Background

The fuse-link in one form or other has been around since the earliest days of electric telegraphs and then later in different forms for the protection of power distribution and other circuits.

Like many other products the fuse-link has undergone considerable evolution since those early days. The modern High Breaking Capacity (h.b.c.) fuse-link provides an economical and reliable protection against over current faults in modern electrical systems.

The basic operation of a fuse is a simple process - the passage of excess current through specially designed fuse elements causes them to melt and isolate the faulty circuit. However fuse-links have now developed for many applications from current ratings of only a few milli-amperes to many thousands of amperes and for use in circuits of a few volts to those for high voltage distribution systems of 72kV.

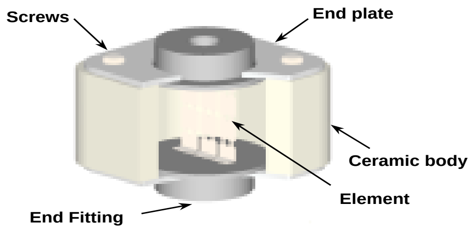
The most common use of fuse-links is in distribution networks where they are graded carefully with others in the system to give protection to the cables, transformers, switches, control gear and equipment. As well as different current and voltage ratings, it is possible to change the operating characteristics of fuse-links to meet specific application areas and protection requirements.

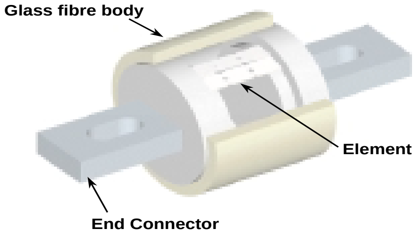
The definitions on how fuses especially designed for a certain purpose (fuse class) are included in the »Glossary of terms« later in this guide.

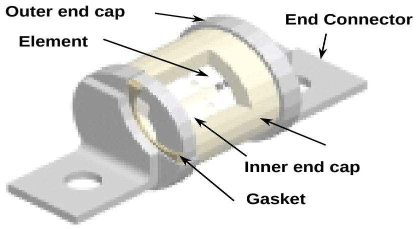
Modern fuse-links are made in many shapes and sizes however there are key features common to all h.b.c. fuse-links. Although all the components used influence the total performance of the fuse-link the key part of the fuse-link is the fuse element; this will be made from a high conductivity material and will be shaped to produce a number of reduced sections commonly referred to as 'neck' or 'weak-spots'. It is mainly these reduced sections that will control the operating characteristics of the fuse-link. The element is surrounded with an arc quenching material, usually graded quartz, which quenches the arc formed when the reduced sections melt. It is this function that gives the h.b.c. fuse-link its current limiting ability.

To contain the quartz will be an insulating container usually of ceramic or engineering plastic often referred to as the fuse body. Finally, to connect the fuse element to the circuits there are end connectors, usually of copper. The other component parts of a fuse-link vary depending on the type of fuse-link and the manufacturing methods used.

Typical fuse link constructions





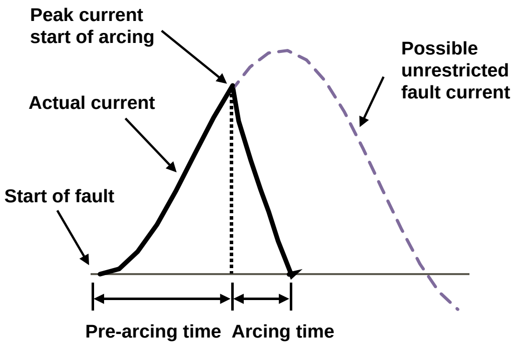


Operation of the fuse-link

The operation of a fuse-link depends primarily on the balance between the rate of heat generated within the element and the rate of heat dissipated to external connections and surrounding atmosphere. For current values up to the continuous maximum rating of the fuse-link the design ensures that all the heat generated is dissipated without exceeding the pre-set maximum temperatures of the element or other components. Under conditions of sustained overloads the rate of heat generated is greater than that dissipated and this causes the temperature of the element to rise. The temperature rise at the reduced sections of the elements (restrictions) will be higher than elsewhere and once the temperature has reached the melting point of the element material, the element will break, thus isolating the circuit. The time taken for the element to break will naturally decrease with increasing values of current. The value of current that causes the fuse-link to operate in a time of 4 hours is called the minimum fusing current, and the ratio of minimum fusing current to the rated current is called the fusing factor of that fuse-link. Under conditions of heavy overloading, as can be obtained in short circuit conditions, there is little time for heat dissipation from the element and the temperature at the restrictions will reach the melting point almost instantaneously. In other words the element will commence melting well before the prospective fault current (ac) has reached its first major peak. The time taken from the initiation of the fault to the element melting is called the pre-arcing time. This sudden interruption of a heavy current will result in an arc being formed at each restriction.
The arc thus created offers a higher resistance, thus reducing the current. The heat generated vaporises the element material; the vapour fusing with the quartz to form a non-conductive rock like substance called »fulgurite«. The arc also tends to burn the element away from the restriction, thus increasing the arc length and further increasing the arc resistance. The cumulative effect is the extinction of the arc in a very short space of time and the final isolation of the circuit. Under such heavy overload conditions the total time taken from initiation of fault to the final clearance of the circuit is very short, typically in a few milliseconds.
The current through the fuse-link will thus have been limited. Such current limitation is obtained at values of current as low as only 4 times the normal continuous rating of the fuse-link
The time taken from the appearance of the arc to its final extinction is called the arcing time. The sum of the pre-arcing and the arcing time is the total operating time.
During the pre-arcing and the arcing times a certain amount of energy will be released depending on the magnitude of the current and the terms pre-arcing energy and arcing energy are similarly used to correspond to the times. Such energy will be proportional to the integral of the square of the current multiplied by the time the current flows, formally written as $\int i^2 dt$, but more often abbreviated to I^2t; where I is the RMS value of the current and t is the time in seconds for which the current flows.

