TTE Training Ltd.

Phase 2

Electrical Course Notes

E2-CN-002

Circuit Protection

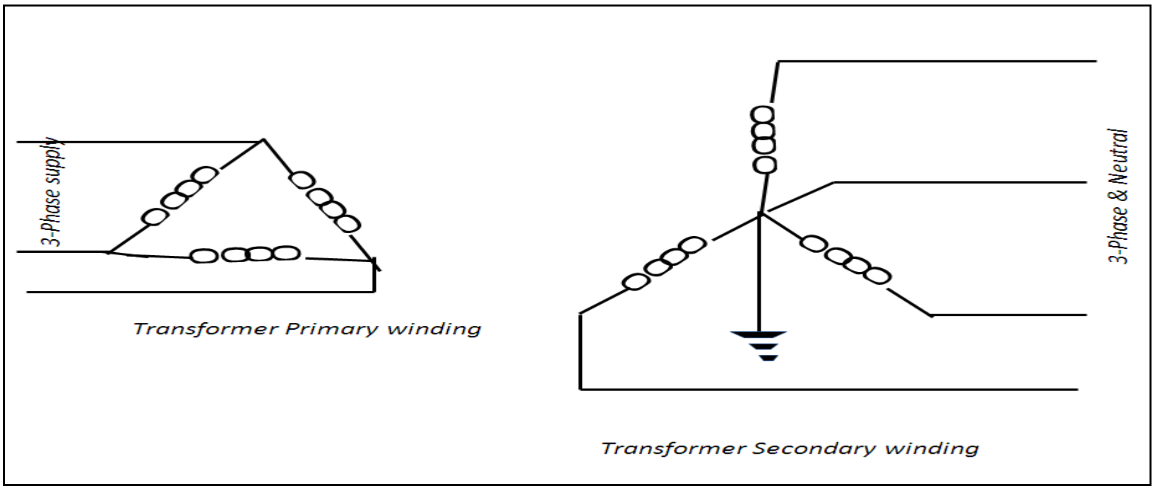
http://www.tteltd.co.uk

Earthing

The earth can be considered to be a vast conductor which is at reference, or zero, potential. People are usually in direct contact with this earth therefore any metal parts which become charged may cause a hazard if touched.

Connection to Earth

In a distribution system it is general practise to directly earth the star point of the secondary winding of the distribution transformer.



An insulation failure on the secondary side of the transformer or on its associated system will result in the current returning to the star point. Due to the unreliability of the earth as a conductor, (seasonal ground conditions can affect the total resistance of the earth path), protective devices are installed to continuously monitor the system and will isolate the supply in the event of a fault condition.

In **High Voltage systems** the purpose of earthing is to limit the fault current so that it can be interrupted safely by the switchgear via the circuit monitoring and protection system.

The purpose of earthing in **Low Voltage systems** is to connect together all metal parts or objects, other than those intended to carry an electrical charge, to the earth so that dangerous potential differences cannot exist, either between different metal parts or between metal and earth. This is known as **Equipotential bonding.**
(see fig 6:2).

It should be noted there are two distinct groups of metal parts, and they are defined as follows: -

Exposed-conductive-part – a conductive part of the equipment which can be touched, and which is not a live part, but which may become live under fault conditions.

Extraneous-conductive-part – a conductive part liable to introduce a potential, generally earth potential, and not forming part of the electrical installation.

Earthing Systems

In any industrial electrical system, all earths are connected to a single earthing point by a continuous metallic path known as the **protective conductor.** This path primarily consists of a separate earth conductor however the armouring in the supply cables will also provide additional paths provided that the cables have been correctly made-off to the glands.

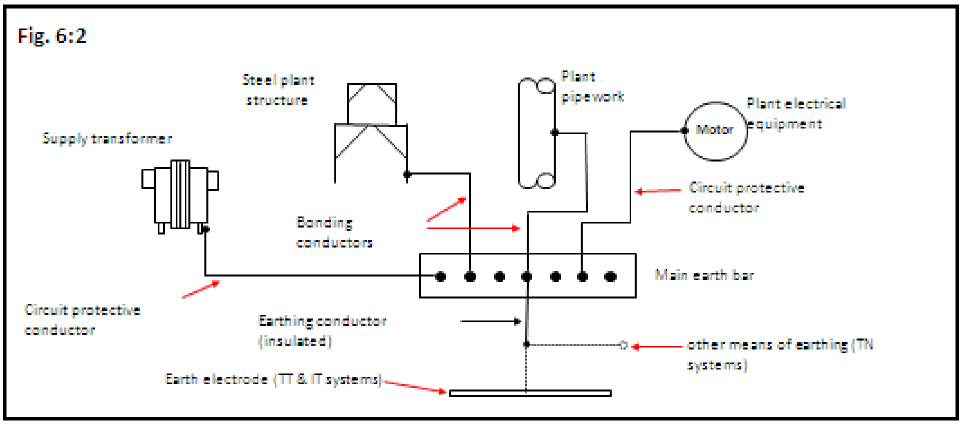


Fig. 6:2

During a supply cable fault to earth, the phase conductor and the earth return path act as a potential divider across the source voltage. Without efficient earthing potentials as high as 160v may occur on the exposed metalwork of the faulty equipment and any other metal parts that may be attached to it. These potentials can give a severe electrical shock to personnel if the affected parts are simultaneously accessible with other exposed metalwork which is at a lower potential (earthed). This is known as '**indirect contact**' and it is required that '**Fault Protection'** is necessary to prevent electrical shock.

The risk of electrical shock from indirect contact can be minimised if all accessible metal parts are at the same potential or within 50VAC. This principle is known as **equipotential bonding** and can be achieved by fitting earth straps, or bonding conductors, between all metal parts which may otherwise be insulated from each other (see fig 6:2 above).

