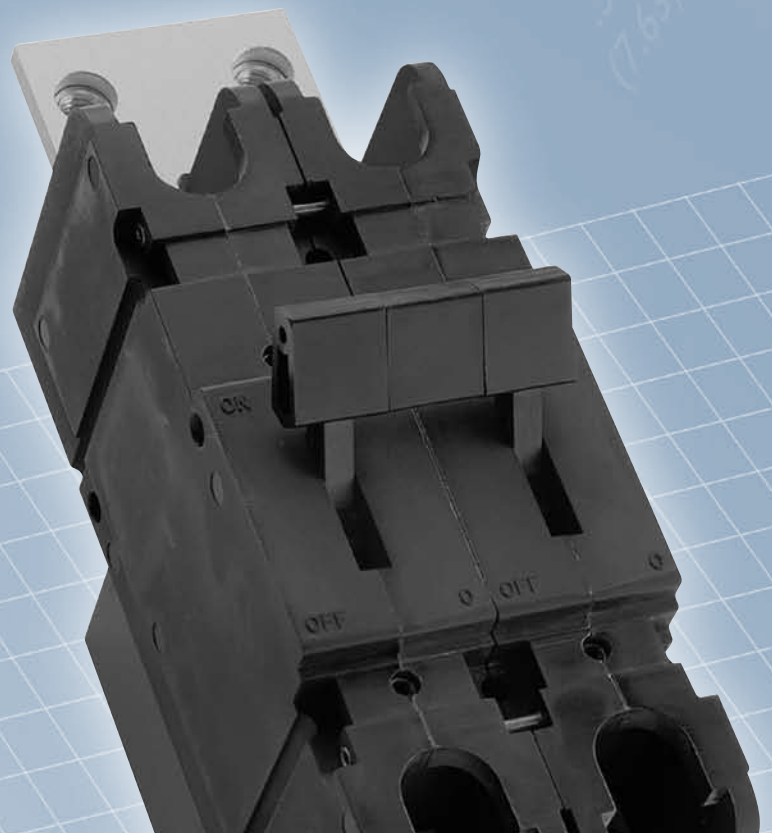
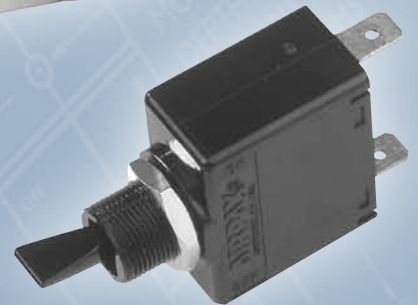


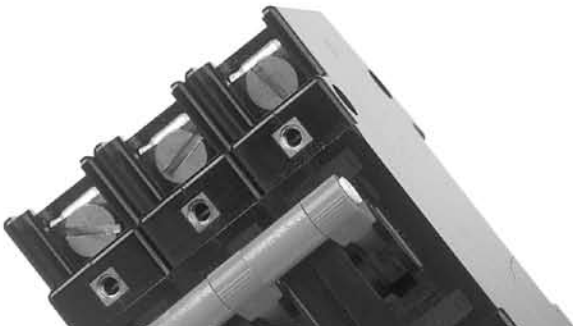
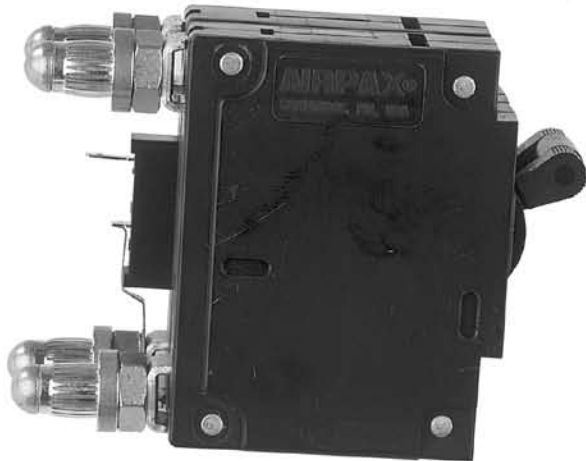
AIRPAX®

Guide to Circuit Protection



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CHOICE OF PROTECTION

INTRODUCTION

Most electric and electronic devices will destroy themselves if you let them. Since they cannot distinguish between normal loads or overloads, they will just keep drawing more current as the load increases – until they burn themselves out.

Protective devices for electric equipment and circuits act as survival kits. Because of the steadily increasing power being fed into transmission lines, these guardians must often respond faster to protect equipment and branch circuits. Suppliers of protective devices provide a diverse selection of devices to handle the spectrum of traditional protection needs, as well as innovative designs for newer applications with their rapidly changing requirements.

Basically, The Choice of Protection is about magnetic circuit breakers, a class of protector in which the breaking of the circuit is a function of current only. We do place in proper perspective the value of, and need for, other devices like fuses and thermal breakers, which, when correctly utilized, serve useful functions.

But our major emphasis is on magnetic breakers, the electromagnetic circuit protectors which lend themselves to a great variety of ingenious devices. Like fuses, they will respond to short circuits caused by faulty wiring to keep a house from burning down; but this is an unlikely spot for their application. You're most likely to find magnetic circuit breakers protecting computers, microprocessors and other solid-state systems, remote controls, industrial automation and air-conditioning, variable speed drives and a myriad of other industrial equipments and systems.



AIRPAX PHILOSOPHY OF PROTECTION

Reliable circuit protection is automatic protection which limits a fault to a single circuit. More importantly, it minimizes the danger of smoke and fire, not only in the equipment, but also in the conductors (or cables) leading to and from the equipment. Besides protecting the conductors, the protector must isolate the fault from the power source so that nonfaulted circuits can continue functioning in a normal manner. These objectives may not always be achieved by a single protective device. To accomplish optimum protection, circuit designers must use the correct combination of devices, correct sizing of wire and safe routing to contribute to the overall circuit protection philosophy.

The choice between circuit breakers, fuses, limiters or other protection means is governed by specifications, customer preference, maintenance, space, environmental restraints and circuit requirements. Proper selection procedures must result in a protective device with the lowest rating that will not open inadvertently. It must sense the fault, then disconnect the faulted line from the power distribution system before the wire insulation is destroyed. In addition, circuit breakers should almost always be trip-free, meaning that they cannot be held on against an overload. There are clear exceptions, such as in aircraft, when under certain conditions operation must be maintained in spite of overload. Besides considering all the variables involved, the time-current characteristics of the protec-

tive device should be compared with the time-current characteristics of the equipment (including starting or overload surges) component or wire.

The entire electrical system, including the power source, wire (single or bundles), switching devices and equipment must be protected from faults. Generally, a circuit protector is used at any point in a circuit where the conductor size is reduced, unless the immediate upstream protector provides adequate protection for the smaller wire.

Circuit components, such as transformers, rectifiers, filters, regulators and electronic circuits, have significantly different overload withstand characteristics from those of wire and cable. Many electronic circuits and components require extremely fast clearing devices, such as very fast acting fuses, to provide adequate protection from thermal damage.

AVAILABLE CHOICES OF PROTECTION

Typically, four principal options are available to the electrical engineer specifying protection devices. Fuses, still the most used device, operate by melting a shaped metal link. There are many types of ingenious thermal mechanical circuit breaker devices where a piece of metal is warped by heating to trigger a release mechanism. Also available are electronic breakers.

EXAMPLE: Devices with silicon controlled rectifiers in their output, which will open on the next zero crossover on alternating current, and magnetic circuit breakers whose trip point is a function of current only.

The engineer uses the protective devices to protect either his equipment or perhaps the power company from catastrophe, or human life – sometimes all three. The Underwriters' Laboratories acknowledge two classes of protection: "Listed" branch circuit breakers and "Recognized" appliance circuit protectors. Branch circuit breakers protect wiring and/or the equipment. They may have a lower rating than the breaker in a machine, thus protecting both wiring and the machine. Appliance protectors protect equipment. The reference "appliance" may be misconstrued; here the term appliance extends to cover industrial equipment and control

units such as computers, terminals, computer peripheral devices, key punches, printers and data processors.

"Ground fault" protection, as later described, is not yet required for all home circuits in the United States because of the partial protection provided by our three-wire electric system. Ground fault interrupters are used extensively in Europe, however, where the usual installation is 230 volts and where the third-wire ground is not commonly carried out to appliances. A sufficiently sensitive ground fault system can detect the presence of current to ground, such as from the hot wire through a human body to ground, and interrupt the circuit before the electric shock becomes fatal.

FUSES

Fuses, usually metal links of a lead alloy, are used extensively in the U.S., and work fairly well considering their intrinsic problems. Being dependent on the melting of a metal link, their exact blow point is subject to considerable variation. In addition, they must also be replaced, depending as they do on self-destruction.

When a fuse operates, the current of melting and the current of circuit interruption may vary greatly. Fuse-clip size and condition, and the size of the conductor attached to it can have a considerable influence on fuse performance. (Figure 1 shows effect of ambient temperature on fuse performance.) In addition, corrosion of fuse and connecting clip causes fuse heating problems.

Silver-link semiconductor fuses are fast-blow devices designed to protect SCR's and power diodes from the damaging effects of heavy short circuits, reversed polarity and the like. When semiconductors are subjected to very high current overloads, thermal damage occurs which is proportional to I^2T . As a result, fast blow silver-link fuses have been developed where performance characteristics are similarly I^2T dependent. Proper matching of fuse to semiconductor results in very effective protection.

The deterioration of semiconductors from overload is progressive, i.e., successive overloads reduce the maximum inverse voltage obtainable and may contribute to eventual device failure. The problem is accentuated by the fact that a rectifier does not turn on instantly across the device; the conducting path spreads through the semiconductor in an appreciable time interval.

The high-speed action of "current limiting" semiconductor fuses (Figure 2) comes from a silver link with a small link section joining a substantial size sheet of silver. Silver provides a maximum of thermal conductivity, and short-circuit protection is provided when the rate of rise of heat in the small link exceeds the rate of thermal conduction away from the link. As the link melts, the voltage across it rises and arcing begins. Arc quenching is aided by silica sand crystals which effectively lengthen the arc path (Figure 3).

During fuse action, there are three time-stages designated as melting time, arcing time and clearing time (Figure 4). Clearing time and peak let-through current are of greatest interest to the circuit engineer.

The voltage rating of a semiconductor fuse is important. Sometimes a user may apply 250-volt fuses to 125-volt circuits, thinking he has achieved greater safety. This is not quite true – voltage ratings should not be interchanged because a high voltage rating may provide a less desirable I^2T rating, and possibly cause excessive voltage transients by clearing the circuit too quickly.

In some cases, fuses offer an adequate low-cost method of protection. However, because of the replaceable nature of fuses and the ease of overfusing, protection may not be adequate. Within certain maximum and minimum ratings, fuse dimensions are usually the same; and it is possible to substitute a 20 ampere fuse where a 5 or 10 ampere fuse should be. Often when a correct value replacement is not available (or the fuse blows too often), a higher rating is substituted.

A less known but still troublesome characteristic is fuse element deterioration, caused by chemical and physical stresses produced in the fuse element during repeated short duration overloads. For example, motor starting produces a short current inrush followed by low running current conditions. The inrush current, usually higher than the fuse rating, is not present long enough to blow a correctly applied fuse. However, deterioration of the element, resulting from repeated motor starting, often causes mysterious fuse failures.

MECHANICAL BREAKERS

Mechanical breakers, both thermal and magnetic, require an appreciable time to operate. Magnetic types are by far the fastest of the two. Under dead short circuit, the operating speed of its mechanical mechanism will be as low as three or four milliseconds. This may not be fast enough for certain kinds of diodes and silicon-controlled rectifiers because their heat sinks are not effective for short duration, high amplitude overloads. The time-to-trip of a typical Airpax breaker is illustrated in Figure 5, up to 10 times rated current (1,000 percent). The band appearing on the curve means that the trip time will not fall below the lower line of the band, and will trip somewhere inside the band.

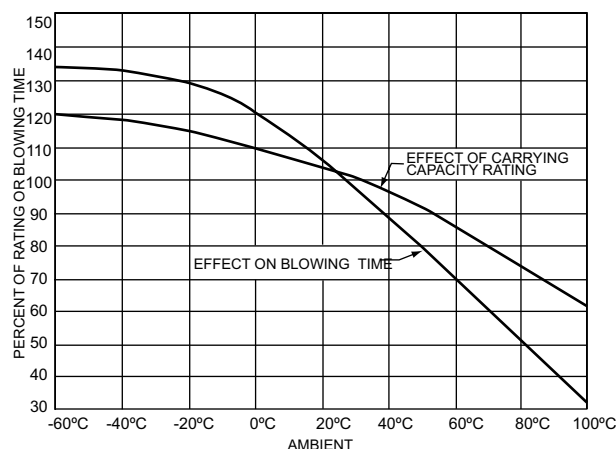


Fig. 1 Ambient temperature versus operating characteristics of fuses.

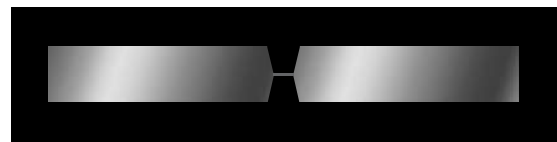


Fig. 2 Silver link semiconductor fuse.



Fig. 3 Typical silver link fuse.

THERMAL CIRCUIT BREAKERS

Thermal circuit breakers function to protect the power wiring, and the power grid behind it, from the mistakes of the power user. As such, they do a good job. A high quality thermal circuit breaker, from sources such as General Electric and others, will open a 10,000 ampere fault at 250 volts AC in about 40 or 50 milliseconds. It probably will even do this more than once. In contrast, a magnetic breaker will open a similar fault in about 10 milliseconds, and also probably more than once.

