent capacitance,

$$1/C_{eq} = 1/C_1 + 1/C_2 + \cdots + 1/C_n \quad (2.24)$$

Note that this is of a similar form to the equation for resistors in parallel.

Capacitors in parallel

Capacitors connected as shown in Fig. 2.19 are said to be in parallel. We have

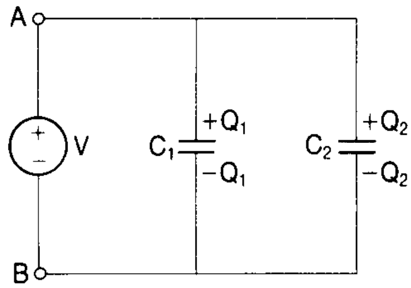

Figure 2.19

that $Q_1 = C_1V$ and that $Q_2 = C_2V$. A single capacitor which is equivalent to the parallel combination would have to have a potential difference of V volts between its plates and a total charge of $Q_1 + Q_2$ on them. Thus

$$C_{eq} = (Q_1 + Q_2)/V = (C_1V + C_2V)/V = C_1 + C_2$$

In general for n capacitors connected in parallel

$$C_{eq} = C_1 + C_2 + \cdots + C_n \quad (2.25)$$

Note that this is of the same form as the equation for a number of resistors in series.

Example 2.15

Determine the values of capacitance obtainable by connecting three capacitors (of 5 μF, 10 μF and 20 μF) (1) in series, (2) in parallel and (3) in series–parallel.

Solution

Let the capacitors of 5 μF, 10 μF and 20 μF be C_1, C_2, and C_3, respectively.

1 From Equation (2.24) the equivalent capacitance is the reciprocal of $(1/C_1 + 1/C_2 + 1/C_3)$ i.e.
$1/[(1/5) + (1/10) + (1/20)] = 1/[0.2 + 0.1 + 0.05] = 1/0.35 = 2.86$ μF

2 From Equation (2.25) the equivalent capacitance is
$C_1 + C_2 + C_3 = 5 + 10 + 20 = 35$ μF

3 (a) When C_1 is connected in series with the parallel combination of C_2 and C_3 the equivalent capacitance is the reciprocal of
$[1/C_1 + 1/(C_2 + C_3)] = 1/[1/5 + 1/30] = 1/[0.2 + 0.033] = 4.29\ \mu F$
(b) Similarly when C_2 is in series with the parallel combination of C_3 and C_1 the equivalent capacitance is
$1/[1/10 + 1/25] = 1/[0.1 + 0.04] = 1/0.14 = 7.14\ \mu F$
(c) Similarly when C_3 is in series with the parallel combination of C_1 and C_2 the equivalent capacitance is
$1/[1/20 + 1/15] = 1/[0.05 + 0.066] = 1/0.116 = 8.62\ \mu F$

Variation of potential difference across a capacitor

From $CV = Q = \int i\,dt$ we have that

$$V = (1/C)\int i\,dt \qquad (2.26)$$

It follows that the voltage on a capacitor cannot change instantly but is a function of time.

Inductance

A current-carrying coil of N turns, length l and cross-sectional area A has a magnetic field strength of

$$H = (NI/l) \quad \text{amperes per metre} \qquad (2.27)$$

where I is the current in the coil. The current produces a magnetic flux (ϕ) in the coil and a magnetic flux density there of

$$B = (\phi/A) \quad \text{teslas} \qquad (2.28)$$

The vectors H and B are very important in electromagnetic field theory.