Circuit Protective Devices

There are many types of protective devices all of which are primarily designed to protect the consumer in the event of a fault occurring. This section will concentrate on the following types of protection:

- High Rupture Capacity (HRC) Fuses
- Miniature Circuit Breakers (MCB's)
- Residual Current Devices (RCD's)
- RCBO's (Residual Current Breakers with overload capability)

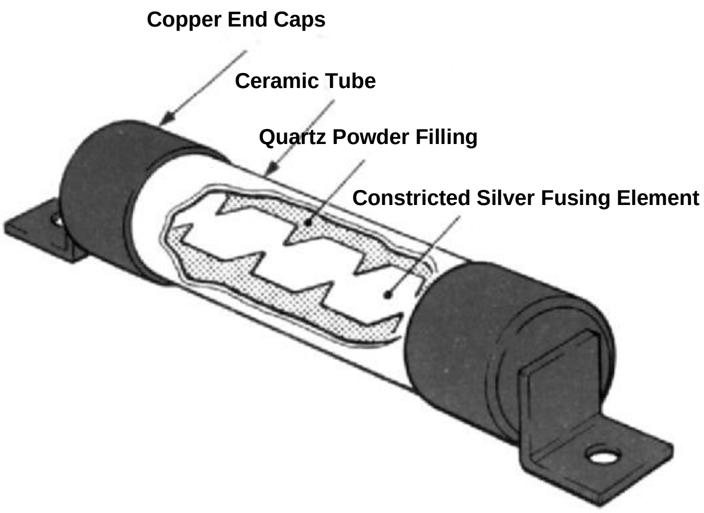
HRC Fuses

In the IET Regulations a **fuse** is defined as 'a device which by the fusing of one or more of its specially designed and proportioned components, opens the circuit in which it is inserted by breaking the current when this exceeds a given value for a sufficient time....'

The part of the fuse that operates in the event of a fault is known as the fuse element. In the IET regulations this is defined as 'a part of the fuse designed to melt when the fuse operates'. It should be noted that the time taken for the element to melt will depend upon the value of the fault current.

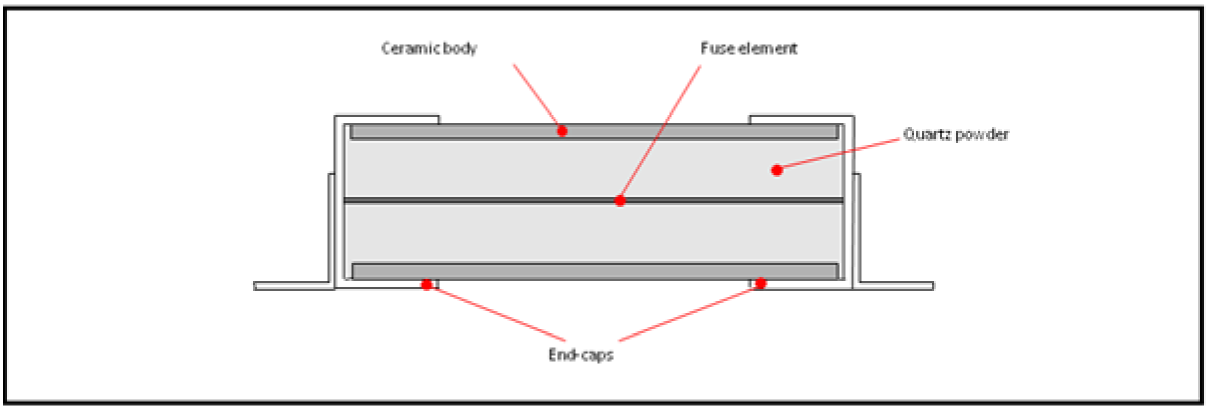
Fusing Element

It is normal with small fuses to use silver wire as the fusing element but for larger ones a silver (or sometimes copper) strip is often used, as shown below.



The strip has a number of constrictions which form hot spots and assist rapid melting under short-circuit conditions. For the heaviest currents a number of such strips may be connected in parallel within the common housing, or many separate fuse links may be permanently bonded in parallel to form a single multiple link.

HRC fuses are designed and constructed to break large fault currents rapidly without damage to the fuse enclosure or its surrounding hence its name **<u>H</u>igh <u>R</u>upture <u>C</u>apacity.** The fuse comprises of a ceramic body, two end-caps, the fuse element and quartz powder (see fig below).



When the current exceeds the rated value of the fuse, the element melts and vaporises. On its own, the vaporised element will still conduct however, because of the intense heat and the surrounding quartz powder, fusion takes place resulting in rapid arc extinction. The two ends of the element are now encased by the fused quartz which acts as an excellent insulator thereby preventing any further arcing across the broken element.

Types of HRC Fuses

HRC fuses are categorised in the following way:

- ☐ ag
- ☐ aM
- ☐ gG
- ☐ gm

a - Partial break capacity interrupts short circuit currents only,

g - Full range breaking capacity – interrupts short circuit and overload currents safely,

G - Fuse link for general application including protection of motor circuits

M - Fuse link protection of motor circuits

The commonly used “Red Spot” fuse links are classified as either gG or gM.

There are three main types of HRC fuses. These are: -

S.S. These are mainly used in lighting circuits.

N.I.T. Used in lighting circuits and power circuits.