Thermal circuit breakers are dependent upon temperature rise in the sensing element for actuation. In normal operation, deflection of a thermal sensing element (e.g. bimetal) will cause the circuit to open when a pre-determined calibration temperature is reached. Temperature rise in the sensing element is caused principally from load current I^2R heating. The thermal element also integrates heating or cooling effects from external sources, and tends to derate or uprate from room temperature calibration with corresponding fluctuations in ambient temperatures.

The size of the thermal element, its configuration, and its physical shape and electrical resistivity determine the current capacity of the circuit breaker. In some cases, a heater coil is placed adjacent to, and electrically in series with, the thermal element to augment self-heating of the thermal trip element. This is especially true in ratings below five amperes.

The most common thermal element used is a "sandwich" of two or three different metals. The low expansion side may be invar, the center may be copper for low resistivity or nickel for high resistivity. Metals used in the high expansion side vary considerably.

In order to protect wiring, upstream components and the breaker itself from unnecessarily long thermal and mechanical stress during high fault level currents, an electromagnet is sometimes added to cause faster tripping of the thermal breaker. This magnetic circuit usually consists of a few turns of a large cross-section conductor in series with the thermal element and has negligible effect on the total breaker impedance. The magnetic assist usually has a crossover point well above the normal overload calibration range. There is little effect on the normal thermal trip response time, but with high overload conditions the current level generates sufficient magnetic force to trip the breaker magnetically without waiting for the bimetal to de-flect. This construction

results in very fast trip times on high overloads.

A simple thermal circuit breaker's trip point is affected by variations in ambient temperature. A temperature (ambient) compensated circuit breaker is a breaker in which a thermal responsive element is introduced to compensate for changes in external temperatures. The compensating element usually is electrically isolated from and is independent of the current carrying thermal trip element, and acts only when a change in ambient temperature occurs. The degree of compensation may vary from partial to full compensation. A fully compensated breaker will operate nearly independently of its ambient temperature within a limited temperature range.

A hot-wire thermal circuit breaker uses the expansion of a high temperature wire as a means to cause the contacts to open. Because the temperature of the wire at time of trip is in the order of 800-900°F, changes in ambient temperature have little effect upon the calibration. Its trip time is faster than the bimetal breaker, but its voltage drop is higher.

Figure 6 shows the outline of a typical, good quality thermal breaker used in wiring applications and arranged to plug into a distribution panel.

Thermal circuit breakers are best suited to protect wire since the thermal element within the breaker tracks the performance of the protected wire. This can be observed by comparing Figure 7 (a) and (b) which shows thermal circuit breaker characteristics and time current limits for copper wire.

The problem of selecting the correct thermal breaker is more complex than simply matching the breaker rating with the wire rating. One must also consider the ambient operating temperature (see Figure 8), the allowable voltage drop and the heat sinking provided. Low cost thermal breakers using simple bimetallic elements only, are limited to applications such as wiring protection in low voltage circuits like those in automobiles.

Thermal breakers are necessarily temperature sensitive, although clever design permits some compensation against ambient change. Many people are familiar with nuisance tripping of the power-panel breakers on a hot summer day. The reasons become quite evident from Figure 8 which compares the relative performance of an Airpax magnetic breaker with a comparable thermal type of about the same rating. As shown, at 85°C this thermal breaker would trip at about 60 percent of its rated continuous current, while at 40°C this increases to about 200 percent of rating.

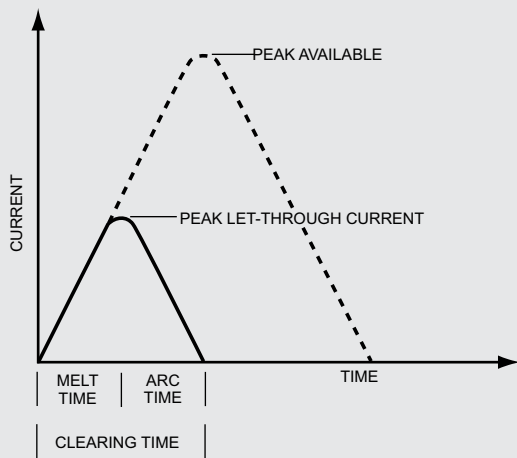


Fig. 4 Silver link fuse characteristics

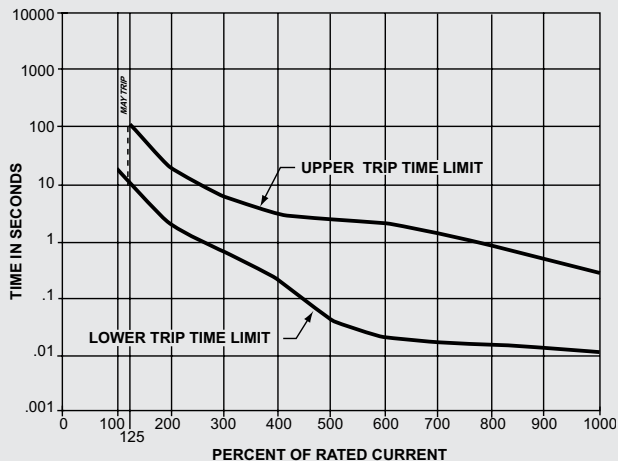


Fig. 5 Trip time characteristics of a typical Airpax magnetic breaker.

MAGNETIC CIRCUIT BREAKERS

A magnetic circuit breaker, sealed or nonsealed, provides manual switching, opens automatically under overload conditions and carries full-rated current. Sealed circuit breakers, which have an advantage in that they are less affected by adverse environments, typically are made only in ratings below 20 amperes. Nonsealed circuit breakers provide for higher power requirements, but most are restricted as to environment.

The magnetic time-delay circuit breaker operates on the solenoid principle where a movable core held with a spring, in a tube, and damped with a fluid, may be moved by the magnetic field of a series coil (Figure 9). As the core moves toward a pole piece, the reluctance of the magnetic circuit containing the armature is reduced. The armature is then attracted, causing the mechanism to trip and open the contacts on an overload or fault condition.

The ultimate trip current – the minimum current that will provide a reliable trip of the breaker (115 percent is typical) – which is independent of ambient temperature, is dependent primarily on the number of ampere turns and the delay tube design. This trip point occurs after a predetermined time when the core has made its full travel in the tube.

The instantaneous trip current is that value of current required to trip the circuit breaker without causing the core to move in the tube. This is possible because excess leakage flux in the magnetic circuit, caused by high overloads or faults, will attract the armature and trip the circuit breaker. Instantaneous trip point is also independent of the ambient temperature. The instantaneous trip current is usually on the order of ten times the current rating of the circuit breaker. Since fluid fill impedes core movement, an inverse overload time-delay results so that trip time is less as the percent of overload is increased.

“Instantaneous-trip” circuit breakers have no intentional time delay and are sensitive to current inrushes and vibration and shock. Consequently, they should be used with some discretion where these factors are known to exist.

Magnetic breakers are versatile and lend themselves to coordination with other forms of protection. In the circuit of Figure 10, three semiconductor fuses provide final protection against a catastrophic short circuit, such as is experienced from wiring errors on start-up of a complex system. The four pole magnetic breaker, which protects against less than absolute shorts, opens before the silver-link fuses blow on such overloads. In Figure 10, three of the poles protect the separate legs of a three-phase system, and the fourth leg sums the DC delivered to the system.

At high overloads, fuses and thermal breakers respond according to the function I^2T with resistance being assumed constant. Magnetic breakers operate as a function of current only, the coil turns being constant.

In time delayed magnetic breakers the oil viscosity changes with temperature. Accordingly, the time of response of a magnetic breaker decreases as temperature increases, a factor sometimes considered a virtue. The current of trip, however, remains essentially unchanged with change in temperature; herein lies one of the major virtues of magnetic circuit protectors. An Airpax protector will repeat the current of trip to about 2 percent. Not being dependent on heating elements, the magnetic protector will trip at values as low as 125 percent of the rated full-load value under all ambient temperature conditions. Thus at 200 percent load, a magnetic breaker can be designed to trip in 25 milliseconds or as long as 50 seconds. At 800 percent load, the thermal type would require about one second, a magnetic type about 15 milliseconds.

The effect of temperature on a magnetic breaker is illustrated in Figure 11. The current of trip remains unchanged; the nominal time of the trip of an Airpax protector, style APG, delay 62 at 125 percent load is 30 seconds at +25°C, 100 seconds at –40°C and 10 seconds at +85°C. The 200 percent trip is 6.0 seconds at +25°C, swinging from 15.0 seconds at –40°C to 2 seconds at +85°C. The faster trip time at the higher temperatures, along with the constant trip current, sometimes is considered to be advantageous.

All trip times and 100 percent hold specifications, as shown on delay curves, assume that the circuit breaker is in a normal mount position as illustrated in Figure 12. With the delay mechanism situated on the horizontal plane, gravity has little or

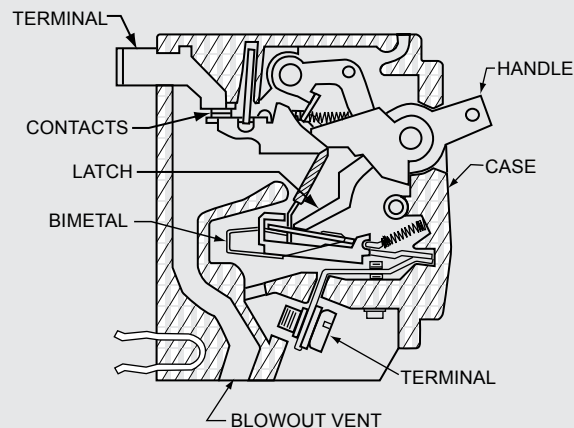


Fig. 6 Outline of a typical thermal breaker. Square D Type QO.

no effect on the core. Obviously, if the delay mechanism is mounted vertically or at any angle, gravity will have either an impeding or increasing effect on the movement of the delay core. If the unit is mounted with gravity impeding, it's likely that the breaker will not trip at the rated trip current. Its ultimate trip current will be beyond the range indicated in the delay specifications for the breaker. Conversely, if gravity is aiding, the ultimate trip current may be less than the 100 percent hold specified.

It is recommended that when other than horizontal mounting attitudes are required, the breaker supplier be contacted for specific delay recommendations. Normal mounting is defined as mounting on a vertical panel with “ON” up.

A magnetic breaker can be reset immediately after tripping, although the delay mechanism does not immediately reset. If the fault is still present, this will reduce the time to trip. This usually is not true with thermal breakers since the heating element must cool down before it will reset.

The magnetic breaker shown in Figure 12 is essentially a toggle switch composed of a handle connected to a contact bar which opens and closes an electrical circuit as the handle is moved to the “ON” or “OFF” position. The handle is connected to the contact bar by a link which is collapsible.

When this link collapses, it allows the contacts of the unit to fly open, thus breaking the electrical circuit. The magnetic circuit within the unit consists of the frame (1) armature (2) delay core (3) and pole piece (12). The electrical circuit consists of terminal (4) coil (5) contact bar (6) contact (7) contact (8) and terminal (9).

As long as the current flowing through the unit remains below 100 percent of the rated current of the unit, the mechanism will not trip and the contacts will remain closed as shown in Figure 12 (a). Under these conditions, the electrical circuit can be opened and closed by moving the toggle handle (10) on and off.

If the current is increased to a point between 100 percent and 125 percent of the rated current of the unit, the magnetic flux generated in coil (5) is sufficient to move

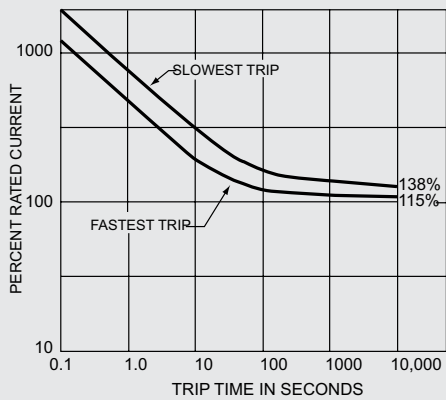
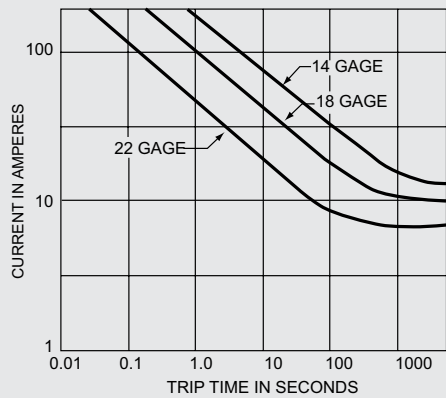


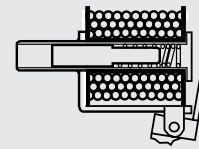
Fig.7 (a) Thermal breaker characteristics.



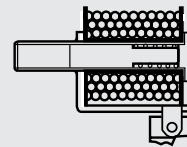
(b) Time current limits for copper wire.



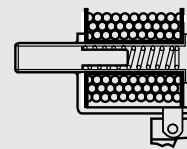
Coil current with-in rating.



Coil current above rating, moderate overload.



Moderate overload, armature operates after delay.



Current far above rating, armature trips without delay.

Fig. 9 Mechanical time delay used in Airpax magnetic breakers.

