Part I : *FUSES*

17.6 FUSES

A fuse in its simplest form is a small piece of metal wire (or strip) which is connected between two terminals and is mounted on an insulating base. A fuse is inserted in series with the circuit (or system) to be protected. It melts when an excessive current (*fusing current*) flows through it and thus breaks the circuit. This prevents damage of system components at the expense of the fuse. Thus a fuse is a protective device which is generally used for protecting cables and electrical equipment against overloads and/or short circuit.

The fuse element is generally made of materials having low melting point, high conductivity and least deterioration due to oxidation *e.g.* silver, copper, aluminium, tin, lead etc. Under normal operating conditions, it carries the normal current without over heating and the fuse element at a temperature below its melting point. However, when a short-circuit or over load occur the current through the fuse increases beyond its rated value and this raises the temperature and fuse element melts or blows out, thereby disconnecting the circuit. In this way a fuse protects the equipment (say machine) from damage due to excessive currents.

The time required to blow out the fuse depends upon the magnitude of excessive current. The greater the current, the smaller is the time taken by the fuse to blow out. That is, a fuse has a inverse time-current characteristics. Such a characteristic permits its use for over current protection.

Desirable Characteristics of Fuse Element

The function of a fuse is to carry the normal current without overheating but when the current exceeds its rated or normal value, it repidly heats up to melting point and disconnects the circuit to be protected by it. In order that it may perform this function satisfactorily, the fuse element should have the following desirable characteristics:

- Low melting point *e.g.* tin, lead.
- High conductivity *e.g.* silver, copper.
- Free from deterioration due to oxidation *e.g.* silver.
- Low cost *e.g.* lead, tin, copper.

Since no material possesses all the above mentioned desirable characteristics, a compromise is made in the selection of material for a fuse. Table 17.1 lists important fuse materials and their melting point.

Table 17.1 Fuse Materials and their Melting Point

Metal	Specific resistance in micro ohm-cm	Melting point in °C
Tin	11.2	231
Lead	21.6	327
Zinc	6.2	419
Aluminium	2.84	659
Silver	1.65	960
Copper	1.72	1085

Advantages

- It is the simplest and cheapest form of protection available.
- It requires no maintenance.
- Its operation in inherently completely automatic unlike a circuit breaker which requires elaborate equipment for automatic action.
- It can break heavy short-circuit currents without noise or smoke.
- The smaller sizes of fuse element impose a current limiting effect under short-circuit conditions.
- The inverse time-current characteristic of a fuse makes it suitable for over current protection.
- The minimum time of operation can be made much shorter than with the circuit breakers.

Disadvantages

- On heavy short-circuits, discrimination between fuses in series cannot be obtained unless there is considerable difference in the relative sizes of the fuses concerned.
- Earth fault protection is impracticable with heavy current fuses, because the fault current is limited by the resistance to earth.
- Time is lost in rewiring or replacing fuses after operation.
- The inverse time-current characteristics of a fuse cannot always be correlated with that of the protected apparatus *e.g.* direct started induction motors, the starting current of which may be six or eight times the full-load value.

Important Terms

The following terms are useful in the study and analysis of fuses:

1. **Current rating of fuse element**
   - It is the maximum current which the fuse element can carry safely without any undue heating and melting.
   - It depends upon the permissible temperature rise of the contacts of the fuse holder, fuse material and the environmental conditions of the fuse (such as the deterioration of the fuse due to oxidation).

- The temperature rise of the contacts should not be more than 55°C.

2. **Fusing Current:** The fusing or minimum fusing current is the minimum current (rms) at which the fuse element melts. Obviously, its value will be more than the current rating of the fuse element.

   When the temperature is steady, heat produced per second = heat lost per second (by convection, radiation and conduction).

   It is assumed that the heat lost per second is proportional to the surface, then for round wires,

$$I^2 R \propto \text{Surface} = k_1\, dl \qquad \text{...(17.1)}$$

where d = diameter of wire

l = length of wire

Since
$$R = \rho\frac{l}{a} = \frac{\rho l}{\frac{\pi}{4}d^2} \qquad \text{...(17.2)}$$

Then, from Eqns. (17.1) and (17.2), we have

$$I^2 = \frac{k_1 dl}{R} = \frac{k_1 dl \pi d^2}{4\rho l} = k_2\, d^3 \qquad \text{...(17.3)}$$

This equation shows that

$$I = kd^{3/2} \qquad \text{...(17.4)}$$

where, k_2 is called the *fuse constant*. Note that Eqn. (17.4) gives the ordinary fuse law.