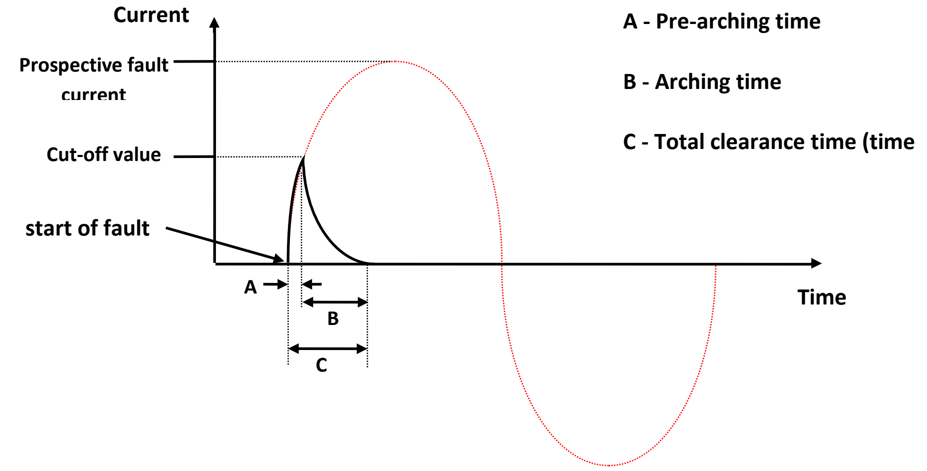
T.I.A. This the general-purpose fuse, they are used in most circuits.

These fuses can be found in a range of sizes and a range of standard current ratings.

Operating Characteristics

In order to protect the consumer and the circuit an HRC fuse must act rapidly. In order to achieve this each fuse has a “cut-off” value of prospective fault current. This means that the short circuit current is interrupted before it can reach its full value in the first half cycle of short circuit (see Fig. 1:2 below).

Fig. 1:2



The energy that is allowed through the circuit before the fuse disconnects can be calculated by the formulae (I^2t).

Under short circuit conditions, a fuse must disconnect a circuit in sufficient time to ensure that the heat generated from the fault current does not damage the cable insulation. For this to be achieved the disconnection time “t” must not exceed the time/current characteristic total clearance time.

$$t = (k^2 \times S^2) \div I^2$$

Where: S = cross-sectional area of cable (mm’s)
I = fault current (amps)
K = constant

(115 for 70 ^{0}C insulated copper cable less than 300mm^2: as per, I.E.T. Regulations). In order to protect the user against electric shock, the I.E.T. Regulations require that, under fault conditions, any circuit protected by an HRC fuse should have an earth fault loop-impedance sufficiently low enough to ensure that the fuse will disconnect the final circuit of a TN system within 0.4 seconds, for TT this is further reduced to 0.2 seconds.

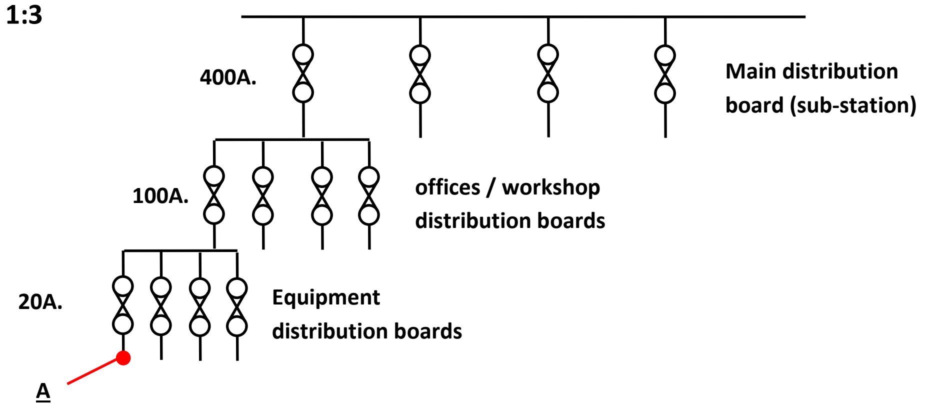
Fuses have to be designed for different applications due to the varying types of load. Typically, steady load circuits would use a fuse that is rated equal to, or just above, the load rating. Alternatively, when selecting a fuse rating for a fluctuating load circuit e.g. a motor, you must consider the load current fluctuations. Whilst the fluctuating current peaks are of comparatively short duration, the selected fuse should have a time/current characteristic that will allow the fluctuation to be carried without blowing.

It is extremely important that correctly rated fuses are used in all applications; whilst they cannot prevent faults, the potential consequences, particularly of using a higher rated fuse, may be fatal. In order to prevent fuse ratings being accidentally changed, any fuses that are removed for the purpose of electrical isolation should be taped together (if they are from a three-phase circuit), labelled, (listing the circuit details), and stored in a secure area.

1.1.8 Discrimination

In any distribution system it is important to ensure that, in the presence of an electrical fault, the lower rated fuses should blow before the higher rated fuses. Each fuse rating would be selected according to the prospective load of the circuit that it is protecting. The diagram below, (Fig. 1:3), indicates how discrimination is achieved in a simple distribution system.

Fig. 1:3



In the event of a fault at point "A" the protection device immediately up-stream of the fault should operate and isolate the faulty circuit. It is desirable that only the upstream device should operate if it is able to clear the fault by itself, hence leaving the healthy circuits unaffected. This is known as discrimination.

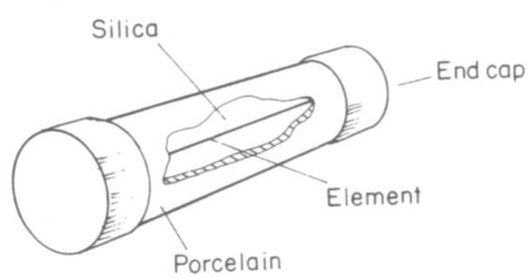
If the fault is greater than the breaking capacity of the upstream device, then the next device in line should operate as well. This is known as back-up protection.