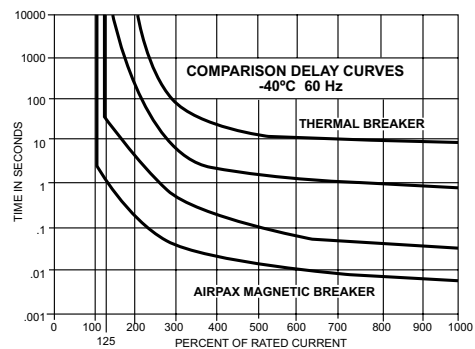
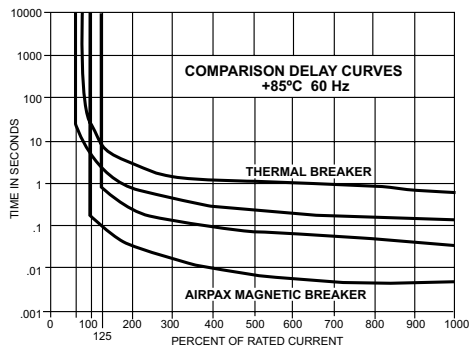


Fig. 8 Magnetic versus thermal breaker characteristics at high and low temperatures.

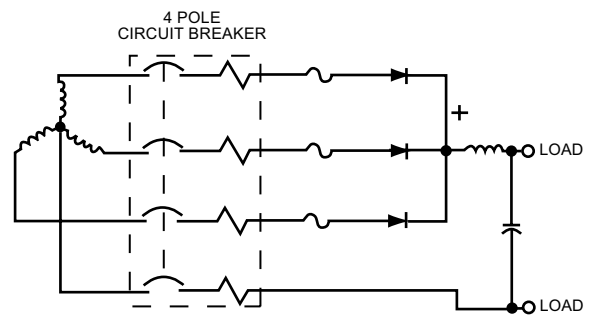


Fig. 10 Combination of AC overload, DC overload and semiconductor fuse protection.

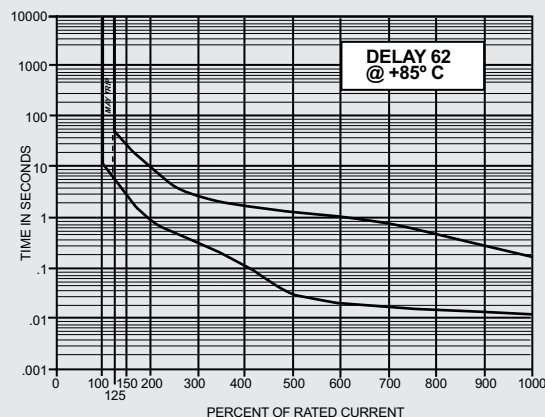
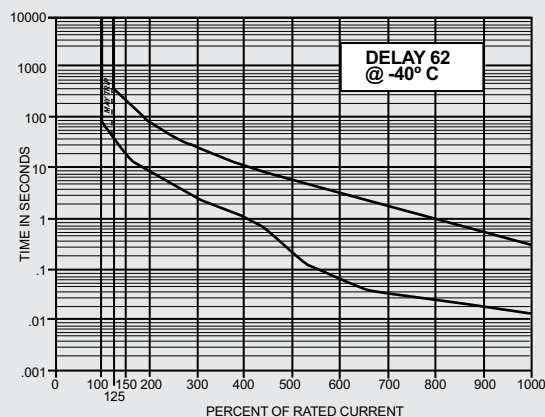
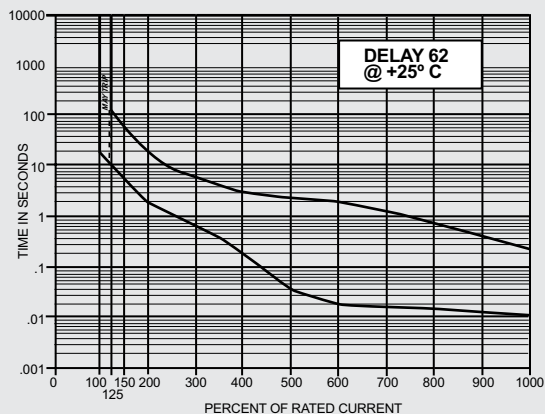


Fig. 11 Effect of temperature on a magnetic breaker trip time.

the delay core (3) against spring (11) to a position where it comes to rest against pole piece (12) as shown in Figure 12 (b).

The movement of this core against the pole piece increases the flux in the magnetic circuit described above enough to cause the armature (2) to move from its normal position shown in Figure 12 (a) to the position shown in Figure 12 (b). As the armature moves it trips sear pin (13) which, in turn, triggers the collapsible link of the mechanism, thus opening the contacts.

The delay tube is filled with a silicone fluid which controls the speed at which the delay core moves, so different delay curves can be obtained by using fluids of different viscosities.

When high surges occur in an electrical circuit, the magnitude of the flux produced in the magnetic circuit should be sufficient to trip the unit without the delay core changing position. For protection of UL appliances such as those listed previously, protector delay curves that provide instant trip at surges of 600 percent or more should be applied.

By comparison, these same protectors would probably cause nuisance tripping if specified for applications such as induction motor starting. In this latter situation, delay curves may be selected that do not become instant until surges of 1200 to 1400 percent are experienced.

Magnetic circuit breakers typically have very low voltage drops at rated load. However, when operating at very low voltages, the drop may become a significant factor and should be taken into account if the load voltage is critical.

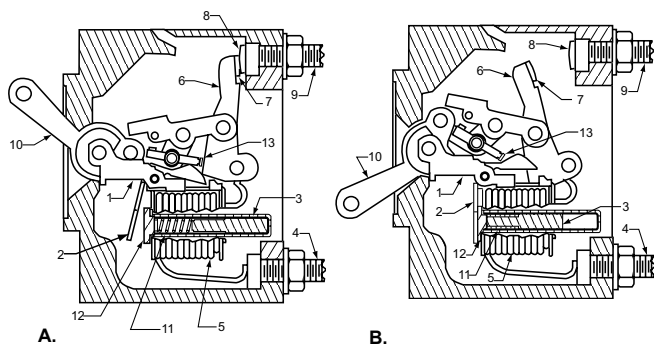


Fig. 12 Operating mechanism of an Airpax magnetic circuit breaker.

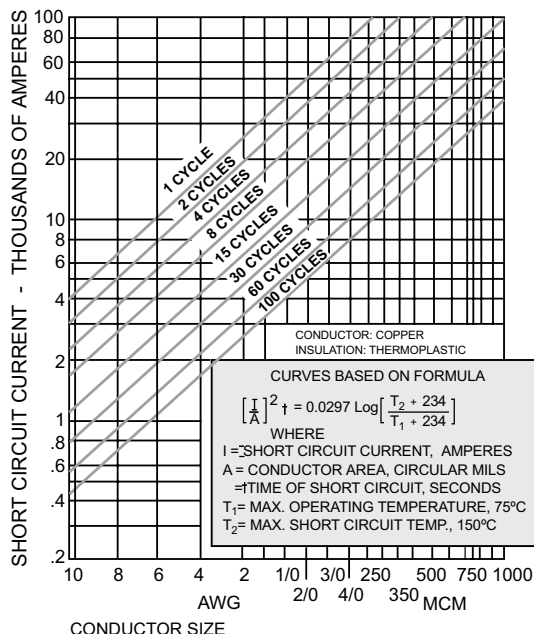


Fig. 13 Short circuit currents for insulated cables.

SHORT CIRCUIT CAPACITY

When applying any overload protection device, it is important to know that the available short circuit fault current at the device is not in excess of that which can safely be interrupted. Available short circuit current is the maximum RMS current which would flow if all active conductors were solidly bolted together at the point of fault protected by the device. In reality, actual fault current is much less than available fault current. The primary factors that determine the available fault current are supply transformer size, the impedance of the cable or wire and that of the connections. These factors, in addition to the fault resistance, determine the actual fault current.

For a three-phase transformer (rating details are usually available on the nameplate), the available fault current on the bus bars may be roughly calculated from the formula:

$$\text{Available Fault Current} = \frac{\text{Transformer Rating (VA)}}{\sqrt{3} \times \text{Rated Voltage} \times \text{Percent Impedance of Transformer (expressed as a decimal)}}$$

As a rule of thumb, the available fault current from a 60Hz transformer is usu-

ally about 20 times the full load current, while a 400Hz transformer can produce about 12.5 times the full load current.

The percent impedance is basically a statement of the internal impedance of the transformer and is available on the nameplate or from the manufacturer. Percent impedance can be expressed as follows:

$$\% Z = \frac{I_{\text{rated}} \times \text{ohms} \times 100}{V_{\text{rated}}}$$

The percent impedance for 60Hz transformers is approximately four to seven percent for average size transformers.

Although a transformer can provide a severe limiting effect on fault current, wire and connector, resistance becomes very significant as distance increases. The resistance of a few yards of cable can reduce the fault current considerably.

The effective current capacity of a line can be computed roughly by a simple differential measurement, i.e., the output voltage difference of the line from no load to full load. For example, if a 120 volt line supplying 30 amperes has a 6 volt drop, the total impedance back to the original generator is $R = 6/30 = 0.2$ ohms and the short-circuit current is 600 amperes until something lets go.

Faults considered as "typical" are usually not destructive to the breaker. The majority of faults are faults-to-ground rather than line-to-line. With the difficulty normally encountered in obtaining a good direct ground, the actual fault current is unlikely to exceed 400 amperes. Obviously as a safety precaution, in the event of a heavy fault trip out, caution should be exercised before attempting to reset the circuit breaker. Corrective measures should be taken to assure that the fault has been cleared, or that the main power is removed from the system by positioning a separate disconnect.

Because of the increasing capacity of power systems, sometimes it is possible to have short-circuit current high enough to seriously damage conductor insulation. For a guide to prevent such damage, see Figure 13. It is based on a short-time temperature limit of 150°C for thermoplastic insulation. Paper, rubber and varnished cloth insulation has a slightly higher short-circuit capability based on a short-time 200°C temperature limit. (Source: Insulated Power Cable Engineers Association: 1 PCEA.)

BATTERY LET-THROUGH CURRENTS

The factors affecting DC short-circuit analysis are similar to those considered in AC. In the simplest terms, the theoretical available DC fault current from a battery can be calculated from the following:

$$\text{Available DC fault current} = \frac{\text{Battery voltage}}{\text{Battery internal resistance}}$$

Table 1, which provides values for let-through currents, was established using data from actual tests on a large number of standard batteries. All interrupt tests were run with Airpax APL family protectors. Note: the protectors provided successful interruption at 5200 amperes at 12 volts.

When batteries are wired in parallel, the effective battery internal resistance drops in accordance with parallel resistance laws. Conversely, when batteries are connected in series, the effective internal resistance increases.

TRANSIENT TRIPPING

The fast operating speeds of magnetic protectors can cause nuisance tripping on high amplitude transients. When a transient of sufficient energy content arrives, the protector responds in an instantaneous trip mode. This is permissible in applications

where transients of this nature are likely to cause damage to circuit components.

For example (Figure 14), the resistance of a tungsten lamp is low when cold, but high when energized. A maximum pulse, about 4 milliseconds in duration, can occur when switch closure coincides with the peak voltage point of the supply and the load is one that has low initial impedance such as an incandescent lamp bank, a high capacitive load, or a ferroresonant transformer.

Nuisance trips will result if pulse energy exceeds the energy needed to trip the protector. The amplitude of tungsten lamp surges may be 15 times the rated steady state current at first – the following cycles are much lower. Here, protector inrush rating can be increased, but only at the expense of overload protection.

In another example (Figure 15), capacitive input filter charging resembles an RC charge curve. At peak current it's limited by charge circuit resistance and the power supply itself. Here, surges are less troublesome; transient duration is very short.

Further, in a typical AC to DC power supply, (Figure 16), measured steady-state AC current is 0.265 amperes RMS and about 0.375 amperes peak. When the circuit protector is closed, the current in the filter circuit reaches 13 amperes. If a standard magnetic protector is used, the current would have to be de-rated to about 2 amperes to avoid nuisance tripping. A reasonable compromise is to use a pulse tolerant protector that permits a more reasonable rating of about 1 ampere.

pulses. The integrator has an effect only on the armature and does not control the longer time delays to any appreciable extent. Figure 19 illustrates the mechanical device used to provide armature delay. However, the time of circuit interruption (by opening contacts) is set effectively by the time to reach zero on the AC cycle (when the source voltage reaches over 50 volts). The "inertia" wheel protector, which is designed for short-duration, high-amplitude pulses, 20 to 30 times rated current for about 4 to 5 milli-seconds, has no particular effect for long-duration, lower-amplitude overloads (such as experienced during motor starting).

Currently, design trends demand a reduction in size and weight of system components, particularly transformers. Newer transformers having grain-oriented, high-silicon steel cores have serious "very high inrush current at turn-on" problems. These currents can be as high as 30 times the normal rated current, compared with approximately 18 times for older transformers.

The "worst condition," highest spikes for 60Hz primary, are of approximately 4 milli-second duration. This turn-on transient is concentrated in the first half cycle with successive half-cycles depreciating in amplitude very quickly. The transient is not very sensitive to transformer load; in fact, a loaded transformer may have slightly less severe transients than when under no load.

At the instant of turn-on, the inrush of transient varies with the residual magnetism of the core and with the relative phase of the primary voltage at turn-on. The worst case transient will not occur at each equipment turn-on, but more likely in 1 in 5 or 10 turn-ons.

Inrush transients are most severe when the power input is a low impedance source, and the line voltage is high. The maximum spike may be as much as 20 to 25 percent higher at 130 volts than at 120 volts with the same circuit.

Pulse tolerant protectors must accept the first surge of current without tripping, while still providing maximum equipment protection. This is accomplished either by shunting high flux peaks away from the armature or using an inertial device to damp the armature from short duration pulses. Each method requires a compromise. Shunts distort the trip time curve in the area of 600 to 1200 percent overload, which may make trip time unacceptable. Dampers (inertia wheels) are effective only in the area of the first half-cycle of high overload currents. If the high current persists past the first cycle, the inertia wheel will tend to aid trip out to provide the necessary protection.