The fusing current (*i.e.*, the current required to produce the temperature rise at which fuse wire melts) depends upon various factors such as:

- Fuse material
- Length the shorter the length of fuse, the greater the currents as all the heat is easily conducted away.
- Diameter.
- Shape in cross-section of the fuse element.
- The previous history.
- Size and location of the terminals.
- The type of enclosure employed.
- Whether stranded or not.

3. **Fusing Factor:** It is defined as the ratio of minimum fusing current to the rated current of the fuse element. That is

$$\text{Fusing Factor} = \frac{\text{Minimum fusing current}}{\text{Current rating of fuse}}$$

4. **Prospective Current:** Figure 17.5 shows how ac current is interrupted by a fuse. The prospective current (shown by dotted line) is the current which would have flown in the circuit if the fuse were not there. It is defined as *the rms value of the first loop of the fault current obtained if the fuse is replaced by an ordinary conductor of negligible resistance*. In Fig. 17.7, I_P is the peak value of the prospective current.

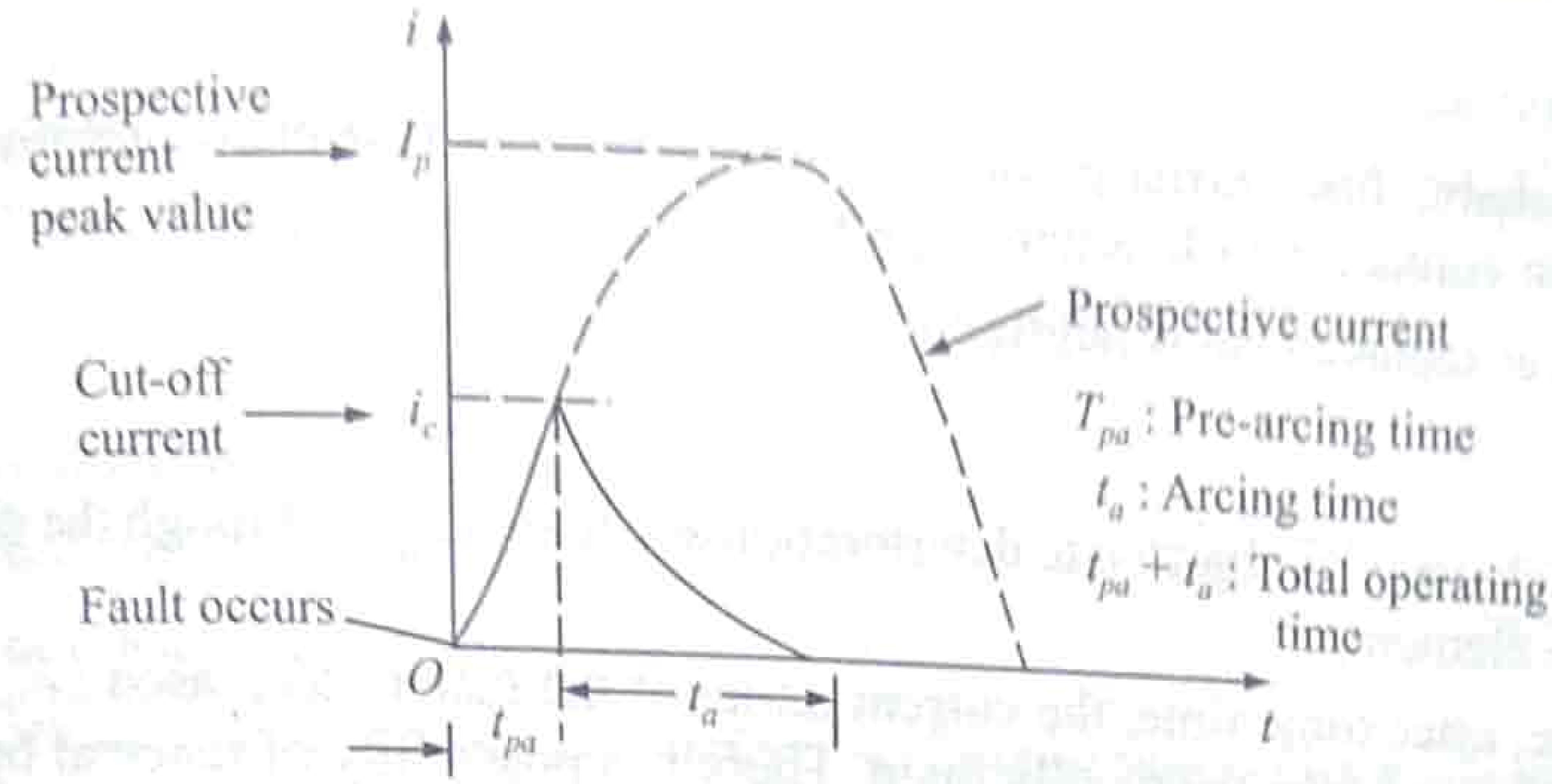

Fig. 17.5 *Cut-off characteristic of a fuse*

5. **Cut-off Current:** It is the maximum value of fault current actually reached before the fuse melts.
6. **Pre-arcing Time:** It is the time between the commencement of fault and the instant when cut-off occurs, t_{pa}.
7. **Arcing Time:** It is the time between the end of pre-arcing time and the instant when the arc is extinguished, t_a.
8. **Total Operating Time:** It is the sum of pre-arcing and arcing times, *i.e.*, $t_{pa} + t_a$. Refer Fig. 17.5 for details of the terms used above.
9. **Breaking (or Rupturing) Capacity:** It is the rms value of ac component of maximum prospective current that a fuse can deal with at rated service voltage.

17.7. TYPES OF FUSES

Fuse is the simplest current interrupting device for protection against excessive current. In general, fuses may be classified into two groups:

(*a*) Low voltage fuses

(*b*) High voltage fuses.

It is a usual practice to provide isolating switches in series with fuses to permit fuses to be replaced or rewired with safety.

17.7A Low Voltage Fuses

Low Voltage Fuses can be further subdivided into two classes namely semi-enclosed rewirable fuses and the cartridge type fuses.

1. **The semi-enclosed rewirable fuses:** A rewirable fuse, also known as *kit-kat* type, consists of (*a*) a base, and (*b*) a fuse carrier. The base is of porcelain and carries fixed contacts for connecting the incoming and outgoing phase wires. The fuse carrier is also of porcelain and holds the fuse element (tinned copper wire) between its terminals. The fuse carrier can be inserted in or taken out of the base as and when desired.