Reasons for using H.R.C fuses.

- They reduce danger to personnel, damage to equipment and the risks of fire.
- They reduce electromagnetic stresses which would, in the event of a fault, tend to distort and/or damage other current carrying parts of the equipment.
- They reduce thermal stresses to other current carrying parts of the equipment (heat is produced as a result of fault current).
- They reduce arc-splash damage.
- They retain all of their characteristics without the need for maintenance however long in service (laboratory tests on 34 types “T” H.R.C. fuse links of various ratings after some 16 to 25 years of service showed no significant changes in any of their original characteristics).
- They contain no mechanisms or components that may wear, go out of adjustment or seize.
- Because of their low “cut-off” values and fast operating times of H.R.C. fuses, they are suitable for a variety of uses including back-up protection for circuit interrupting devices of inherent low rupturing capacity such as motor starters, contactors and circuit breakers.
- They operate without emission of smoke or flame.
- They ensure continuity of supply to healthy circuits when electrical faults occur.

Cartridge Fuses

The construction of a cartridge fuse to **BS1362** is shown below and consists of a porcelain tube with metal end caps to which the element is attached. The tube is filled with silica.



These fuses are generally found in 13Amp plug tops, and in some distribution boards and at the mains intake positions (Electricity Board fuse).

You can calculate the correct fuse for domestic appliance by using the following formula: -

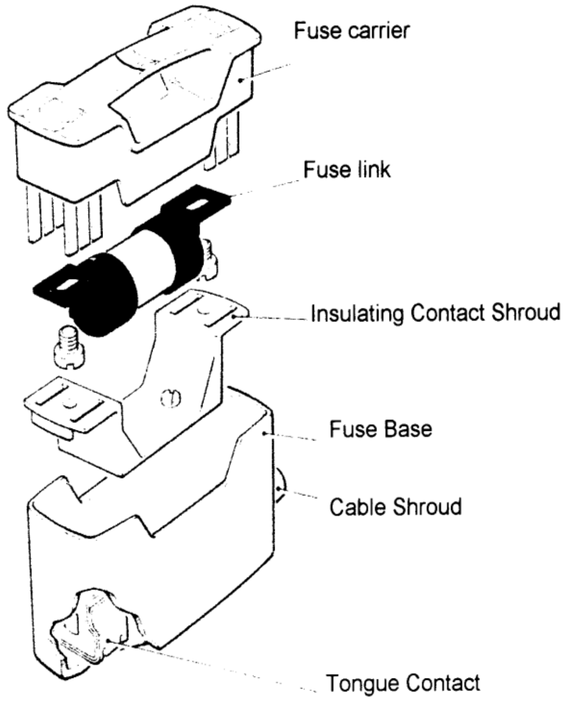
$$\text{Current} \quad \mathbf{I} = \frac{\text{Power } \mathbf{P}}{\text{Voltage } \mathbf{V}}$$

Nominal Current Rating

A fuse has a *nominal current rating*, which is the current, which it can carry continuously without melting or deteriorating and without altering its characteristics.

Fuse Mountings

On low voltage boards, fuses are housed in a fuse assembly such as the typical one shown below. The replaceable ceramic cartridge with its metal terminal caps is known as the *fuse link* and is held in an insulated *fuse carrier*, which completely shrouds all live metal. The carrier is supported on an insulated *fuse base*, where it is firmly fixed by various mechanical means, amongst them tongue contacts, butt contacts held by insulated screw pressure, or wedge contacts pressed in by insulated screws. A typical fuse carrier is shown below.



Motor Protection Fuses

Fuses

In any motor starter circuit, the use of fuses is of paramount importance in short circuit protection but limited in motor protection. In the larger motor starter, there are two different sets of fuses: -

1. Motor Fuses
2. Control Fuses

Motor Fuses

These fuses being the main fuses in the circuit provide protection against short circuits in the motor cable and motor terminal box. They do not provide motor overload protection, the reason being that they are rated to withstand the inrush current, which occurs on motor start. In the case of star connected motors this can be 6-7 times full load current, so close protection against electric motor overload is supplied by motor overload protection units (overload units). These units are capable of being graded in minute percentage of full load current, thereby fulfilling this role of close motor overload protection.

Control Fuses

These fuses protect only the control circuit e.g. Contactor Solenoid, push buttons etc, together with all ancillary devices and cables. They are generally on very small current ratings i.e. 2- 4 amperes.

Assumed starting conditions DOL up to 1kW = 5x FLC for 5 secs; 1.1 kW to 7.5 kW = 6 x FLC for 10 secs; 7.6 to 75 kW = 7 x FLC for 10 secs; over 75kW = 6 x FLC for 15 secs. Assisted start up to 1kW = 2.5 x FLC for 20 secs: over 1kW = 3.5 x FLC for 20 secs

Full load currents for 3 phase induction motors at average efficiencies, power factor, with recommended fuse ratings.