Some typical let-through currents on various battery configurations subjected to near short circuit conditions.			
Battery Configurations	Battery Temp F	Circuit Configurations (1)	Average Let-Through Current Amps
(2) 3-205 AH(ea.) 12V in parallel	65	8ft. 4.0 cable	3700
(3) 3-205 AH(ea.) 12V in parallel	65	8ft. 4.0 cable	5200(4)
(3) 1-205 AH 12V	63	7ft. 4.0 cable	2800
(3) 4-240AH(ea.) 8V in series	65	7ft. 4.0 cable and 4ft. 1.0 cable	2600
(3) 1-70 AH 12V	65	8ft. 4.0 cable	1400

In all cases, the batteries were fully charged and had been left on trickle charge until time of the test. The series circuit breakers interrupted these loads in 7 msec to 11 msec. Neither the batteries nor the breaker suffered any apparent damage. This data was collected in cooperation with the AMF Hatteras Engineering staff at High Point, N.C.

Notes: (1) Heavy duty contractor, 200A shunt and 50 Amp magnetic circuit breaker were also in the circuit.
 (2) Batteries about 1 year old and heavily used.
 (3) New batteries cycled once to 50% charge and recharged.
 (4) With 350A Aircraft type fuse replacing the circuit breaker the let-through current was 6400A.

Table 1

Transformer inrush (Figure 17), is the most common application problem. Its waveform is similar to that of lamp-load inrush. However, unlike a lamp-load inrush, the transient will not occur on every turn-on. But, like the lamp load, it has a maximum peak value when the circuit is closed near the maximum voltage point of the supply wave.

To assure application of the correct breaker, the designer should perform a repeated turn-on, turn-off exercise. This will help verify that the breaker selected is one that will avoid nuisance tripping. Also, the exercise should be conducted with the highest line voltage that is anticipated in the circuit.

This type of short-time transients may be handled by Airpax inertial delay type 62F, Figure 18, a pulse tolerant design which uses inertial integration of short time

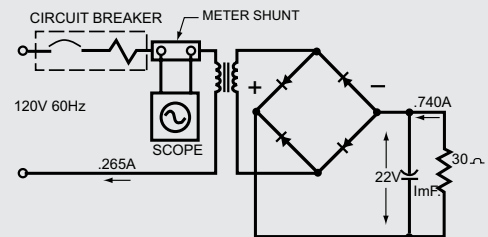


Fig. 16 Typical capacitive filter circuit.

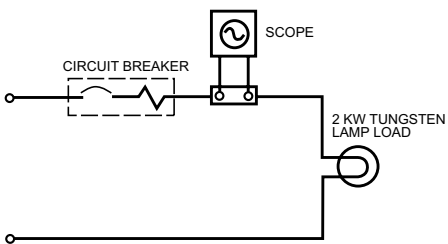
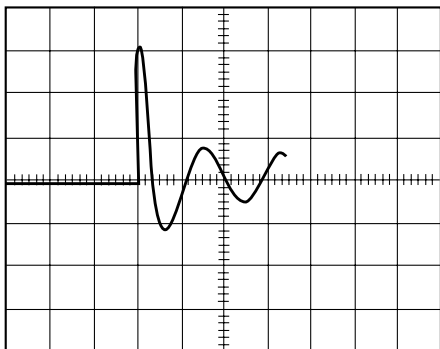


Fig 14 Transient current from a tungsten lamp load.

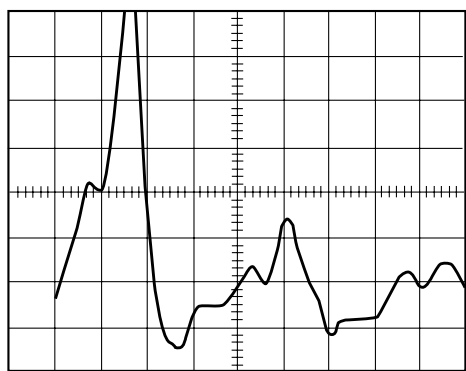


Fig. 15 Transient from capacitive filter.

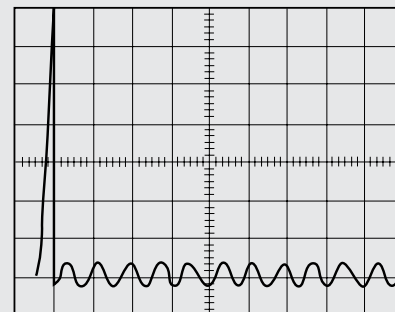


Fig. 17 Transformer starting transient.

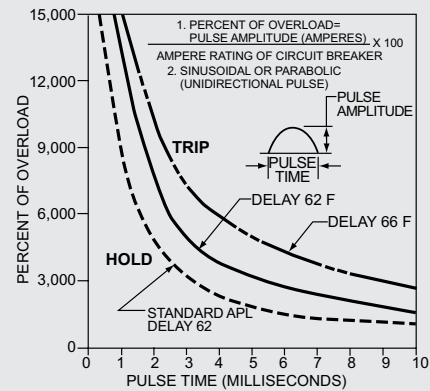


Fig. 18 Percent of overload versus pulse time of an Airpax magnetic breaker.

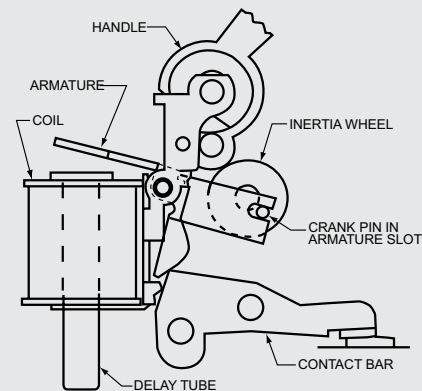


Fig. 19 Inertial integration against nuisance tripping.

	(1)	(2)	(3)	(4)	(5)
Motor Type	Start Current Peak Ampl. RMS	Duration of Start Surge in Sec.	Load Second %1 x t Sec.	APL Delay 62	AP
Shaded Pole	150%	2.0 sec.	.3	ok	
Series AC-DC	530%	.100	.5	no	
Series AC-DC	200%	.400	.8	ok	
Series AC-DC	333%	.167	.5	ok	
Split Phase	600%	.116	.7	no	
Split Phase	425%	.500	2.0	no	
Capacitor Load	400%	.600	2.4	no	
Capacitor No Load	300%	.100	.3	ok	
Capacitor Load	420%	.500	2.1	no	
Induction	700%	.750	5.0	no	
3 Phase	350%	.167	.6	ok	
Cap. Start. Split Phase Run	290%	.083	.24	ok	

Table 2
Motorstart

MEASURING INRUSH CURRENTS

Precise measurement of inrush current is needed to tailor delays for protection against nuisance tripping. Current meters and chart recorders respond too slowly to measure the problems: therefore, an oscilloscope must be used. Caution: oscilloscope current probes will saturate and distort wave forms above a value 12 to 14 times the rated currents, giving the impression of a much lesser value than actual. It would be better to insert a current meter shunt in the primary circuit and then sense voltage drop across the shunt with a calibrated scope. This would provide a visual readout of time duration amplitude and wave-shape of the turn on currents. Another technique uses a resistor of known value of less than 0.10 ohms and of sufficient wattage for the anticipated load.

Figure 20 shows a circuit employed to evaluate inrush currents typical of auto-transformers. Measured steady-state AC current in the primary portion of this circuit is 10 amperes RMS, or 14.1 amperes peak.

When it's used to evaluate the circuit in Figure 20, the current in the test circuit reaches 180 amperes. For the best steady-state protection without nuisance tripping, a pulse-tolerant protector rated at 10 amperes is recommended.

One final word on transient tripping. The primary function of newer delays is to improve transient tripping characteristics. In the applications mentioned previously,

along with many others, the potential of uninterrupted on-line operation will be enhanced by precisely defining the pulse train anticipated and then tailoring delays for the need.

MOTOR PROTECTION

The starting energy requirements of AC motors are spread over seconds rather than milliseconds, and vary considerably with the type of load and with the inertia of the load. However, the peak amplitude of the starting current is generally within reasonable values.

Table 2 provides some typical figures as observed on motors selected at random. Note that single-phase induction motors are the worst, usually having a starting winding which can draw 7 or 8 times the running current for the best part of a second. A 750-millisecond surge duration was observed on several of the various horsepower ratings.

Most magnetic breakers exhibit a reasonably flat frequency response – trip point versus frequency – in applications between 20 and 200Hz. Beyond 200Hz, up to 440Hz, special design considerations are required. Beyond 440Hz, the breaker supplier must be consulted.

Induction motors usually are protected by a thermal device imbedded inside the

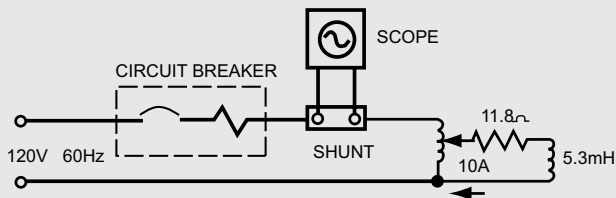


Fig. 20 Circuit to evaluate transformer transients

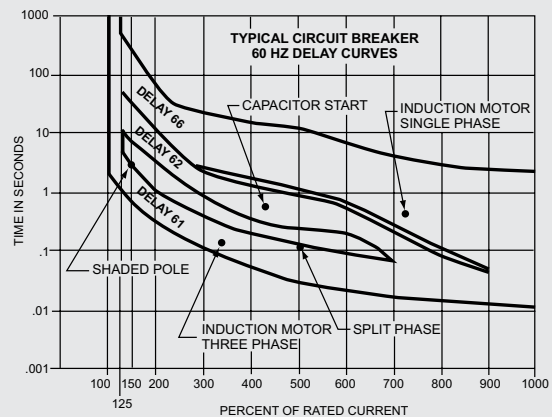


Fig. 21 Time position of various motors on start.

motor. Most protectors which will handle the starting surge will not trip out soon enough on lesser overloads to prevent damage to the motor. Here you are protecting the power wiring rather than the device. Magnetic protectors are available which offer a better compromise. Figure 21 shows three delays for several different motors. The marginal position of single-phase induction motors is obvious.

SCR MOTOR DRIVES

Typically, SCR motor drives exhibit non-sinusoidal load currents and necessitate derating of the protector.

Let's look at an example. With a full wave rectified unfiltered load, the load may be 10 amps as read on an average responding meter. Using an RMS responsive meter, the actual RMS current reading for this load is 11.1 amps. The inclusion of an SCR device introduces a firing angle which will further increase the form factor. The form factor is actually the ratio of the RMS current to the average current. This ratio could be as high as 2 or 3; that is, the RMS current may be 2 or 3 times the value of the average current. In a typical circuit, a 20 amp protector may be tripping, even though measurement indicates lower than 20 amps exists. Battery chargers create a particularly severe problem because they exhibit a very high, spiked form factor. Again, both manufacturers of the batteries and breakers should be contacted.

Generally speaking, protectors for these applications would be an AC type even though they are being used for pulsed DC application. Therefore, before specifying a protector for pulsed SCR motor drives, it's usually necessary to consult the supplier to establish the details of the protector, its delay, rating, etc. As a starting point, consider the actual current rating of the protector to be the reading obtained on an RMS meter.

To say the protector is RMS responsive, is only an approximate statement. The degree to which it is truly RMS probably varies somewhat with the actual form factor. For very high form factors, you may need additional correction. In this case, describe the applications to the supplier and allow him to select and tailor the protector to the application.

MAGNETIC CIRCUIT BREAKERS FOR SWITCHING POWER SUPPLIES

Protecting any equipment obviously requires an understanding of what you are protecting. Switching power supplies (commonly called switchers) have different characteristics than the familiar linear types.

When compared with linear type power supplies, switchers are smaller, lighter, and more efficient. They can tolerate a much greater range of input voltage and frequency than the linear types. On the other hand, switchers do not have as fast a recovery time, have slightly higher ripple content and a little less regulation factor than linears. Switchers also require a minimum load current of 20 to 25 percent for proper operation, whereas, the linear supplies are designed to operate from no load to full load.

The peak value of current at turn-on of linear supplies is in the range of 10 to 20 times RMS rated load values depending on the type of input transformer used. Switchers, almost without exception, do not use an input transformer but rectify the source power directly (see Illustration I). This can produce a peak turn on current as much as 40 to 100 times the rated RMS value of current. (See Illustration II.)

For this reason most switchers include some circuitry in series with the input line to limit this high peak value of current. Most of the smaller units up to 350 watts use a thermistor for this purpose. The thermistor has an initial cold resistance that is high, which quickly decreases to a very low resistance when hot. This limits the cold turn on peak current quite adequately, however, if the circuit is turned off and turned back on while the thermistor is in its low resistance condition the limiting characteristic is much less and can allow a high peak current that may cause nuisance tripping if the circuit protector is rated too low.

Larger wattage supplies use a resistor paralleled with a triac or some other "soft start" means to limit the high initial inrush current to the order of 20 times the rated RMS value of the supply. Though this inrush is quite high it is of short duration, usually from 3 to 5 cycles of 60Hz or 50 to 80 milliseconds and in a decaying amplitude. This high value of current is destructive to on-off switches that do not have contacts designed to resist these stresses.

The steady state input current of switchers is a train of pulses instead of a sinusoidal wave. These pulses are two to four milliseconds duration each when on 60Hz power, with peak values two to three times the RMS value of the input current. (See Illustration III.) This high peak pulse train has a tendency to advance the delay tube core of magnetic circuit protectors and can cause a buzzing sound or nuisance tripping if the current rating of the protector chosen is too near the rated input current of the power supply.