If the coil is wound on a non-ferromagnetic former or if it is air-cored, then $B \propto H$ and the medium of the magnetic field is said to be linear. In this case

$$B = \mu_0 H \qquad (2.29)$$

where μ_0 is a constant called the permeability of free space. Its value is $4\pi \times 10^{-7}$ SI units. If the coil carries current which is changing with time then the flux produced by the current will also be changing with time and an emf is induced in the coil in accordance with Faraday's law. This states that the emf (E) induced in a coil or circuit is proportional to the rate of change of magnetic flux linkages (λ) with that coil ($E \propto d\lambda/dt$). Flux linkages are the product of the flux (ϕ) with the number of turns (N) on the coil, so $E \propto d(N\phi)/dt$. It can be shown that the magnitude of the emf induced in a coil having N turns, a cross-sectional area of A and a length l and which carries a current changing at a rate of dI/dt ampere per second is given by

$$E = [(\mu_0 N^2 A)/l](dI/dt) \qquad (2.30)$$

The coefficient of $\mathrm{d}I/\mathrm{d}t$ (i.e. $\mu_0 N^2 A/l$) is called the coefficient of self-inductance of the coil or, more usually, simply the inductance of the coil. A coil having inductance is called an inductor. The symbol for inductance is L and so

$$L = (\mu_0 N^2 A)/l \tag{2.31}$$

Substituting in Equation (2.30) we have

$$E = L(\mathrm{d}I/\mathrm{d}t) \tag{2.32}$$

From Equation (2.32) we see that the unit of L is the unit of E times the unit of t divided by the unit of I, i.e. the volt-second per ampere ($\mathrm{V\,s\,A^{-1}}$). This is called the henry in honour of Joseph Henry (1797–1878), an American mathematician and natural philosopher.

A coil has an inductance of 1 henry when a current changing in it at the rate of 1 ampere per second causes an emf of 1 volt to be induced in it. The circuit symbol for inductance is shown in Fig. 2.20.

Figure 2.20

Non-linear inductance

If the coil is wound on a ferromagnetic former it is found that the flux density B is no longer proportional to the magnetic field strength H (i.e. the flux produced is not proportional to the current producing it). We now write

$$B = \mu H \tag{2.33}$$

where $\mu = \mu_r \mu_0$ and is called the permeability of the medium of the field. It (and μ_r, the relative permeability) varies widely with B. The inductance is now given by

$$L = \mu_0 \mu_r N^2 A/l \tag{2.34}$$

This also varies with B (and H and current) and so is non-linear.

Example 2.16

(1) A wooden ring has a mean diameter of 0.2 m and a cross-sectional area of 3 cm^2. Calculate the inductance of a coil of 350 turns wound on it.

(2) If the wooden ring were replaced by one of a ferromagnetic material having a relative permeability of 1050 at the operating value of magnetic flux density, determine the new value of inductance.

Solution

1 Since the ring, shown in Fig. 2.21, is of wood (a non-ferromagnetic material) the inductance of the coil is given by Equation (2.31) with $N = 350$, $A = 3 \times 10^{-4}\ \text{m}^2$, $l = \pi \times$ the mean diameter (d) of the coil. Also $\mu_0 = 4\pi \times 10^{-7}$ H/m, therefore

$$L = (\mu_0 N^2 A)/l = (4\pi \times 10^{-7} \times 350^2 \times 3 \times 10^{-4})/0.2\pi = 73.5 \times 10^{-6}\ \text{H}$$

2 For the ferromagnetic ring we have, from Equation (2.34), that $L = \mu_0 \mu_r N^2 A/l$. This is just μ_r times the value in part (1). Thus

$$L = 1050 \times 73.5 \times 10^{-6} = 77.18 \times 10^{-3}\ \text{H}$$

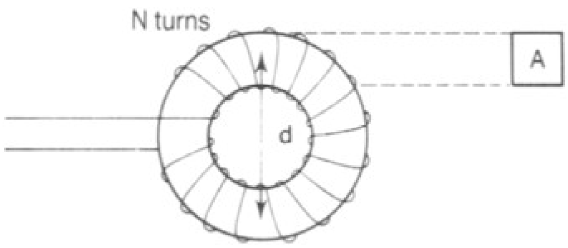

Figure 2.21

Change of current in an inductor

Since $E = L\,\mathrm{d}I/\mathrm{d}t$ it follows that

$$I = (1/L)\int E\,\mathrm{d}t \qquad (2.35)$$

This indicates that the current in an inductor is a function of time and therefore cannot change instantaneously. Remember that, in a capacitor, the *voltage* cannot change instantaneously.