   When a fault occurs, the fuse element melts and the circuit is interrupted. The fuse carrier is taken out and the blown-out fuse element is replaced by the new one. This type of fuse is used where low values of fault current are to be interrupted.

   A semi-enclosed rewirable fuse has the following features.

Advantages

- The detachable fuse carrier permits the replacement of fuse element without any danger of coming in contact with live wires (parts).
- The cost or replacement is negligible.

Disadvantages

- The fuse element is subjected to deterioration due to oxidation through the continuous heating up of the element.
- Therefore, after some time, the current rating of the fuse is decreased *i.e.*, the fuse operates at a lower current that originally rated. There is a possibility of renewal by the fuse wire of wrong size or by improper material.
- The protective capacity of such a fuse is uncertain as it is affected by the ambient conditions.
- Accurate calibration of the fuse wire is not possible because fusing current depends upon the length of the fuse element. For example, a longer fuse operates eariler than one of short length.
- This type of fuse has a low-breaking capacity and hence cannot be used in circuits of high fault level.
- There is a possibility of change of fuse wire both in diameter as well as improper material.

It is to be noted that semi-enclosed rewireable fuses are image up to 500 A rated current. Since their breaking capacity is low (*e.g.* on 400 V system the breaking capacity is about 4000 A), the use of this type of fuse is limited to domestic and lighting loads.

2. **High-rupturing Capacity (HRC) Cartridge Fuse:**
   - When large concentrations of power are concerned, as in modern distribution system, it is essential that fuses should have a definite known breaking capacity and also that this breaking capacity should have high value. This requirement is met by the use of HRC cartridge fuse.
   - In its simplest form a HRC cartridge fuse consists of a heat resisting ceramic body having metal end caps to which are welded fusible silver (or bimetallic) current-carrying elements (Fig. 17.6). The space within the body surrounding the element is competely packed with a filling power which may be a chalk, plaster of paris, quartz or marble dust. This filling material acts as an arc quenching and cooling medium.