One of the features of most switchers is the inclusion of fold-back circuitry that shuts off or limits the pulse width modulator in the event of an overload in an output circuit. This feature protects against overloads on the output and leaves the circuit protector to afford protection for the input circuitry. The probable fault areas of the input circuitry are:

Number 1

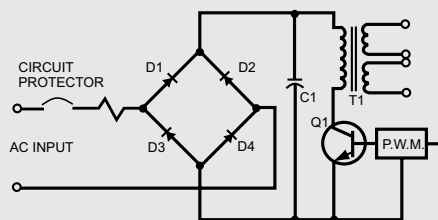


Illustration I

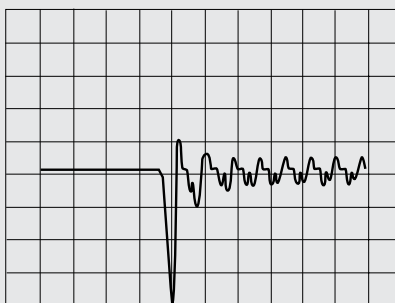


Illustration II

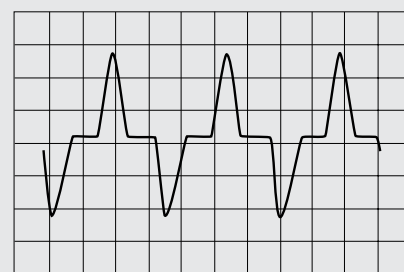


Illustration III

Shorting of one or more of the diodes in the bridge.

Number 2

Shorting of the input capacitor.

Number 3

Shorting of the power switching transistor.

Number 4

Shorting of a winding in the transformer.

Any of these will cause an overcurrent much higher than the rated load current of the supply. By choosing a protector 2 to 3 times the rated input current with a high pulse tolerance delay you have eliminated the possibility of nuisance tripping, protected against potential faults and provided an on/off switch with suitable contacts, all in one component.

If the circuit protector has a load in addition to the switcher, the total load current and its waveform must be taken into consideration in sizing of the protector.

Since the inrush currents of switchers are typically 50 to 80 ms in duration and in a decaying pattern, the switcher can best be protected with a fast delay with high pulse tolerance such as the Airpax 61F or 64F. If you select a protector of less than 2 times the rated load you may encounter a buzzing or nuisance tripping from the protector. If the switcher has a soft start feature, the delay choice should be 61F. If there is no soft start feature, the 64F is recommended for its higher pulse tolerance to avoid the nuisance tripping of the inrush spike. One exception to this choice is when the input power is a 400Hz source. In this case, the delay used should be 41F to give better tripping characteristics.

If the appliance or equipment is to be used internationally, your choice of Airpax circuit protector should be from the SNAPAK, IEG, IEL or 209 families to provide the 8mm spacing requirements. Also many countries require both sides of the input lines to be switched in some applications, so a two pole unit may be required.

In summary, to determine the protector for a switching power supply application, choose from the Airpax circuit protector families with a 61F or 64F delay, 41F if for 400Hz, and a current rating two to three times the switcher rating.

ENVIRONMENTAL CONDITIONS

Obviously, operational environment must be evaluated along with electrical considerations. Heat, high vibration and shock conditions can cause nuisance tripping or even damage protective devices. For example, a fuse element is more fragile when hot than when it is cold. Also, improper mounting of a circuit protector can cause amplification of vibration through resonances of the basic vibration frequency and amplitude. Correctly designed magnetic breakers are those which incorporate balanced armatures that help minimize the effects of shock and vibration.

Applications where circuit protectors are exposed to high humidity or corrosive atmosphere require environmental protection for the protector. Here, extensive use of corrosion resistant plating and stainless steel components is necessary to insure proper mechanical operation of unsealed protectors. If the protector must function under extreme conditions, a sealed protector (Figure 22) will insure reliable operation. In applications where a panel is exposed and the equipment is sealed, a panel seal protector (Figure 23) may be used as a compromise.

Probably the most difficult environment to tolerate is one that includes sand and dust. Over a period of time, the mechanism of most unsealed protectors will collect enough "grit" to impede operation. Every precaution should be taken to seal the installation, and to check protector functioning, procedures should be established to mechanically operate the protector on a regular basis. Whenever possible, dust sealed protectors should be specified.

When explosive atmospheres are anticipated, special system design is necessary to insure that open flame or sparks from electrical sources are not possible. This often requires hard conduit, sealed protectors and switch panel boxes. Some protectors have successfully passed the ignition test designed to simulate use in a gasoline vapor situation.



Fig. 22 Airpax Type AP circuit protector.



Fig. 23 Airpax Type APGN panel seal circuit protector.

WHAT'S AVAILABLE IN PROTECTORS

It probably would be helpful to review the many protector variations available. The following highlights provide basic application data.

TIME DELAYS MATCH PROTECTION TO NEED

Trip delays must be long enough to avoid nuisance tripping caused by harmless transients, yet fast enough to open the circuit when a hazard exists. Continuing development of new delay configurations that exactly match the protector's performance to the specific needs is crucial to the life cycle economics of equipment.

Basically, four categories of trip delays are available:

Instantaneous

Usually under 100 ms, with most at approximately 15 ms – for very sensitive circuits where low overloads of short duration may be harmful, or where specific high currents definitely should not pass.

Fast Delay

Trips in less than 10 seconds – for circuits and electronic applications where temporary overloads of 200 percent cannot be tolerated for more than a few seconds.

Slow Delay

Trips in 10 to 100 seconds – for most large transformer-coupled loads where brief overloads can be tolerated without damage. Slow delays allow turn-on surges to pass without tripping.

Very Slow Delay

Trips in more than 100 seconds – for protection of wiring where a limited overload will usually not cause damage. For example, some motors have starting current surges lasting for seconds and drawing 600 percent or more of their running current rating. Protectors with very slow delays are the answer for these applications.

As overloads increase, time delays decay, to the point where the protector's mechanical inertial and arc quenching capability alone determine the circuit interrupting speed. At very high fault currents, the practical limit for magnetic protectors varies about 4 to 10 ms. They operate in the instantaneous mode when overload is increased beyond 10 times the rated load, for most breakers, and from 12 to 14 for other delays.

Newer delays have an inrush capability about the equivalent of a current flywheel. These delays, with the flywheel added, will up inrush withstanding capability even more, as much as 60 percent more.

Further, with the newer delays, up to 400 percent overload, the trip times actually are shorter than with conventional delays. Above 400 percent, the trip times are longer. For a motor starting load, for example, this provides more protection and better resistance to nuisance tripping at turn-on. Additional obvious applications for the newer delays include power supplies that have very large capacitance filters and with ferro-resonant power supplies used in the computer industry that need more protection – sometimes 30 times the normal inrush is possible.

MAGNETIC TIME DELAYS

The six magnetic time-delays shown in Figure 25 cover a variety of load and overload conditions. Delay 60 represents only the delay of the armature. Delay 61 is a quick-acting general purpose time delay for general use on electronic instruments. Both 60 and 61 are particularly useful in low voltage applications. Delay 62 is long enough to start several types of motors and is useful for most transformer, capacitor and tungsten lamp inrush currents. Delay 66 has a long delay especially for motors, as previously illustrated.

TRIP; SWITCHING CONFIGURATIONS

The most popular configuration for magnetic protectors is the series trip where the sensing coil and contacts are in series with the load being protected. The handle position conveniently indicates circuit status. In addition to providing conventional overcurrent protection it's simultaneously used as an on-off switch.

Some other configurations, (Figure 26), include:

Shunt Trip

Designed for controlling two separate loads with one assembly. The control is established by providing overload protection for the critical load. When the current through this load becomes excessive and reaches the trip point, the protector will open and remove power from both loads simultaneously. The total current rating of both loads must not exceed the maximum contact rating.

Relay Trip

This permits the overload sensing coil to be placed in a circuit which is electrically isolated from the trip contacts. The coil may be actuated by sensors monitoring pressure, flow, temperature, speed, etc.; other typical applications include crowbar, interlock and emergency/rapid shutdown circuitry. Trip may be accomplished by voltage or current, which must be removed after trip.

Auxiliary Switch

This is furnished as an integral part of a series pole in single or multi-pole assem-

blies. Isolated electrically from the protector’s circuit, the switch works in unison with the power contacts and provides indication at a remote location of the protector’s on-off status.

Voltage Trip

Sometimes called “dump circuits” or “panic trip circuits,” these units make it possible to open main power contacts with lower power inputs from one or more sources. This configuration is becoming increasingly more important for sensitive circuitry and denser packaging in automation systems.

Dual Function/Single Pole

Providing for both a voltage trip and a current trip function in a magnetic circuit protector is common practice. As illustrated in Figure 27, these two coil protectors provide remote or automatic opening of one or more circuits with a low level signal.

It is also possible to have both the instantaneous voltage trip coil and the overcurrent coil in a single pole. To provide the dual function, the obvious size and cost-savings over multi-pole configurations

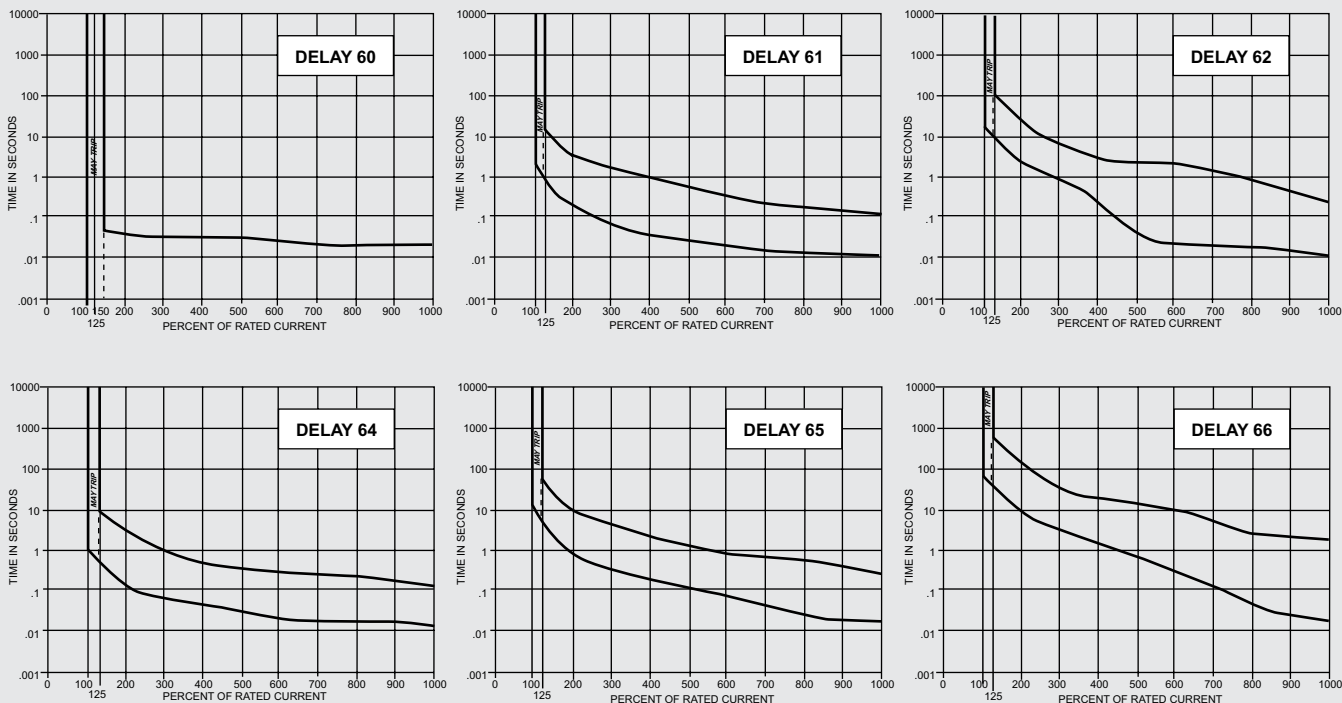


Fig. 25 Typical Airpax magnetic breaker time delays (50/60Hz). See individual products for specific delay curves.

are substantial. Referring to Figure 28, since the voltage and current coils share the same magnetic path, a current in either coil will actuate the armature and trip the protector. The voltage coil will trip the protector instantaneously while the current coil provides normal inverse time delays. The voltage coil is not rated for continuous duty and, therefore, the voltage must be removed when the breaker trips.

Cross Trip/Common Tripping

It is a general misconception, when operating crosslinked handles on two or three pole protectors, that one handle pulls the other down when the protector trips.

Common trips are independent of the handles. In the six pole circuit protectors several poles can be turned on separately for sequencing of operations. But, if one trips, all will trip out. Circuit arrangement flexibility is immediately obvious. For example, two poles can be the AC line, and the third can be a voltage trip coil for remote control.

Handle movement is, of course, a fault indicator. Most magnetic protectors are trip free, meaning that the handle cannot be held against a fault; the mechanism will trip out anyway. When the handle is released later, it returns to the off position.

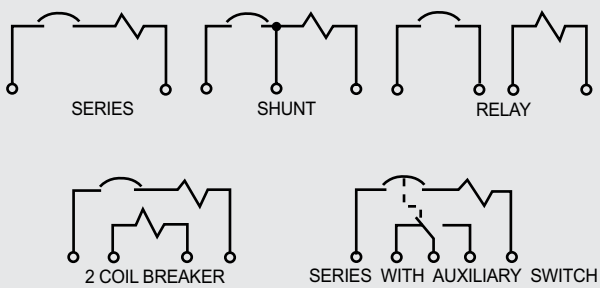


Fig. 26 Single pole breaker flexibility.

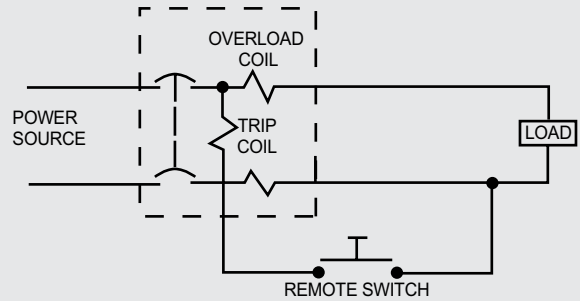


Fig. 27 Two coil breaker for remote tripping.