Mutual inductance

The diagram of Fig. 2.22 shows two coils placed such that some of the flux produced by a current in either one will link with the other. These coils are said to be mutually coupled magnetically and this is usually indicated in circuit diagrams by a double-headed arrow and the symbol M. Transformer windings are examples of coupled coils.

Let the flux produced by the current i_1 flowing in coil 1 be ϕ_{11} and that part of

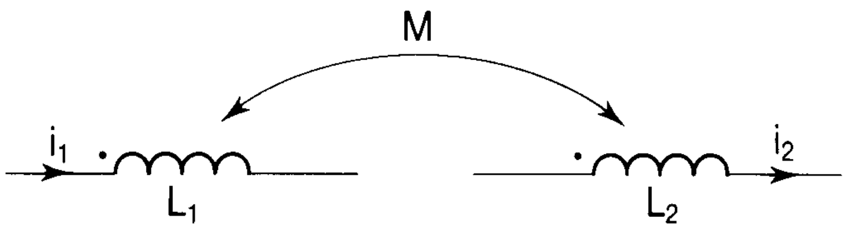

Figure 2.22

it which links coil 2 be ϕ_{21}. Similarly, let the flux produced in coil 2 be ϕ_{22} and that part of it which links coil 2 be ϕ_{12}. The dots are used to indicate the sense of the winding. Thus if current enters the dotted end of coil 1 it will produce a magnetic flux in the same direction as that produced by the current in coil 2 when it enters its dotted end.

If the current in coil 1 is changing with time then the fluxes ϕ_{11} and ϕ_{21} will also change with time. In accordance with Faraday's law, therefore, an emf will be induced in coil 1 because the flux linking it is changing. The magnitude of this emf is given by

$$E_{11} = \mathrm{d}(N_1\phi_{11})/\mathrm{d}t \tag{2.36}$$

and is called a self-induced emf because it is due to the current changing in the coil itself. Similarly, the changing flux linkages with coil 2 cause an emf to be induced in it and the magnitude of this is given by

$$E_{21} = \mathrm{d}(N_2\phi_{21})/\mathrm{d}t \tag{2.37}$$

and is called a mutually induced emf because it is caused by the current changing in another coil. We saw (Equation (2.32)) that the self-induced emf is also given by $E_{11} = L_1\mathrm{d}i_1/\mathrm{d}t$ where L_1 is the self-inductance of coil *l*.

Similarly the mutually induced emf in coil 2 may be expressed as

$$E_{21} = M_{12}\mathrm{d}i_1/\mathrm{d}t \tag{2.38}$$

where M_{12} is called the mutual inductance between the coils 1 and 2. If there are only two coils involved there is no need for the double subscript and we can simply write $E_{21} = M\mathrm{d}i_1/\mathrm{d}t$. If the current in coil 2 is changing with time then there will be a self-induced emf E_{22} set up in it and a mutually induced emf E_{12} set up in coil 1 and these are given by

$$E_{22} = L_2\mathrm{d}i_2/\mathrm{d}t \tag{2.39}$$

$$E_{12} = M\mathrm{d}i_2/\mathrm{d}t \tag{2.40}$$

Coefficient of coupling

If a lot of the flux produced in one coil links with another coil the coils are said to be closely coupled, whereas if only a small amount links, the coils are loosely coupled. It can be shown that for two coils of self-inductance L_1 and L_2 placed such that the mutual inductance between them is M, then

$$M = k\sqrt{(L_1L_2)} \tag{2.41}$$

where k is called the coefficient of coupling. If $k \rightarrow 1$ the coils are closely coupled whereas if $k \rightarrow 0$ the coils are loosely coupled. If two coils are placed with their magnetic axes at right angles to each other then there is no magnetic coupling between them and k is virtually zero.