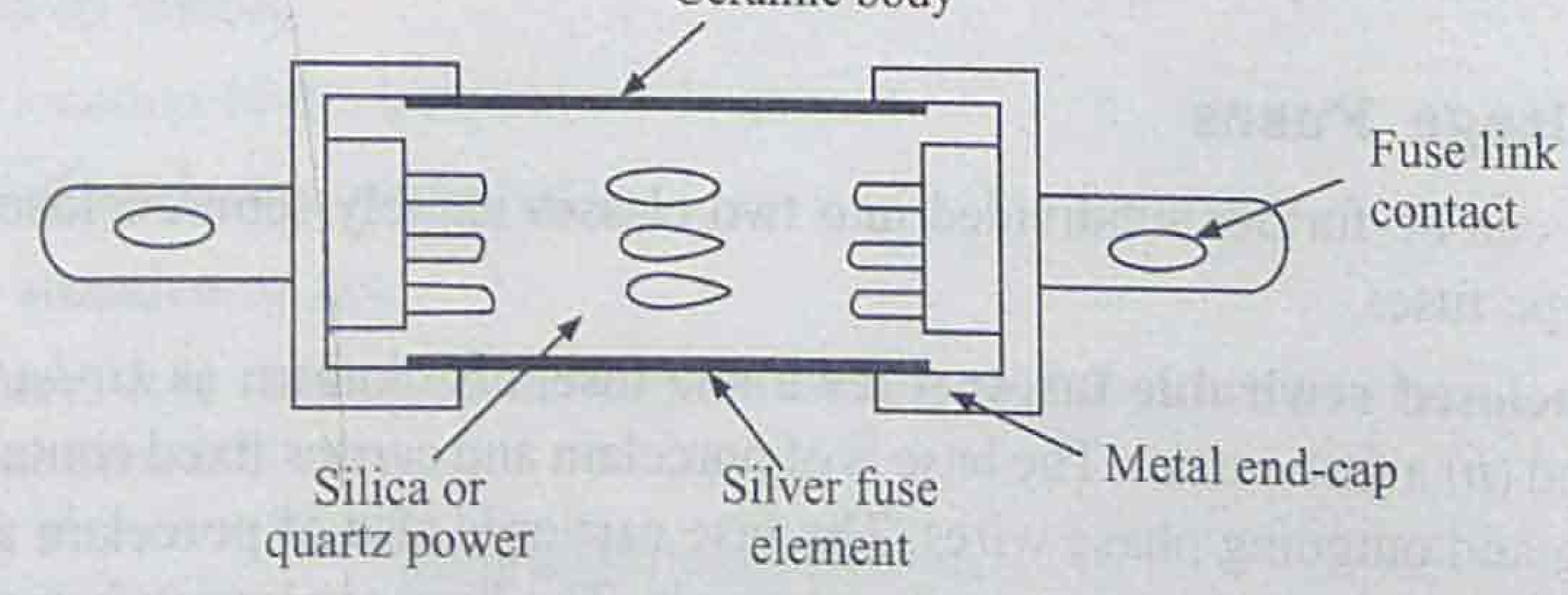

Fig. 17.6 *HRC cartridge fuse*

Under normal load conditions, the fuse element carries the normal current without overloading and is at a temperature below its melting point. When a fault occurs, the current increases and the fuse element melts before the fault current reaches its first peak. The heat produced in the process vaporises the melted silver element and the chemical reaction between the silver vapour and the filling powder results in the formation of a high resistive substance which help in quenching the arc.

The HRC cartridge type fuse has the following features:

Advantages

- They have high speed of operation.
- They do not require maintenance.
- They do not deteriorate with age.
- They are cheaper as compared to other circuit interrupting devices of equal breaking capacity.
- They are capable of clearing high as well as low fault currents very efficiently.
- They are capable of providing reliable discrimination.
- They permit consistent performance.

Disadvantages

- They require replacement after each operation.
- The heat developed by the arc may affect the associated switches.

Additional Remarks

1. HRC fuse with tripping device is also in use. The tripping device under fault condition causes the circuit breaker (discussed in Section *B*) to operate.
2. Low voltage HRC fuses may be designed to have a breaking capacity of 16,000 A to 30,000 A at 440 V.
3. They are extensively used on low-voltage distribution system against overload and short-circuit conditions.

17.7B High Voltage Fuses

The low-voltage fuses discussed above have low current rating and breaking capacity restricting their use only for low voltage applications. Therefore, for modern high voltage applications high voltage fuses have been desinged. Some of the high voltage fuses are presented below:

1. **Cartridge Type Fuse:** This is similar in construction to the low voltage cartridge fuses with special design features. Some design incorporates fuse elements in helix form so as to avoid corona effects particularly at high voltages, and in some other design two fuse elements in parallel are used one having low resistance (silver) and the other having high resistance (tungsten wire). Under normal load conditions, low resistance element carries the normal current. Under fault condition the low resistance fuse blows out and the high resistance element reduces the short-circuit current and finally breaks the circuit.

   High Voltage cartridge type fuses are used up to 33 kV with breaking capacity of about 8700 A at that voltage. Fuse of rating such as 200 A at 6.6 kV and 50 A at 33 kV are also available.
2. **Liquid Type Fuse:** The liquid type fuses are filled with carbon tetrachloride and have the widest range for application in high voltage systems. They may be used for circuits upto about 400 A rated current on systems with 132 kV or above with breaking capacities of the order of 6100 A.

3. **Metal Clad Fuse:** Metal clad oil-immersed fuses are developed with the objective to provide a substitute for oil circuit breaker. These fuses can be used for very high voltage situations and operate satisfactorily under short-circuit conditions approaching their rated capacity.