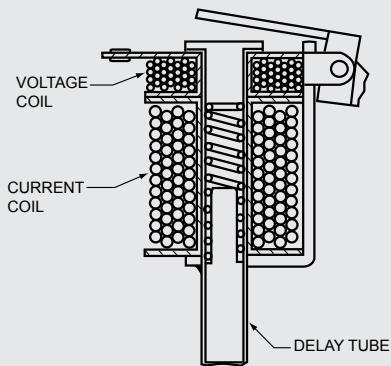


Fig. 28 Dual coil circuit breaker.

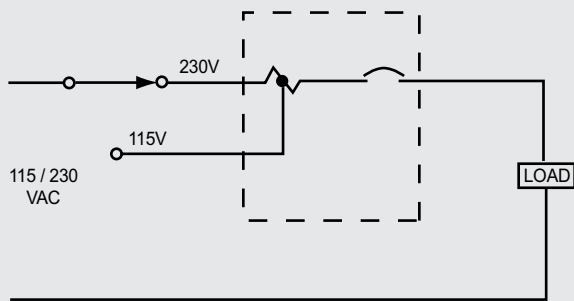


Fig. 30 115/230 volt tapped coil.

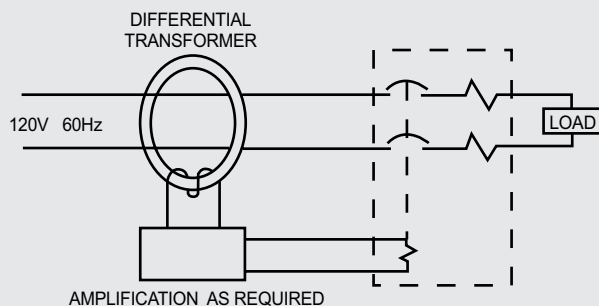


Fig. 31 Ground fault protection using differential transformer.

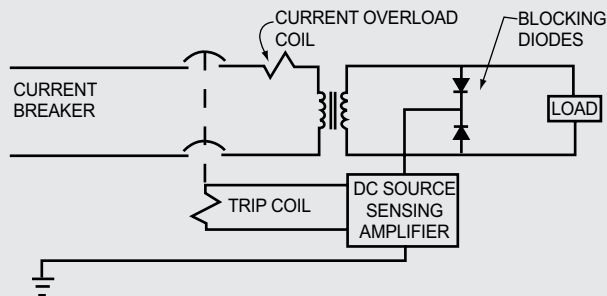


Fig. 32 Ground fault protection using isolation transformer.

115/230 VOLT PROTECTOR (TAPPED COIL)

A tapped coil permits using this protector in a system on both 115 and 230 volt service, as in Figure 30. Since the protector trip responds to ampere-turns, if the current is halved, the ampere-turns' product is maintained by doubling the turns.

GROUND FAULT INTERRUPT

Ground fault protection applied to motors and distribution systems will detect ground leakage across insulation before damage becomes extensive. Maintenance applied promptly can then save a great deal of expense.

Ground fault thresholds in such cases may range from milliamps, for protection of personnel, to several amps for equipment protection, and the time delay may be considerable.

If a current transformer is used to sense leakage to ground, the breaker supplier should be consulted for advice on a special circuit breaker with parameters which match the specific current transformer being used. On the other hand, for protection of personnel, an arrangement as shown in Figure 31 provides greater sensitivity when summing the currents in a differential toroidal transformer.

Today, ground fault interrupters can respond to currents which are only 1/20,000 of the full load current. Solid-state devices amplify this weak signal to help energize the magnetic protector trip coil.

Protection of personnel presents a different problem because the intensity of electric shock in a human is a function of current. Following are a few examples of the effect on humans:

Example 1:
45 microamps, threshold on the tongue

Example 2:
500 microamps, threshold on the skin

Example 3:
10 to 15 milliamps, acute discomfort, let-go limit

Example 4:
15 to 30 milliamps, muscles tighten, dangerous

Example 5:
50 milliamps and up, heart fibrillation

For very low level fault currents, transformer isolation is needed (Figure 32). The National Electrical Code places special regulations for home facilities and devices where ground fault hazards could exist.

Crowbar Circuits

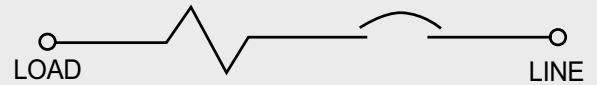
The versatility of the magnetic circuit breaker is evident when applied in electronic crowbar circuits. With help from the manufacturer, it's a simple task to provide a simple crowbar-type circuit which permits time delay opening of a circuit. For more information contact the manufacturer.

HOW MAGNETIC CIRCUIT BREAKERS WORK

All Airpax circuit protectors and circuit breakers are available in many mechanical and electrical configurations to provide maximum versatility for the designer. The following internal circuits are available on most breaker types and they usually can be combined in multi-pole units. Specific internal circuits for each magnetic circuit breaker type are alluded to in the following catalog pages.

Series Trip

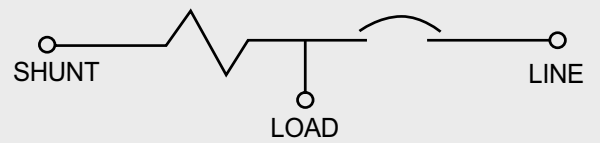
This is the most popular configuration as the sensing coil and contacts are in series with the load being protected. Handle position conveniently indicates circuit status. In addition to providing conventional overcurrent protection, the unit can also be simultaneously used as an ON-OFF switch. The addition of an auxiliary switch operated by the internal mechanism would provide trip indication at a remote location.



Series Trip

Shunt Trip

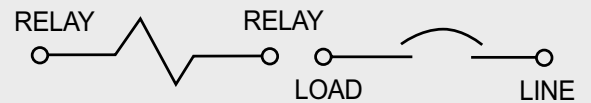
The construction of the shunt trip circuit breaker is similar to that of the calibrating tap unit. The shunt trip circuit breaker is designed for controlling two separate loads with one breaker assembly. The control is established by providing overload protection for the critical load. When the current through this load becomes excessive and reaches the trip point, the breaker will open and remove power from both loads simultaneously. A shunt resistance added across the trip coil may be used to calibrate the trip level; hence the term "calibrating" tap.



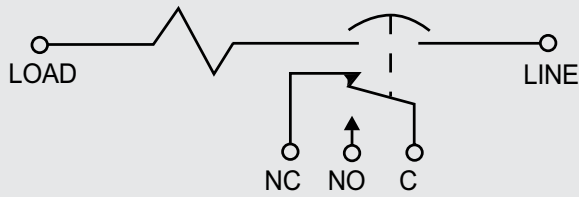
Shunt Trip

Relay Trip

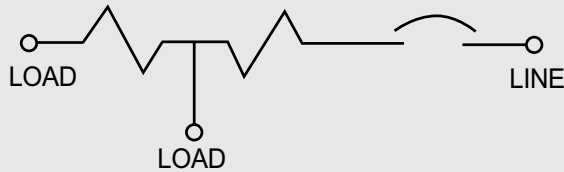
Coil and contact leads are electrically and mechanically isolated in the relay trip configuration. This permits the overload sensing coil to be placed in a circuit which is electrically isolated from the trip contacts. The coil may be actuated by sensors monitoring pressure, flow, temperature, speed, etc. Other typical applications include crowbar, interlock, and emergency/rapid shutdown circuitry. Trip may be accomplished by voltage or current, which must be removed (usually self-interrupting) after trip. Consult factory on continuous duty applications.



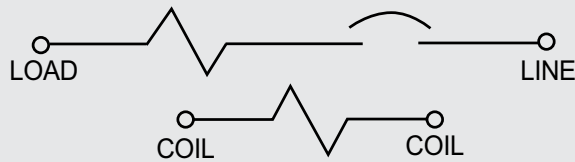
Relay Trip



Auxiliary Switch
 Note: Breaker Shown in "off" position.



Dual Rating



Dual Coil

Auxiliary Switch

An auxiliary switch can be furnished as an integral part of a series pole in single or multi-pole assemblies. Isolated electrically from the breaker circuit, the switch works in unison with the power contacts and provides indication at a remote location of the breaker's ON-OFF status.

Dual Rating

The dual rating circuit breaker is manufactured with tapped coil construction, which makes available the choice of two current ratings within a single pole unit. A prime example is a unit which allows 120 or 240VAC operation, without derating the protection at a higher voltage level. This type unit is available in all standard delays and frequencies except 64, 65, and 66 delays. Dual current ratings must be established and coordinated in order to give optimum protection. Factory consultation is available.

Dual Coil

By combining two electrically independent coils on a common magnetic circuit, it is possible to provide contact opening when either an over-current or trip voltage is applied to the respective coils. One coil will be a current trip coil with standard specifications. The second, or dual coil, can be used to provide a control function permitting contact opening from a remote interlock or other transducer functions. Standard coils are 6, 12, 24, 48, 120, and 240 volts. Tripping is instantaneous and must be removed (usually self-interrupting) after trip. Not available in delays 64, 65, 66.

Switch Only

In the event that over-current protection is not desired, the coil mechanism can be deleted, providing an excellent low cost, single or multi-pole power switch. Maximum current rating is 100 amperes.

Voltage Trip

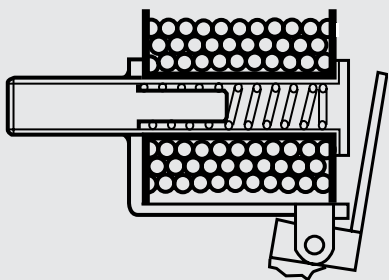
All breakers can be supplied for voltage trip application, sometimes called “Dump Circuits” or “Panic Trip Circuits,” which make it possible to open main power contacts with low power input from one or more sources. To match voltage trip applications, specify the minimum voltage that will be available to the coil and the frequency (DC, 50/60 or 400Hz).

Magnetic circuit breakers operate on the solenoid principle where a core, held with a spring in a tube and dampened with a fluid, may be moved by the magnetic field of a coil. As the core moves toward a pole piece, the reluctance of the magnetic circuit containing the armature is

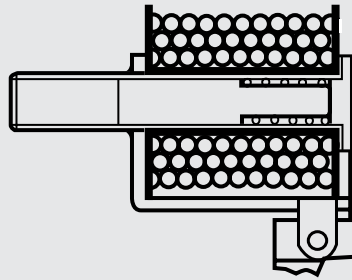
reduced. The armature is then attracted, causing the mechanism to trip and open the contacts on an overload or fault condition. This trip point occurs after a time delay when the core has made its full travel in the tube. The result is an inverse time delay and the trip time is decreased as the percent of overload is increased.

The fluid viscosity changes with temperature, causing the trip time of a magnetic breaker to decrease as temperature increases and vice versa. The trip current remains essentially unchanged despite changes in temperature, making possible accurate protection throughout the ambient temperature range without derating the breaker.

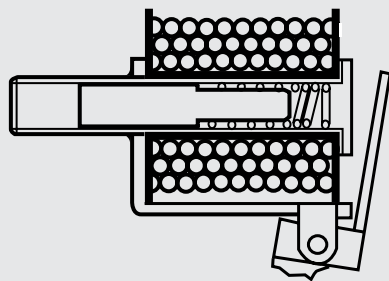
The instantaneous trip circuit is that value of current required to trip the circuit breaker without causing the core to move in the tube. This happens because the flux caused by a large overload or fault (six to ten times the breaker current rating) is sufficient to attract the armature.



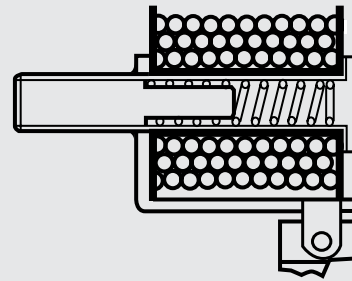
Coil current within rating.



Coil current above rating.
Moderate overload.



Moderate overload.
Armature operates after delay.



Current far above rating.
Armature trips without delay.

Delay Characteristics

A choice of delays is offered for DC, 50/60Hz, and 400Hz applications. Delays 40, 50, 60, 49, 59, and 69 provide fast-acting, instantaneous trip and are often used to protect sensitive electronic equipment. Delays 41, 51, and 61 have a short delay for general purpose applications. Delays 42, 52, and 62 are long enough to start certain types of motors and most transformer and capacitor loads. Delays 43 and 53 are long delays for special motor applications at 400Hz and DC. The following catalog pages provide delay curves and charts for each magnetic circuit breaker type.

Delays 64, 65, 66

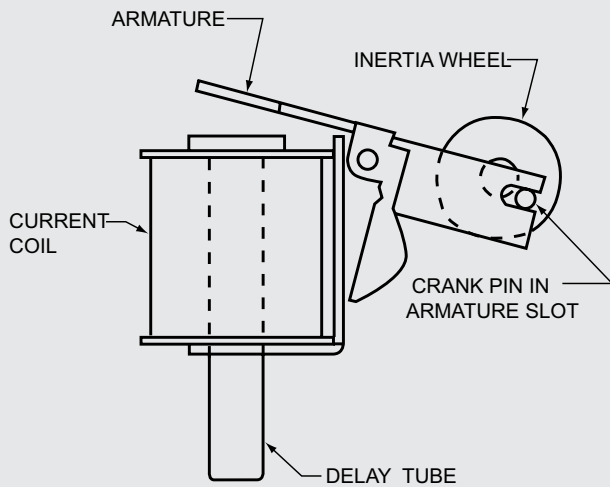
Delays 64, 65, and 66 are the latest 50/60Hz delays with short, medium and long trip times respectively. The patented breaker design provides both increased tolerance to high inrush induced nuisance tripping, and longer trip times at 600 percent. These delays are ideally suited for applications where thermal devices are presently used, such as motor protection or where short duration high inrush currents are experienced. As shown in a typical motor start-up curve, the delay 66 will provide locked rotor and overload protection. Nuisance tripping is avoided since acceptable short periods of overload will not trip the breaker.