Example 2.17

Calculate the mutual inductance between two coils having self-inductances of 2.5 mH and 40 mH if

(1) they are so placed that the coefficient of coupling is 0.8;

(2) one of the coils is wound closely on top of the other;

(3) the coils are places as shown in Fig. 2.23.

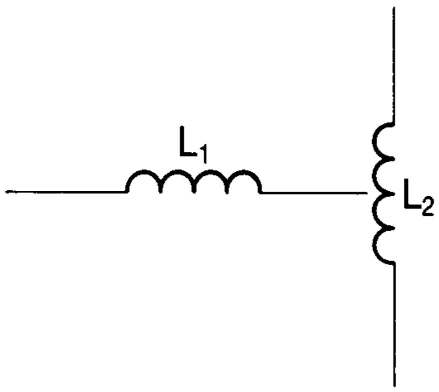

Figure 2.23

Solution

1 From Equation (2.41) we have that

$$M = k\sqrt{(L_1 L_2)} = 0.8\sqrt{(2.5 \times 40)} = 8\text{ mH}$$

2 Since the coils are wound one on top of the other, then virtually all the flux produced will link with both coils and so $k = 1$. Thus

$$M = k\sqrt{(L_1 L_2)} = \sqrt{(2.5 \times 40)} = 10\text{ mH}$$

3 In this case the magnetic axes of the two coils are at right angles so that there is no magnetic coupling and so $k = 0$ and $M = 0$.

Inductance in series

The diagram of Fig. 2.24 shows two coils connected in series electrically and coupled magnetically. The total emf induced in coil 1 is the sum of the self-induced emf due to the current changing in itself and the mutually induced emf due to the current changing in coil 2. Thus

$$E_1 = E_{11} + E_{12} = L_1\mathrm{d}i/\mathrm{d}t + M\mathrm{d}i/\mathrm{d}t = (L_1 + M)\mathrm{d}i/\mathrm{d}t \tag{2.42}$$

Similarly

$$E_2 = E_{22} + E_{12} = L_2\mathrm{d}i/\mathrm{d}t + M\mathrm{d}i/\mathrm{d}t = (L_2 + M)\mathrm{d}i/\mathrm{d}t \tag{2.43}$$

The total emf induced in the series combination is therefore given by

$$E_1 + E_2 = (L_1 + L_2 + 2M)\mathrm{d}i/\mathrm{d}t \tag{2.44}$$

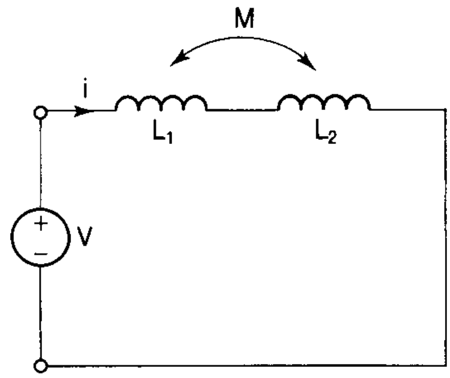

Figure 2.24

This assumes that the coils are wound such that their fluxes are additive (i.e. in the same direction). In this case the coils are said to be connected in series aiding.

If the connections to one of the coils were reversed the flux produced by it would be reversed and the total emf in coil 1 would be $(L_1 - M)\mathrm{d}i/\mathrm{d}t$ while that in coil 2 would be $(L_2 - M)\mathrm{d}i/\mathrm{d}t$ and the total emf in the series combination would be

$$E_1 + E_2 = (L_1 + L_2 - 2M)\mathrm{d}i/\mathrm{d}t \qquad (2.45)$$

In this case the coils are said to be connected in series opposing.

A single coil which would take the same current from the same supply as the series aiding combination would need to have an inductance equal to

$$(L_1 + L_2 + 2M) \quad \text{henry} \qquad (2.46)$$

and this is called the effective inductance of the circuit. Similarly, the effective inductance of the series opposing combination is

$$(L_1 + L_2 - 2M) \quad \text{henry} \qquad (2.47)$$

Example 2.18

Calculate the effective inductance of the two coils arranged as in Example 2.17 (1), (2) and (3) if they are connected in (1) series aiding and (2) series opposing.