FULL LOAD CURRENT (FLC)							
Motor full load current (FLC) in amperes							
KW	**H.P.**	**220V**	**240V**	**380V**	**415V**	**440V**	**550V**
0.37	0.50	2.00	1.75	1.15	1.05	1.00	0.8
0.55	0.75	2.70	2.60	1.60	1.50	1.40	1.10
0.75	1.0	3.90	3.30	2.30	2.00	1.90	1.50
1.10	1.5	4.70	4.35	2.80	2.50	2.40	1.90
1.50	2.0	6.50	5.90	3.80	3.50	3.30	2.60
2.20	3.0	9.30	8.30	5.40	5.00	4.70	3.80
3.00	4.0	2	11.0	7.10	6.50	6.10	4.90
4.00	5.5	15.4	14.0	9.00	8.40	7.90	6.40
5.50	7.5	20.7	20.0	11.9	11	10.3	8.2
7.50	10	28	25.0	16.1	14.4	14	11.2
11.0	15	39.1	36.5	23	21	19.8	15.8
15.0	20	52.8	48	30.5	28	26.4	21.1
18.5	25	66	60	38	35	33	26.4
22	30	77	72	45	41	39	31
30	40	103	96	60	55	52	42
37	50	128	120	75	69	65	52
45	60	151	144	87	80	75	60
55	75	185	171	107	98	92	74
75	100	257	235	148	136	128	102
90	120	308	278	180	164	154	123
110	150	370	345	214	196	185	148
132	175	426	403	247	226	213	170
150	200	500	454	292	268	252	202

HRC FUSE RATINGS		
Direct on-line start (DOL) (See notes)		
Motor FLC Amperes		**HRC fuse Type ‘gG’**
From	To	
	0.70	2
0.80	1.40	4
1.50	2.00	6
2.10	3.00	10
3.10	6.10	16
6.20	9.00	20
9.10	11.00	25
11.1	14.4	32
14.5	15.4	35
15.5	18	40
18.1	22	50
22.1	28	63
28.1	45	80
45.1	58	100
58.1	80	125
80.1	99	160
99.1	128	200
128.1	180	250
180.1	216	315
216.1	270	355
270.1	328	400
328.1	385	450
385.1	430	500

CIRCUIT BREAKERS

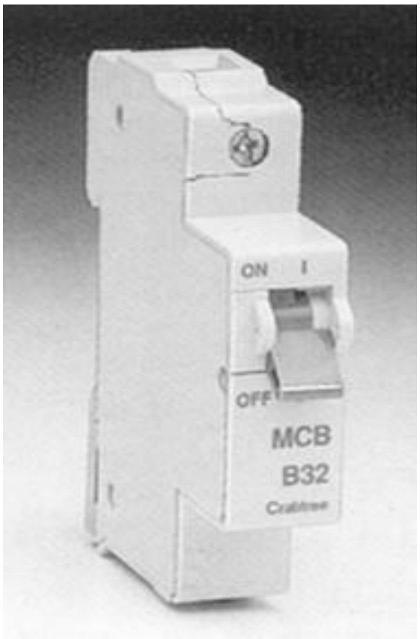
Circuit breakers are sub-divided into three types:

- Air Circuit Breakers - ACB
- Moulded Case Circuit Breakers - MCCB
- Miniature Circuit Breakers - MCB

We will only look at the MCB.

MCB – Miniature Circuit Breaker

The miniature circuit breaker or MCB for short finds wide application as an effective means of over current protection. The main advantage of the MCB is that it may be reset at the operation of a switch, i.e. resetting is easy and quick. However, the following note of caution should be borne in mind – resetting of an MCB should only be carried out when the fault responsible for its operation has been cleared. Whilst MCB's may be used widely for protection, they must be backed up by HRC fuses where the fault level is too great to be handled safely and effectively by the MCB itself. Therefore, the choice of the appropriate type of over current is a matter of professional judgement and should be made by a Competent Electrical Person. The appearance of an MCB is shown below. Most commonly available MCB's have two modes of operation:



Ratings of MCB's are in the range 6A to 100A.

Miniature Circuit Breaker (MCB)

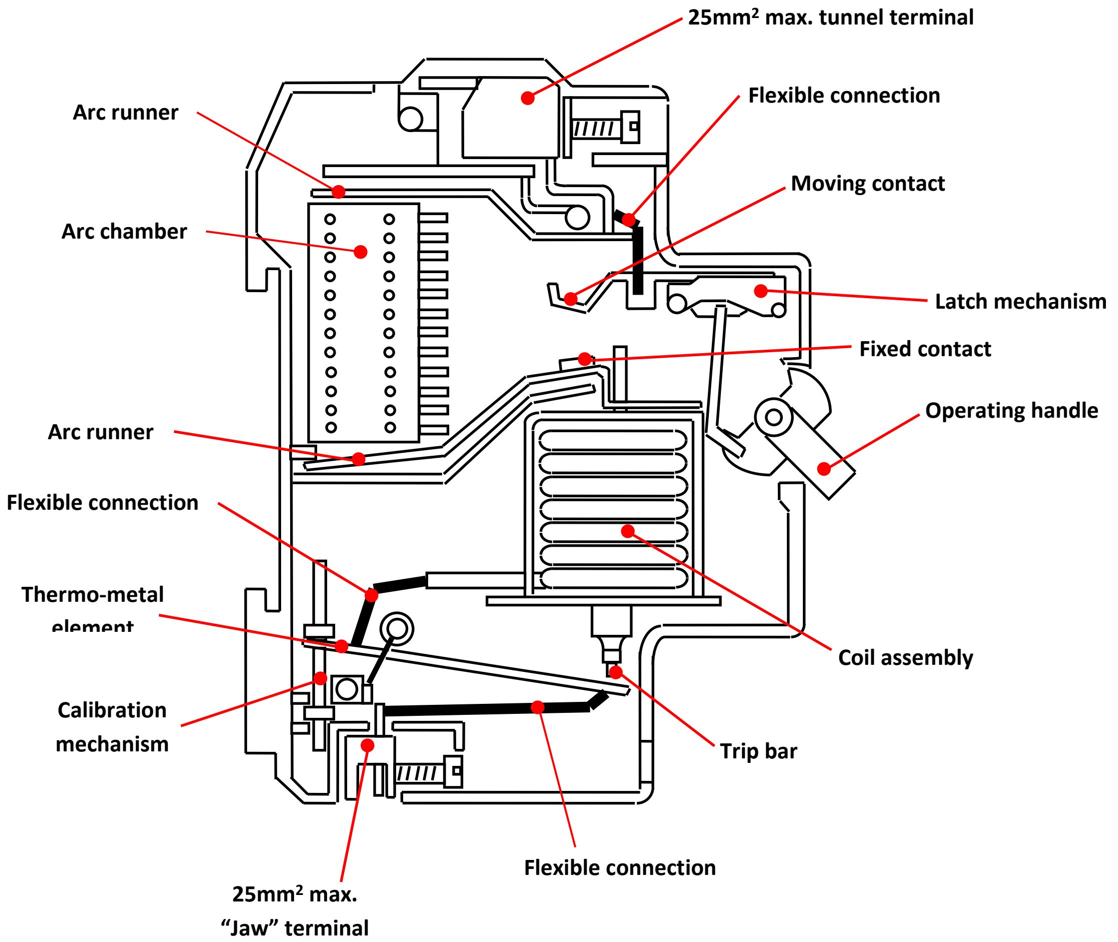
A miniature circuit breaker is a circuit protection device similar to a fuse, but re-settable. Most commonly available MCB's have two modes of operation:

Thermal overload protection – to protect cables and equipment's from "long term" over current damage i.e. generated heat.

Magnetic short circuit protection – to protect cables and equipment against very high fault currents caused by catastrophic component failure.

All MCB's are rated by the normal current carrying capacity, operating voltage and by the maximum fault current and voltage that they can repeatedly break.

Fig. 1:4



The diagram shown above, (Fig. 1:4), shows a "Polestar" MCB manufactured by Crabtree. It has two modes of operation:

Small overload conditions

This is when too much equipment is plugged into the supply. Light overload currents are detected by the use of thermo-metal which deflects at a rate in proportion to the size of the overload. The thermo-metal moves against a latching system which releases the contacts allowing them to open under spring pressure.

Large overload conditions

This is when a piece of equipment draws too much current for the circuit to supply. If the overload current reaches a predetermined level (which depends on the current rating and type classification of the MCB), then the current in the coil produces a magnetic field in the solenoid which is strong enough to pull in the armature and operate the latching mechanism to open the contacts.

Short circuit conditions

If the fault current is of a high enough level, not only does the solenoid trip the mechanism, it also forces the contacts apart very rapidly in a process known as “hammer trip”. Under these conditions as the contacts separate an arc is drawn between them. The combination of magnetic fields in the MCB and the flow of the current in the arc acts to push the arc along the runners and into the arc chamber where it is quickly extinguished. The rapid opening of the contacts and extinction of the arc gives a total operating time that is typically 3.5 to 5 milliseconds.

MCB Selection

MCBs or Miniature Circuit Breakers are intended to give protection against overloads and short circuits, which can cause damage to cables and equipment.

MCBs have current ratings (6A 10A etc) above which they will start to open or trip and give protection to the equipment.
The first characteristic is the overload which is intended to prevent the accidental overloading of the cable in a no-fault situation.
The speed of the MCB tripping will vary with the degree of the overload. This is usually achieved by the use of a thermal device in the MCB. The second characteristic is the magnetic fault protection, which is intended to operate when the fault reaches a predetermined level and to trip the MCB within one tenth of a second. The level of this magnetic trip gives the MCB its type characteristic as follows: -

Type B – trips between 3 and 5 times full load current

Type C – trips between 5 and 10 times full load current

Type D – trips between 10 and 20 times full load current

Apart from compliance with the Wiring Regulations, the importance of the “types” is to ensure that the MCB does not give unwanted tripping when equipment is started up.

For instance, **electric motors or low voltage lighting the use of a type B MCB may give unwanted tripping** and the choice of a type C MCB will probably solve the problem. In some instances, the type D MCB may have to be selected but in this case, it may be advisable to discuss with a qualified engineer before there may be other problems created.

The third characteristic is the short circuit protection, which is intended to protect against heavy faults maybe in thousands of amps caused by short circuit faults. The capability of the MCB to operate under these conditions gives its short circuit rating in Kilo amps (KA). In general, for consumer units a 6KA fault level is adequate whereas for industrial boards 10KA fault capabilities or above may be required.

MCBs are offered in types B, C and D characteristics. Where normal resistive loads are being fed the type B characteristic may be sufficient but in many industrial application motors and special lighting and data equipment is being fed which may adversely affect the MCB's during starting and it will be necessary to use type C characteristic breakers.

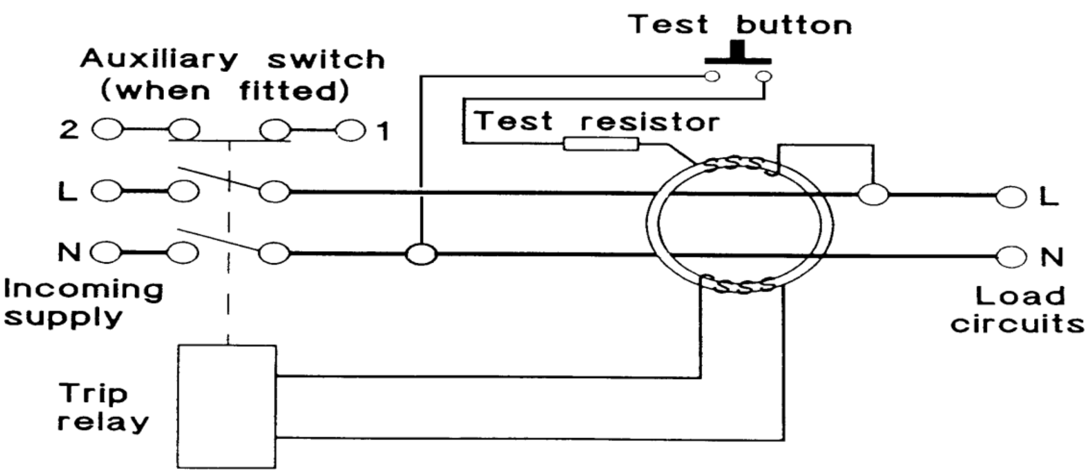
In some cases, such even these MCBs may not be sufficient when compressor motors are used and a type D MCB may be necessary. However, caution should be practised because the characteristics for these MCBs may make compliance with the Wiring Regulations difficult without a change in the specifications of the other equipment.