For high values of current the melting time is too short for heat to be lost from the reduced section (is adiabatic) and pre-arcing I^2t is therefore a constant. The arcing I^2t, however, also depends on the circuit conditions. The published data quoted is based on the worst possible conditions and is measured from actual tests. These will be detailed later in this guide.
The creation of the arc causes a voltage across the fuse-link; this is termed the arc voltage. Although this depends on the element design it is also governed by circuit conditions. This arc voltage will exceed the system voltage. The design of the element allows the magnitude of the arc voltage to be controlled to known limits. The use of a number of reduced sections in the element in series assists in controlling the arcing process and also the resultant arc voltage

Thus, a well-designed fuse-link not only limits the value of the prospective current, but also ensures that the fault is cleared in an extremely short space of time. Thus the energy released to protected equipment is considerably smaller than that available.



Protection Requirements for High Speed fuses

Since the development of silicon based semiconductor devices began they have, in numerous forms (diodes, thyristors, Gate turn-off thyristors - (GTO), transistors and more recently insulated gate bipolar transistors - (IGBT)), found an increasing number of applications in power and control circuit rectification, inversion and regulation.
Their advantage over other types of rectifiers and control elements lies in their ability to handle considerable power within a very small physical size. Due to their relatively small mass, their capacity to withstand overloads and overvoltages is rather limited.
In normal industrial applications of such devices, fault currents of many thousands of amperes could occur if an electrical fault were to develop somewhere in the circuit. Semiconductor devices can withstand these high currents only for extremely short periods of time.
High values of current cause two harmful effects on semiconductor devices. Due to non-uniform current distribution at the p-n junction(s) in the silicone, damage is caused by the creation of abnormal current densities. Secondly, a thermal effect is created, proportional to the product I^2, (RMS value of current)^2, x t, (time for which the current flows). The protection equipment chosen, therefore, must:

a interrupt safely very high prospective fault currents in extremely short times

b limit the value of current allowed to pass through to the device

c limit the thermal energy ($\int i^2 dt$ or I^2t) let through to the device during fault interruption

Unfortunately, ultra fast interruption of such large currents leads to the creation of high overvoltages. If a silicon rectifier is subjected to this, it will fail due to breakdown phenomena. The protective device selected must, therefore, also limit the overvoltage during fault interruption.
So far, consideration has mainly been given to protection against high fault currents. In order to obtain maximum utilisation of the device, coupled with complete reliability, the protective device selected must:

d not require maintenance

e not operate at normal rated current or during normal transient overload conditions

f operate in a predetermined manner when abnormal conditions occur.

The only device to possess all these qualities at an economical cost is the modern High Speed fuse-link.
Normal fuse-links (e.g. those complying with IEC60269-2) designed primarily to protect industrial equipment, are found to be lacking when used for protecting such sensitive devices. They do possess all the qualities mentioned above, but not to the degree required.
For these reasons special types of fuse-links have been developed to protect semiconductor devices, they are characterised by their high speed of operation and are referred to as either semiconductor fuse-links or more accurately High Speed fuse-links - but both terms mean exactly the same.
As we will see the term semiconductor fuse is miss-leading as there is in fact no semiconductor material involved within the fuse-link.

How High Speed fuse-links are different to other fuse types.

High Speed fuse-links have been developed from the methods used to produce »industrial« fuse-links. However, to minimise the I^2t, peak currents let-through and arc voltages the fuse-links designs have to be modified.
To ensure rapid melting of the elements, the necks have a different design than a similarly rated industrial fuse.
High Speed fuses are typically operated at more elevated temperatures that other fuse types.
High Speed fuse-links also typically operate with higher power dissipations than other fuse types because of the higher element temperatures; often they are also in smaller physical dimension packages. For this reason the body or barrel materials used are often higher-grade materials than those used in other fuse types.
High Speed fuse-links are primarily for short circuit protection of semiconductor devices, the high operating temperatures often restricts the use of low melting point alloys to assist with low over current operation. The result is that High Speed fuse-links often have more limited capability to protect against these low over current conditions
Many types of High Speed fuse-links are physically different to the standard sizes used for other protection systems. Although this requires additional mounting arrangements for High Speed fuse-links, it does avoid use of incorrect fuse-links in a graded system.

Characteristics required / provided

For the protection of semiconductors with fuse-links a number of parameters of the devices and fuse-links need to be considered. Of the parameters there are a number of influencing factors associated with each one. The manner in which these are presented and interpreted will be shown below. These parameters and associated factors will need to be applied and considered with due reference to the specific requirements of the circuits and application.
Some of these factors are explained below. Others are described in the sections on voltage dimensioning, current dimensioning and applications.