Solution

1 Series aiding.
From expression (2.46) the effective inductance is $(L_1 + L_2 + 2M)$. Now $L_1 = 2.5$ mH and $L_2 = 40$ mH.
As connected in Example 2.17 part (1) we calculated M to be 8 mH so that the effective inductance is given by $2.5 + 40 + (2 \times 8) = 58.5$ mH.
As connected in Example 2.17 part (2) we found M to be 10 mH so that the effective inductance becomes $2.5 + 40 + (2 \times 10) = 62.5$ mH.

In Example 2.17 part (3) the M was zero so that the effective inductance is simply 2.5 + 40 = 42.5 mH.

2 Series opposing.
From expression (2.47), the effective inductance is $(L_1 + L_2 - 2M)$.
For Example 2.17 part (1) this becomes 2.5 + 40 − (2 × 8) = 26.5 mH.
For Example 2.17 part (2) it is 2.5 + 40 − (2 × 10) = 22.5 mH.
For Example 2.17 part (3) the effective inductance is just
2.5 + 40 = 42.5 mH

2.4 LUMPED PARAMETERS

The resistance, capacitance and inductance of transmission lines are not discrete but are distributed over the whole length of the line. The values are then quoted 'per kilometre'. When using equivalent circuit models in such cases the whole of the resistance, capacitance and inductance are often assumed to reside in single elements labelled R, C, and L. These are then called 'lumped parameters'.

Example 2.19

A 50 km three-phase transmission line has the following parameters per phase:

- resistance: 0.5 Ω per kilometre;
- inductance: 3 mH per kilometre;
- capacitance: 16 nF per kilometre.

Draw an 'equivalent circuit' for this line.

Solution

One approximate method of representing this line would be to assume that the whole of the line resistance and inductance is concentrated at the centre of the line and that the whole of the line capacitance is concentrated at one end of the line. This representation is usually quite acceptable for lines of this length because calculations based upon it yield reasonably accurate results.

- The total resistance of the line, $R = 0.5 \times 50 = 2.5\ \Omega$.
- The total inductance of the line, $L = 3 \times 50 = 150$ mH.
- The total capacitance of the line, $C = 16 \times 50 = 800$ nF $= 0.8\ \mu$F.

If the capacitance is considered to be at the sending end of the line, the equivalent circuit takes the form shown in Fig. 2.25(a); if the capacitance is placed at the receiving end (or load end) of the line, the equivalent circuit is as shown in Fig. 2.25(b).

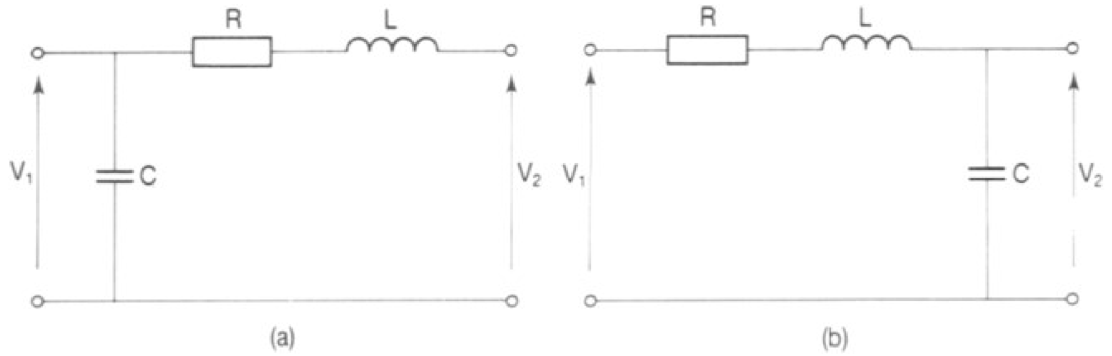

Figure 2.25

2.5 ENERGY STORED IN CIRCUIT ELEMENTS

The circuit elements having inductance and those having capacitance are capable of storing energy. It can be shown that

- the energy stored in a capacitor of C farad across which is maintained a potential difference of V volts is given by

  $W = (CV^2)/2$ joules (2.48)

- the energy stored in an inductor of L henry through which a current of I ampere passes is given by

  $W = (LI^2)/2$ joules (2.49)

Example 2.20

Determine the energy stored in a capacitor of 0.1 μF when a potential difference of 400 V is maintained across its plates.