Residual Current Devices (R.C.D), (RCCB)

The residual current device, or RCD, is principally designed to offer personal protection against accidental electrical shock. Most types work by monitoring the current normally flowing to and from a piece of equipment. Any difference (residual) resulting from a current path to earth, for example an individual touching the live conductor, is monitored and at a pre-determined level the device will remove the supply from the equipment.

Most modern types are double pole i.e. they switch both live and neutral connections. The device is rated by the amount of residual current required to trip; the time taken to trip and the nominal voltage and current the device will carry.

It should be noted that most RCD's do not protect against live to neutral faults hence back-up protection by fuse or MCB is required.



NOTE

The IET wiring regulations now specifically require the use of an R.C.D for socket outlets intended to supply portable electrical equipment outdoors i.e. outside the zone of earthed equipotential bonding.

Note 1: All exposed metalwork must be earthed.

Note 2: A test button is provided on all RCD's to enable the operation of the device to be checked.

Speed of Operation

RCD's typically operate on earth fault currents as low as 30mA and with response times as fast as 30mS. The response time of 30mS complies with the requirements of the IET regulations.

a) In a healthy circuit the currents in the phase (live) and neutral conductors should be equal.

b) A fault which results in a leakage to earth causes an imbalance in the phase and neutral currents.

c) This creates a magnetic field in the current balance transformer, which creates a current in the fault detector coil.

d) This operates the tripping relay, which disconnects the mains supply.

The RCD employs the current balance principle which involves the supply conductors to the load (phase and neutral), being wound onto a common transformer core to form the primary windings. The secondary winding of the current transformer is then connected to the trip mechanism which is either an electro-magnetic or electronic relay. Under healthy circuit conditions the current in the phase conductor is equal to the current in the neutral and the vector sum of the current is zero.

In the event of an earth fault, an amount of current will flow to earth creating an out of balance situation in the transformer assembly. This out of balance is detected by the secondary winding of the transformer and when it reaches a pre-determined level, the current activates the trip mechanism. It should be noted that the RCD trip mechanism will operate at a residual current of between 50 and 100% of its rated tripping current.

Applications

Residual current devices may be required for one of two main reasons:

An RCD may be installed to meet requirements, where a high earth fault loop impedance disqualifies the use of over current protection devices as a means of providing protection against indirect contact.

To provide a higher level of protection than that given by direct earthing, against fire or shock risks caused by earth leakage currents.

Over current protection devices cannot detect earth fault currents below their operating current. If they are the only means of earth fault protection it is possible for sufficient earth fault current to flow undetected to constitute a fire risk. By using an RCD, the flow of the sustained earth fault current above the tripping current of the RCD is prevented hence the shock risk associated with these currents is also greatly reduced. Residual current devices are completely selective in their operation.

They are unaffected by parallel earth paths and are thus ideally suitable for the protection of modern-day installations. They are virtually tamperproof and provide a pre-determined level of protection. Even if earthing conditions substantially deteriorate, they will continue to provide a higher level of protection than would have been given by direct earthing.

Residual Current Breaker with Overload (RCBO)

These types of circuit protection device employ both the characteristics of the RCD and the MCB in that not only will it provide leakage current protection by detecting an imbalance between phase conductors, but it will also detect small overloads and short circuits.

THE OVERLOAD UNIT

The overload unit is purely a safety device. It is used to protect the motor from excessive currents.

On start-up, a motor can draw as much as eight times the supply current from the mains. The fundamental operation of the overload unit is to differentiate between the high current due to a fault condition and a high current due to start up characteristics. The main problem would occur, if the overload unit would shut off, when the high current is caused by the starting up process.

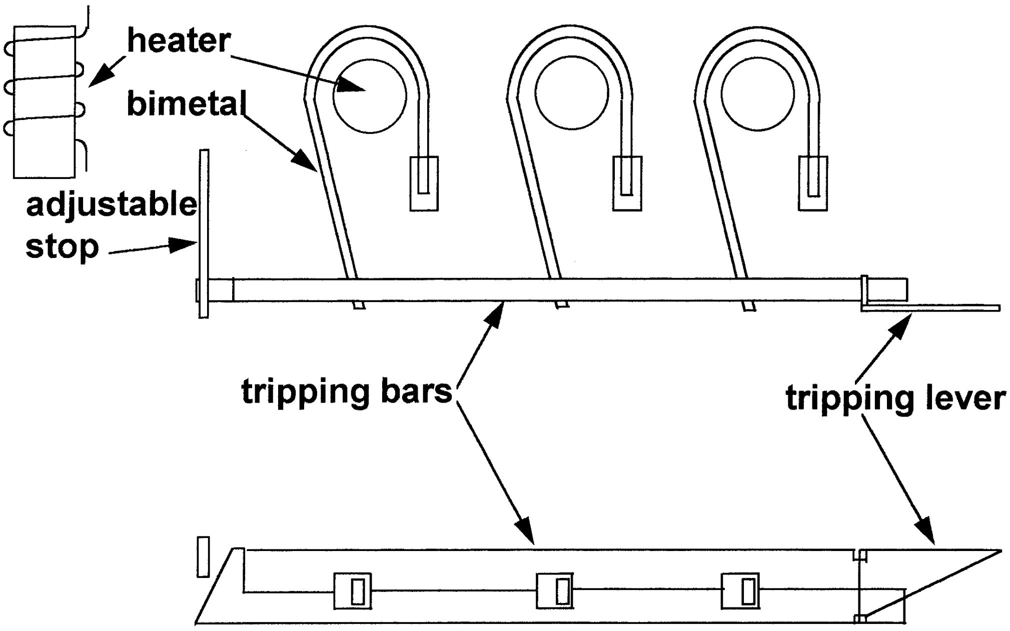
The effect of this shut off would therefore prevent the motor from starting. The overload could also be set to allow the large current on start up to flow, the overload may never detect a fault condition, and this would cause a motor to burn out. To overcome these problems the overload system is equipped with a timer device. This timer is set so that it will allow the large current to pass through on start up. Then the current will be restricted and any large fluctuations in current will cause the overload to trip.