Inrush Pulse Tolerance

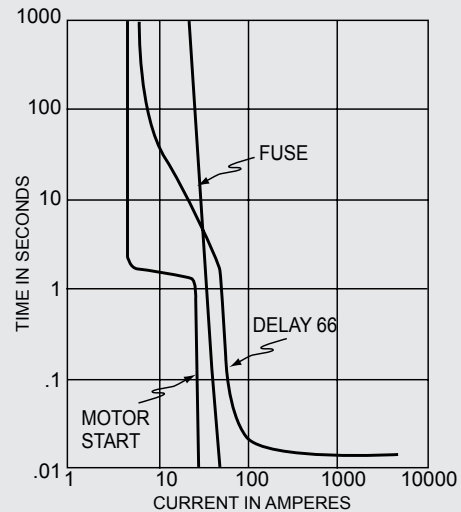
Many circuit protector applications involve a transformer turn-on, an incandescent lamp load, or a capacitor charge from a DC source. Each of these applications have one common factor: a steep wave front transient of very high current amplitude and

short duration. This takes the form of a spike, or a single pulse, and is the cause of most nuisance tripping of circuit breakers.

The patented Airpax inertial delay provides tolerances of short duration inrush currents without decreasing steady state protection.



Inrush Pulse Tolerance



Delays 64,65,66

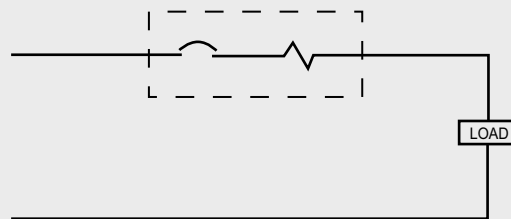
HOW TO USE AIRPAX MAGNETIC CIRCUIT BREAKERS

Here are just a few illustrations of magnetic circuit breakers in action. Since it is possible to select unique delays and operating currents from a wide range of available time delays and current ratings for each pole of multi-pole breakers, the number of possible combinations is greatly increased.

Generally, you may assume that any Airpax breaker type will qualify in most of the following examples. However, certain application needs dictate the selection of specific breaker types, as will be noted in our examples.

Example 1

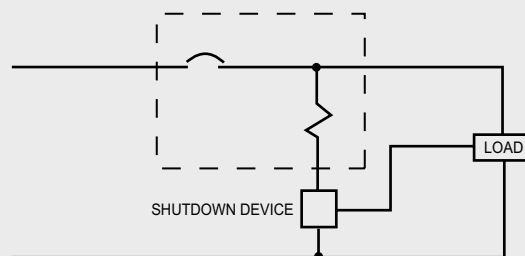
Many magnetic circuit breakers perform double duty as ON-OFF switches, while providing overcurrent protection.



Example 1

Example 2

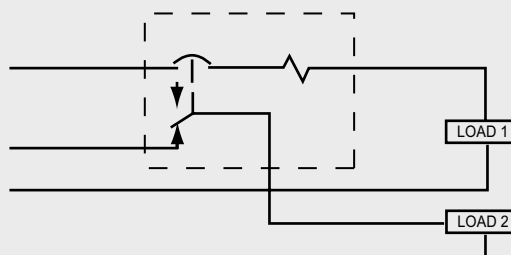
In this illustration, a shunt trip, included in the circuit, performs the function of an ON-OFF switch, while providing a remote turn-off capability. This arrangement is useful when remote shutdown of equipment is necessary, as in emergency situations.



Example 2

Example 3

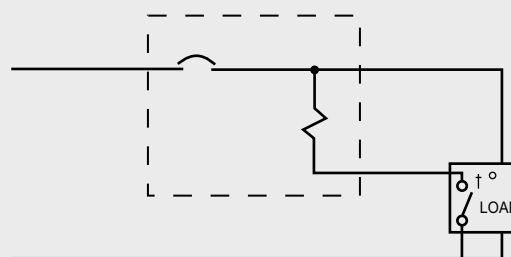
Auxiliary contacts can be included in the magnetic circuit breaker to permit a remote indication of protector operation. These are available to safely carry up to 10 amperes at 250VAC and can be used to operate a non-critical load.



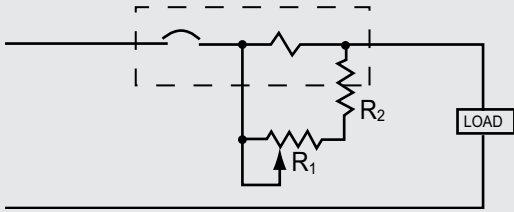
Example 3

Example 4

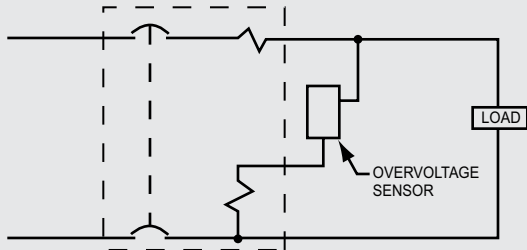
The shunt coil of a magnetic circuit breaker can be in series with a thermostat that is strategically located on or near the load to provide protection against an excessive temperature rise.



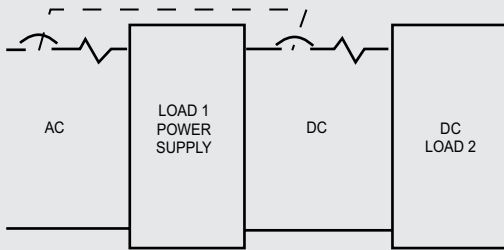
Example 4



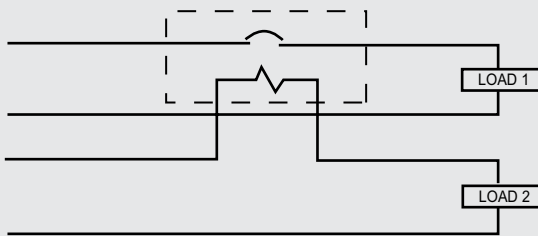
Example 5



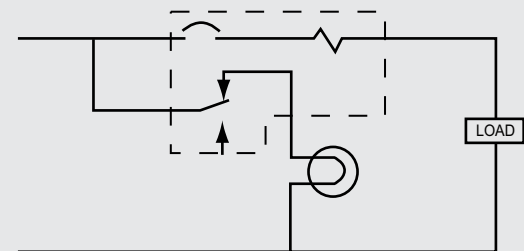
Example 6



Example 7



Example 8



Example 9

Example 5

The trip point of a shunt trip type magnetic circuit breaker can be closely adjusted by varying a resistor. The resistor "R1" may be programmed to provide changes in the trip point as required by sequencing changes in the load. If "R1" is operator available, a fixed resistor "R2" should be added in series with "R1" to provide a minimum protection for the load in case of a zero resistance setting of "R1."

Example 6

A two pole magnetic circuit breaker, configured with both a shunt trip and a series trip can be used to provide both overcurrent and over voltage protection.

Example 7

A two pole type magnetic circuit breaker can have a combination of two series poles, where one pole is protecting the power input to an AC/DC power supply, while the other pole is protecting the DC power output. In this configuration, an overload on the output side that causes a trip will remove the AC power.

Example 8

This magnetic circuit breaker is configured with its actuating coil and contacts internally isolated. The breaker senses an overcurrent condition in load 2 and opens the circuit to load 1. Both circuits may be opened, if desired, by using one series and one relay type in a two pole circuit breaker.

Example 9

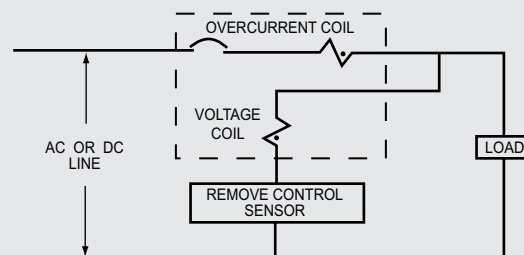
When a type-RS auxiliary alarm switch is used, (available in UPL, IUL and IUG circuit protectors), the light will illuminate only in the event of an electrical trip of the main contacts. If an -REC or -RO type auxiliary switch is used, the light will indicate circuit condition regardless of how the main contacts are opened (manual or electrical trip).

Example 10

Dual coil magnetic circuit breakers in applications with remote control sensors can be configured so that their contacts will open at 125 percent or more of rated current, thereby providing load protection. This percentage will vary depending on such factors as frequency, current required and/or delay requested.

In addition, when the proper voltage is applied to the voltage coil by the remote control sensor, breaker contacts will open, removing power from the load. Voltage must be removed from the voltage trip coil and is usually self-interrupting. Control signals can come from sensors that sense temperature, pressure, flow, level, weight, etc., located in one or more strategic locations. The voltage coil can also be used to provide emergency shutdown from one or more remote locations.

Although shown as a single dual coil application, multiple poles (up to 9 poles on the APL/UPL and up to 4 poles on the APG/UPG) can be combined with the dual coil breaker in one of the poles to provide common trip of all poles. Because of physical space limitations and interaction of the two coils, the trip time of the current sensing coil may vary approximately 10 percent from the standard chart. Delays 43, 53, 64, 65, or 66 are not available in these configurations. It is suggested that you consult the factory with your application data.



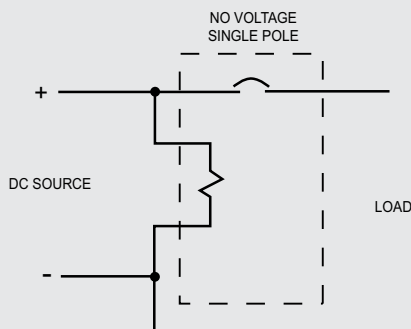
Example 10

Example 11 (See Examples 2, 3 or 4 on page 27)

Voltage trip applications may have manual, remote, or automatic sensing such as in examples 2, 3 and 4. They may also have one or more sensors in parallel to actuate a single coil and open the associated contacts. Since the electromagnetic characteristics of the voltage trip pole are quite different from those of the current trip types, it is recommended that you contact a factory representative with your requirements.

Example 12

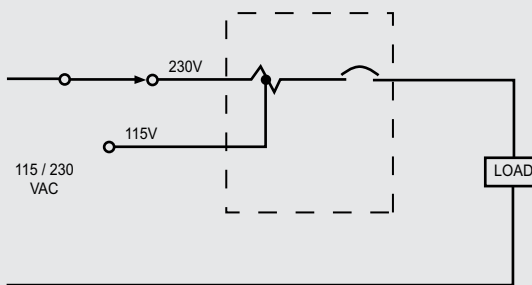
For no-voltage trip requirements, a special model designed to prohibit contact closure in the absence of DC voltage is available. By combining a no-voltage pole with overcurrent poles in a multi-pole assembly, it is possible to protect equipment from overcurrent, interruption, or loss of DC voltage. A bridge arrangement is required for all AC operation.



Example 12

Example 13

Tapped Coil. There are applications where the source voltage may be either 115 or 230 volts with the 115 volt current being approximately twice that at 230 volts. Airpax APL/UPL, APG/UPG, and 203 are available with a tapped coil having this option in delays 60, 61 and 62. Tapped coil trip time may vary from the standard chart due to special, required construction. Current (I) combinations available are: APL/UPL, APG/UPG – 30/15, 22/10, 12/8, 10/5, 7.5/3.75, 5/2.5, 4/2, 2/1. The 203 is rated at 10/5 amps maximum. Consult factory with application data.



Example 13 115/230 volt tapped coil.

DESIGNING FOR THE INTERNATIONAL MARKET

Markets can no longer be categorized simply as North American or European or Asian. Designers should view the market as an International one. In particular, the engineer must consider various performance and safety standards from around the world, especially in the data processing, medical and office equipment fields.

Most countries have regulatory agencies that determine the safety and performance standards required for products used in that country. For example: Underwriters Laboratories (UL) in the United States, Canadian Standards Association (CSA) in Canada, Verband Deutscher Elektrotechniker (VDE) in Germany, Schweizerischer Elektrotechnischer Verein (SEV) in Switzerland, etc.

The International Electrotechnical Commission (IEC) is a standards writing organization with the objective of correlating the various national safety standards and requirements, as agreed upon by representatives from the major countries in the world. Certification of conformance to IEC standards by UL is available, but IEC does not issue any kind of approval at this time nor does IEC have any legal authority to enforce its standards. However, this is expected to change in the future.

VDE standards are generally acknowledged as the most stringent standards enforced. Therefore, when designing for the international market, the engineer should choose components with both IEC certification and VDE approval to help assure acceptance of his product worldwide. IEC specifications generally meet or exceed the requirements of individual nations including VDE.

Additionally, we are registered by Underwriters Laboratories to ISO-9001. ISO-9001 is an International Quality Systems Standard that includes Quality Assurance in Production and Installation. Established by the International Organization for Standardization, Geneva, Switzerland, 1987, these standards are being adopted throughout the world by companies whose business priorities include customer satisfaction through Total Quality Management.

However, the designer must be aware that simply using a VDE approved or IEC certified breaker does not assure compliance. It is no longer a case of selecting the proper voltage, current and interrupt capabilities. An equipment manufacturer has to be aware of the operational and environmental conditions of the intended application. The circuit breaker selected must be approved for the specific standard to which the equipment is to be tested.

For example:

IEC 601

Safety of medical electrical equipment.

IEC 950

Safety of information technology equipment, including electrical business equipment.