Solution

From Equation (2.48) the energy stored is given by

$W = CV^2/2 = 0.1 \times 10^{-6} \times (400)^2 \times 0.5 = 8 \times 10^{-3}$ J

Example 2.21

Calculate the current required to flow through an inductance of 0.5 H in order to store the same amount of energy as that stored by the capacitor in Example 2.20.

Solution

From Equation (2.49) the energy stored is given by $W = LI^2/2$ joules. We know that $W = 8$ mJ (from Example 2.20) and we have to find I. Rearranging the equation to make the current the subject we have $I = \sqrt{(2W/L)}$ amperes. Putting in the numbers,

$$I = \sqrt{(2 \times 8 \times 10^{-3}/0.5 \times 10^{-3})} = \sqrt{32} = 5.66 \text{ A}$$

2.6 POWER DISSIPATED IN CIRCUIT ELEMENTS

Power is the rate of doing work and is measured in watts (W) in honour of James Watt (1736–1819), a British engineer. If we denote power by P and work by W then

$$P = \mathrm{d}W/\mathrm{d}t \tag{2.50}$$

We may write this as $P = (\mathrm{d}W/\mathrm{d}Q)(\mathrm{d}Q/\mathrm{d}t)$. Since work is done when charge is moved through a voltage we have seen above that $W = QV$ so $\mathrm{d}W/\mathrm{d}Q = V$. Also we have seen (Equation [2.1]) that $\mathrm{d}Q/\mathrm{d}t = I$. Therefore

$$P = VI \quad \text{watts} \tag{2.51}$$

Using Ohm's law we can also write

$$P = (IR)I = I^2R \tag{2.52}$$

and

$$P = V(V/R) = V^2/R \tag{2.53}$$

Any circuit element having resistance and carrying a current will therefore have an associated power loss given by I^2R watts where R is the resistance in ohms and I is the current in amperes. From Equation (2.50), $P = \mathrm{d}W/\mathrm{d}t$, from which it follows that energy is power multiplied by time. The energy lost in the element is therefore given by

$$W = I^2Rt \tag{2.54}$$

where t is the time in seconds for which the element is carrying the current I.

Example 2.22

A resistor has a current of 20 A flowing through it and a potential difference of 100 V across it. Calculate (1) the power dissipated in the resistance; (2) the resistance of the resistor; (3) the energy lost in the resistor during each minute of operation.

Solution

1. From Equation (2.51) the power dissipated is
   $P = VI = 100 \times 20 = 2000 \text{ W} = 2 \text{ kW}$

2. From Equation (2.52), $R = P/I^2 = 2000/20^2 = 5\ \Omega$
3. From Equation (2.54) the energy lost is
   $W = I^2Rt = 20^2 \times 5 \times 60 = 120\,000\ \text{J} = 120\ \text{kJ}$

Example 2.23

A generator in a power station generates 200 MW of power at 12.7 kV per phase. Calculate the current supplied by the generator.

Solution

From Equation (2.51)

$I = P/V = 200 \times 10^6/12.7 \times 10^3 = 15.75\ \text{kA}$

2.7 SELF-ASSESSMENT TEST

1 Define a passive circuit element.

2 State the effect of connecting a copper bar across the terminals of an ideal voltage source.

3 Draw the circuit symbol for an ideal current source.

4 Give two examples of good conductors of electricity and explain why they are good conductors.

5 State Ohm's law.

6 Give the unit of resistivity.

7 What is the reciprocal of conductivity?

8 Calculate the equivalent resistance of three 10 Ω resistors when they are connected (1) in parallel (2) in series and (3) in series–parallel.