There are two main designs of the overload units, which although they perform the same function, carry out motor protection in two completely different ways.

Thermal Overload Protection

Where the timer device is a carefully designed bi-metallic strip wrapped around a heater element, which expands a set amount under a designated current in a pre-determined time. Eli Lilly have various makes of thermal overload units, but all new or replacement units are Telemechanique.

BIMETALLIC STRIP TYPE OVERLOAD RELAY

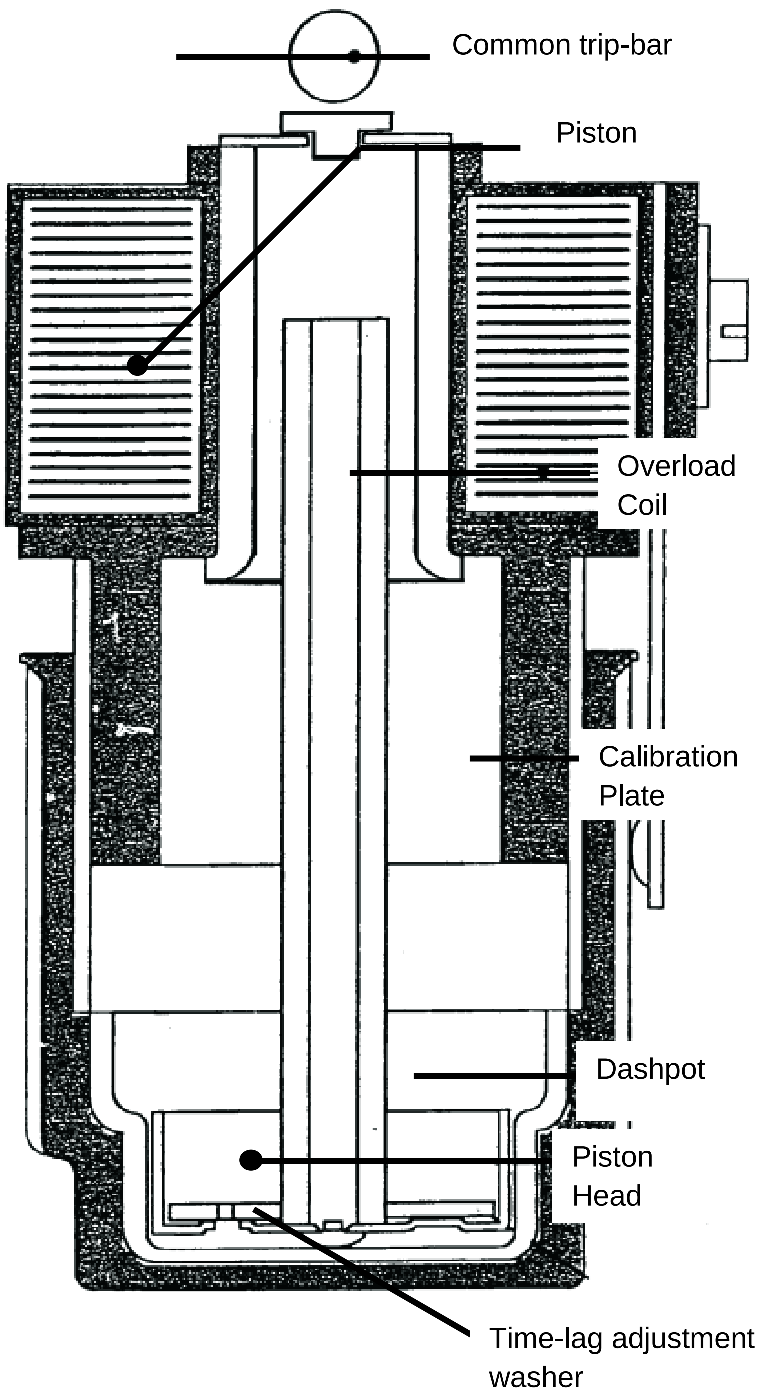


The diagram shows a simple course thermal overload device.

ALLAN WEST CONTACTOR OVERLOAD UNIT

Oil Dashpot Damped Magnetic Units

These units although old in technology still perform effectively if correctly set. The principle action is that the motor current passes through an electro-magnet acting as a solenoid, thereby attracting the armature, this would normally instantaneously operate but to supply the timing device a piston or plunger is fitted on the end of the armature. This piston is immersed in oil in a carefully machined container (Dashpot) which in effect supplies the damping; this can be varied via a section of small holes in the piston and washer assembly. Eli Lilly use this type of overload unit in the Allan West starter equipment.



Cross sectional view of a magnetic overload unit