VDE 0804

Particular safety requirements for equipment to be connected to telecommunication networks.

VDE 0805

Safety of information technology equipment, including electrical business equipment.

The circuit breaker manufacturer and the equipment manufacturer who uses the breaker must take into account four different aspects of the standard chosen: (1) the class of the equipment that the breaker is to be used in; and (2) the environmental conditions that the equipment must be qualified for have to be considered. (3) whether or not the breaker is operator accessible and (4) if the circuit breaker is to function as a disconnect device must also be determined.

The degree of "isolation" required must be identified. Isolation is determined by various operating conditions and is a combination of creepage, clearance and insulation. Clearance distance is defined as the shortest distance between two conductive parts or between a conductive part and the bounding surface of the equipment, measured through air. Creepage distance is the shortest path between two conductive parts or between a conductive part and the bounding surface of the equipment, measured along the surface of the insulation.

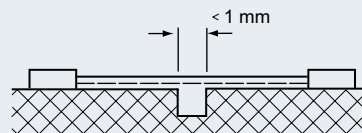
Some of the geometrics often encountered are shown in the following cases. A key dimension with respect to creepage is 1 mm.

If a gap is less than 1 mm, the gap is considered nonexistent; if the gap is greater than 1 mm, the creepage path follows the surface.

Case 1

Condition: Path under consideration includes a parallel-or converging sided groove of any depth with a width less than 1 mm.

Rule: Creepage distance and clearance are measured directly across the groove as shown.

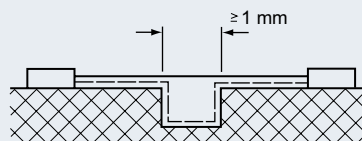


Case 1

Case 2

Condition: Path under consideration includes a parallel sided groove of any depth and equal to more than 1 mm wide.

Rule: Clearance is the "line of sight" distance. Creepage path follows the contour of the groove.

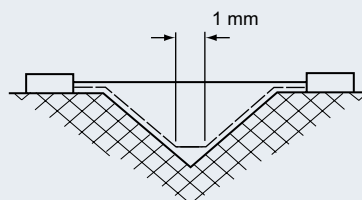


Case 2

Case 3

Condition: Path under consideration includes a V shaped groove with an internal angle of less than 80° and a width greater than 1mm.

Rule: Clearance is the "line of sight" distance. Creepage path follows the contour of the groove but "short circuits the bottom of the groove by 1 mm. (0.25 mm for dirt-free situations) link.

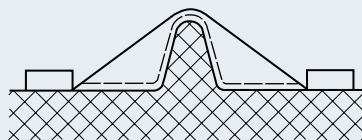


Case 3

Case 4

Condition: Path under consideration includes a rib.

Rule: Clearance is the shortest direct air path over the top of the rib. Creepage path follows the contour of the rib.

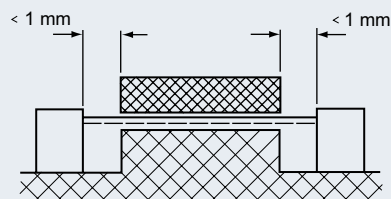


Case 4

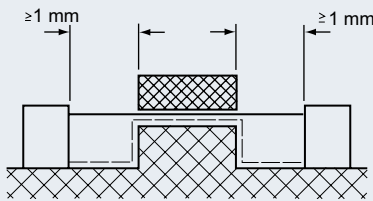
Case 5

Condition: Path under consideration includes an uncemented joint with grooves less than 1 mm (0.25 mm for dirt-free situations) wide on either side.

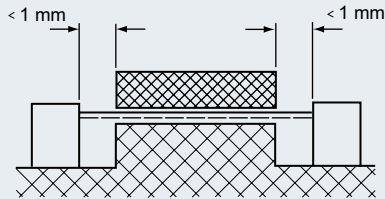
Rule: Creepage and clearance path is the "line of sight" distance shown.



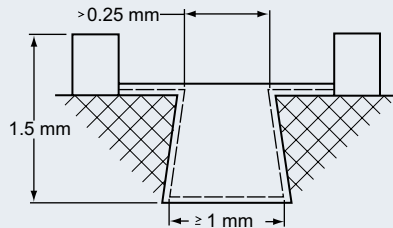
Case 5



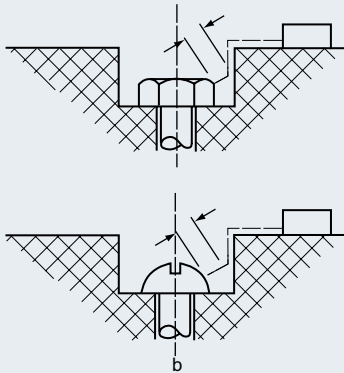
Case 6



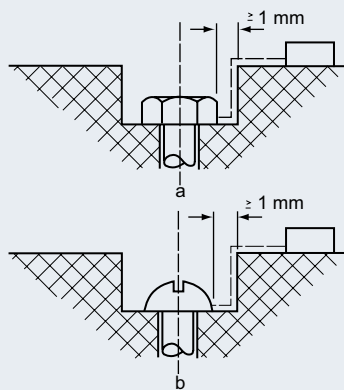
Case 7



Case 8



Case 9



Case 10

Case 6

Condition: Path under consideration includes an uncemented joint with grooves equal to more than 1 mm wide each side.

Rule: Clearance is the "line of sight" distance. Creepage path follows the contour of the grooves.

Case 7

Condition: Path under consideration includes an uncemented joint with a groove on one side less than 1 mm wide and a groove on the other side equal to or more than 1 mm wide.

Rule: Clearance and creepage paths are as shown.

Case 8

Condition: Path under consideration includes a diverging-sided groove equal to or greater than 1.5 mm deep and greater than 0.25 mm wide at the narrowest part and equal to or greater than 1 mm at the bottom.

Rule: Clearance is the "line of sight" distance. Creepage path follows the contour of the groove.

Case 9

Gap between head of screw and wall of recess too narrow to be taken into account.

Case 10

Gap between head of screw and wall of recess wide enough to be taken into account.

Note: Clearance: _____
 Creepage Distance: _____

IEC CLASSES OF ELECTRICAL EQUIPMENT

There are four classes that IEC uses to categorize electrical equipment.

Class I

Defined as equipment which does not depend upon insulation only, but has an added safety precaution in that all non-energized conductive parts are connected to an earthing conductor in the fixed wiring of the installation, such that they cannot become live in the event of insulation failure. Circuit breakers designed to meet this criteria have more stringent isolation requirements than those designed for Class III and may be used in either Class I or III equipment. Under suitable conditions, a circuit breaker designed to meet this class may be used in Class II equipment as an inaccessible component.

Class II

Equipment depends entirely upon isolation (creepage, clearance and/or insulation) to provide protection. This equipment has the most stringent isolation requirements and circuit breakers designed to meet this criteria may be used in any other class of equipment.

Class III

Safety Extra Low Voltage (SELV) is defined as equipment which provides the protection required by being designed so that the voltage cannot ever reach a hazardous level. Circuit breakers designed for this class of equipment have the minimum isolation requirements and are not to be used in any other class of equipment. However, under suitable conditions it may be used as an inaccessible unit for hazardous voltages.

Class IV

Extra Low Voltage (ELV) is sometimes considered. However, since the power supply may not always be a SELV unit, circuit breakers designed for use in this equipment must meet the requirements of either Class I or II. This class may be ignored because low voltage is considered hazardous unless it is SELV.

Airpax circuit protector types IPG, IEG, IEL and SNAPAK have been examined by UL and are in compliance with the requirements of Class II of IEC 435, which is the most stringent of those standards listed and thus could be used for any of the four classes.

Another decision deals with environmental conditions which are divided into a range of pollution degrees. Pollution Degree #1 requiring the least protection and #4 requiring the most. The circuit breaker industry has generally adopted Pollution Degree #3 as the basic design standard for the greatest economical advantage since it does not require the extreme precautions of Pollution #4. An equipment manufacturer may use this unit in equipment designed for Pollution Degree #4 by providing suitable auxiliary physical protection such as an additional cover or enclosure around the circuit breaker. Pollution Degree #3 is defined as "Conductive pollution occurs or dry non-conductive pollution occurs which becomes conductive due to condensation which is expected."

CLASSES OF INSULATION

LEAKAGE CURRENT TEST

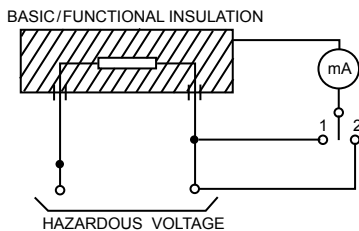


Figure 1

A third decision concerns classes of insulation. There are five classes of insulation to be considered:

Case 1

Operational insulation (Figure 1) is the insulation provided between live parts of different potential which is necessary for proper operation of the unit. This may be considered as line to line insulation.

Case 2

Basic insulation (Figure 2) is the insulation applied to live parts for protection against electric shock. This requires 3mm clearance and 4mm creepage up to 400V rms.

Class 3

Supplementary insulation is an independent insulation applied to basic insulation to ensure protection against electric shock in event of failure of the basic insulation.

Case 4

Double insulation is comprised of both basic and supplementary insulation.

Case 5

Reinforced insulation is a single insulation applied to live parts which provides a degree of protection against electric shock equivalent to double insulation. This requires 8mm creepage and clearance up to 250V rms, and 8mm clearance and 10mm creepage up to 570V rms.

Double or reinforced insulation must be designed into circuit breakers if they are to be used as accessible components. Basic or supplementary insulation are sufficient for units considered inaccessible, assuming that the application does not mix hazardous and SELV voltages in the same circuit breaker.

If the circuit breaker is to be used as a disconnect device, the open contacts must be separated by at least 3mm.

LEAKAGE CURRENT TEST FOR CLASS II MACHINE

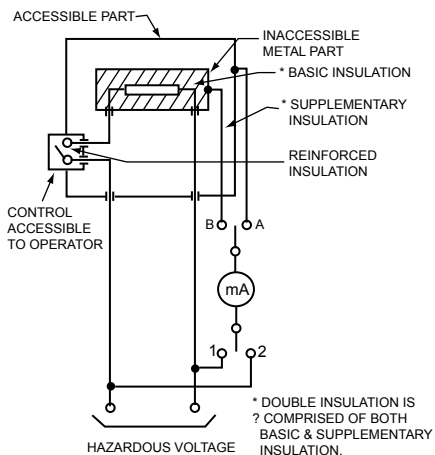


Figure 2

COMBINATIONS

At Airpax, our assumptions are that worst case combinations on circuit breakers designed to meet these international requirements are as follows:

Case 1

The equipment designed will be Class II and the circuit breaker operating handle is operator accessible. This requires that creepage and clearance both be 8mm from the base of the handle to any electrically energized internal part of the circuit breaker up to 250V. Higher voltages require greater clearance and creepage.

Case 2

Hazardous and SELV voltages will be mixed in adjacent poles of a multi-pole unit. This requires the same creepage and clearance as in Case 1 between the adjacent poles.

Case 3

On a pole with an auxiliary switch, hazardous and SELV voltages may be mixed, such as 240V on the main contacts and 5V (from a SELV rated source) on the auxiliary switch. This requires the same creepage and clearance between electrically energized parts of the circuit breaker mechanism and the switch mechanism as in Case 1 above.

Equipment designers must be especially cautious about a design that requires mixing hazardous and SELV voltages. If the application is all hazardous or all SELV, the creepage and clearance requirements are 3 or 4mm, depending upon which standard the equipment will be tested to. The 8mm always applies around the handle if it is operator accessible.

The equipment designer has a responsibility to investigate the appropriate standards and know precisely what kind of approvals are required for circuit breakers and other components. The component manufacturers have the obligation of clearly communicating to potential users precisely what kind of approvals their products have. With this information, the equipment designer is assured that he has a proper match.

The two examples below illustrate how possible confusion can arise if careful attention is not given to the requirements of the specific equipment application.

Example 1

The first is the SNAPAK® circuit protector line. This protector has been certified by UL to IEC Standard 435 for Class II, front panel use. SNAPAK has passed the functional requirements of VDE 0642, and carries the VDE logo.

Example 2

The second is the IEG and IEL families. These protectors have been certified by UL to IEC standard 435 to Class II, front panel use. They have passed the functional requirements of VDE 0642, and as a result are now qualified to carry the VDE logo.

These two very similar sounding approvals are not the same. What is the difference? The difference is the insulation class. The SNAPAK circuit breaker family is approved for operational or basic insulation and the IEG and IEL families are

approved for double or reinforced insulation.

What does that difference mean to the user? It means that hazardous and SELV voltages can be mixed on the IEG and IEL and not on the SNAPAK, because it does not have the 8mm clearance pole to pole internally. However, it does have the required 8mm clearance between the auxiliary switch and the main circuit. In addition, the contacts must have at least a 3mm opening in the OFF position if the breaker is used as a disconnect device and the operating environment must be no worse than Pollution Degree #3.

Circuit Breaker Selection

To select a properly approved circuit breaker for an individual application, the following points should be considered.

Point 1

Equipment Class I, II, III.

Point 2

Pollution Degree 1, 2, 3, 4.

Point 3

Insulation Class. (See Note).

Point 4

Operator Accessible — Yes, No.

Point 5

Used as a disconnect device — Yes, No.

Make sure that the circuit breaker approval meets or exceeds the criteria in the checklist. Do not assume that any unit with the VDE logo will meet your needs.

The preceding is a summary of inputs from many engineers in our customer base and consultations with VDE personnel. It is intended as a guide in the circuit protection selection process and should not be viewed as absolute, in that the various standards are subject to change and no two applications are precisely the same. We suggest communication between the equipment design engineer and the application engineering staff at Airpax.

Note: Will be a function of whether or not hazardous and SELV voltages are mixed.