9 A voltage source has an open circuit terminal voltage of 15 V and a terminal voltage of 12 V when it supplies a current of 20 A to a load connected across it. Determine the internal resistance of the source.

10 Explain the effect of an increase in temperature upon the resistance of a resistor.

11 A resistor has four colour coded bands as follows: red; red; brown; silver. Between what limits does the resistance of this resistor lie?

12 Explain what is meant by 'a non-linear' resistor.

13 Upon what factors does the capacitance of a capacitor depend?

14 Give an expression for the equivalent capacitance of a number of capacitors connected in series.

15 Can the current change suddenly in a capacitor?

16 Upon what factors does the inductance of an inductor depend?

17 Under what circumstances is the inductance of a coil variable?

18 Can the current through an inductor change suddenly?

19 Two coils of inductance 40 μH and 10 μH are placed such that there is a coefficient of coupling of 0.8 between them. Determine the mutual inductance between them.

20 If the two coils of Question 19 were connected in series-aiding electrically, what would be the effective inductance of the combination?

21 Explain the meaning of lumped parameters.

22 Give an expression for the energy stored in a capacitor in terms of its capacitance and the potential difference across its plates.

23 Give an expression for the energy stored in an inductor in terms of its inductance and the current passing through it.

24 Give an expression for the power dissipated in a resistor in terms of its resistance and the current passing through it.

25 Give the relationship between energy and power.

2.8 PROBLEMS

1 Determine the equivalent resistance of four resistors connected in parallel if their resistances are 1 Ω, 2 Ω, 2.5 Ω and 10 Ω.

2 A 20 Ω resistor is connected in series with a 40 Ω resistor and the combination is connected in series with three 12 Ω resistors which are connected in parallel. Determine the equivalent resistance of the whole arrangement.

3 Calculate the resistance of a 200 m length of copper wire of diameter 1 mm. The resistivity of the copper is 0.0159 μΩ m.

4 Two resistors ($R_1 = 5\ \Omega$ and $R_2 = 20\ \Omega$) are connected in series across a 100 V supply. Determine the voltage across R_1.

5 If the two resistors in Problem 4 are connected in parallel across the same supply, determine the current through R_2.

6 A battery has an open circuit terminal voltage of 24 V. When it supplies a

current of 2 A the terminal voltage drops to 22 V. Determine the internal resistance of the battery.

7 The winding of a motor has a resistance of 98 Ω at a temperature of 16 °C. After operating for several hours the resistance is measured to be 114 Ω. Determine the steady state operating temperature of the winding. Take the temperature coefficient of resistance to be 0.004 per °C.

8 A 2.2 kΩ resistor has a tolerance of 10 per cent. What are the colour bands on the body of this resistor?

9 A resistor having colour bands orange, orange, brown and silver is connected in parallel with one with bands of yellow, violet, red and gold. Determine the limits of resistance values of the combination.

10 Capacitors of 5 μF, 10 μF and 20 μF are connected in series–parallel in all possible ways. Calculate the values of capacitance obtainable.

11 A wooden ring having a mean diameter of 16 cm and a cross-sectional area of 2 cm^2 is uniformly wound with 500 turns. A second coil of 400 turns is wound over the first such that the coefficient of coupling is unity. Calculate the inductance of each coil and the mutual inductance between them.

12 Calculate the two possible values of effective inductance obtainable by connecting the two coils of Problem 11 in series electrically.

13 Two coils having self-inductances of 100 μH and 50 μH are placed such that the mutual inductance between them is 65 μH. Determine the coefficient of coupling.

14 The energy stored in a coil having an inductance of 30 μH is 1.215 mJ. Determine the current in the coil.

15 A capacitor having a capacitance of 0.1 μF has 200 V maintained across its plates. Determine the energy stored in it.

16 A current of 6 A is passed through a resistor having a resistance of 40 Ω. Determine the power dissipated in the resistor.