

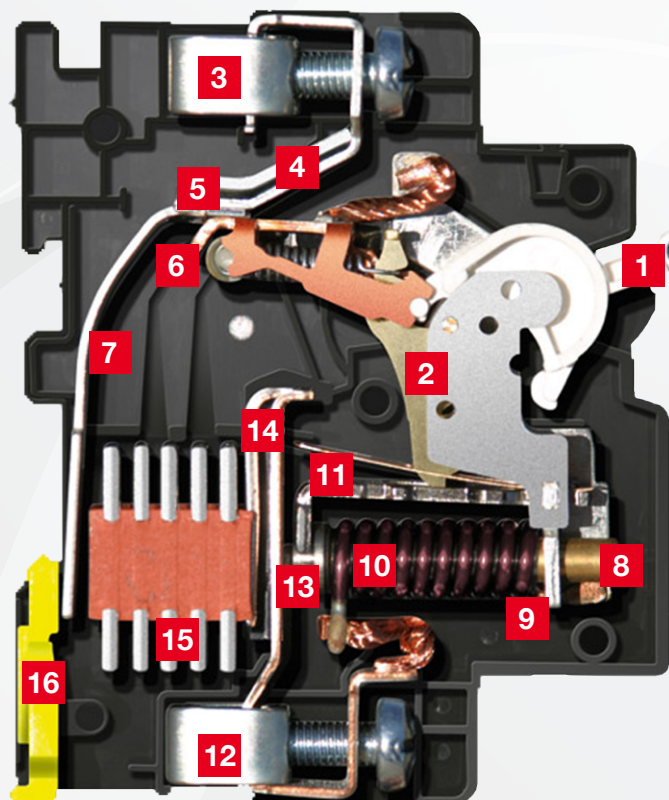
## Features

### Features of the Hydraulic-Magnetic Principle

- Circuit breakers can carry 100% of rated current independent of ambient temperature
- Do not require de-rating for temperature
- Always trip at 125% of rated current independent of ambient temperature
- Immediate resetting after trip
- Any current rating possible, even fractions of amperes
- Large range of time delays available
- Can mount a large number of circuit breakers side by side

### Features of the Construction Common to all CBI Circuit Breakers

- **Trip free operation:** Even if the handle is locked in the ON position, the breaker will trip if an overload occurs
- **Positive ON and positive OFF:** The handle always indicates the status of the breaker contacts
- **Silver alloy contacts:** The contact tips ensure a long, trouble-free life, even in harsh environments, ensuring a low impedance connection throughout the life of the breaker
- **Superior quality polymer materials:** Materials meet or exceed the requirements laid down by international specifications for polymer materials to be used in circuit breaker applications, such as IEC 60947-2 and UL 489
- **Environmental Safety:** Ensures better safety properties for flammability, toxicity and isolation, ensure safety for users and the installation
- **Hermetically sealed sensing / time delay mechanism:** These ensure no aging or deterioration and thereby a longer service life, with precise time-delay and tripping characteristics throughout the life of the breaker
- **Multi-pole Circuit Breakers are fitted with common trips:** All CBI multi-pole circuit breakers are externally coupled with a handle tie-bar and internally with a common trip linkage, ensuring that all poles switch and trip simultaneously



Hydraulic-Magnetic Circuit Breaker

### Circuit Breaker Components

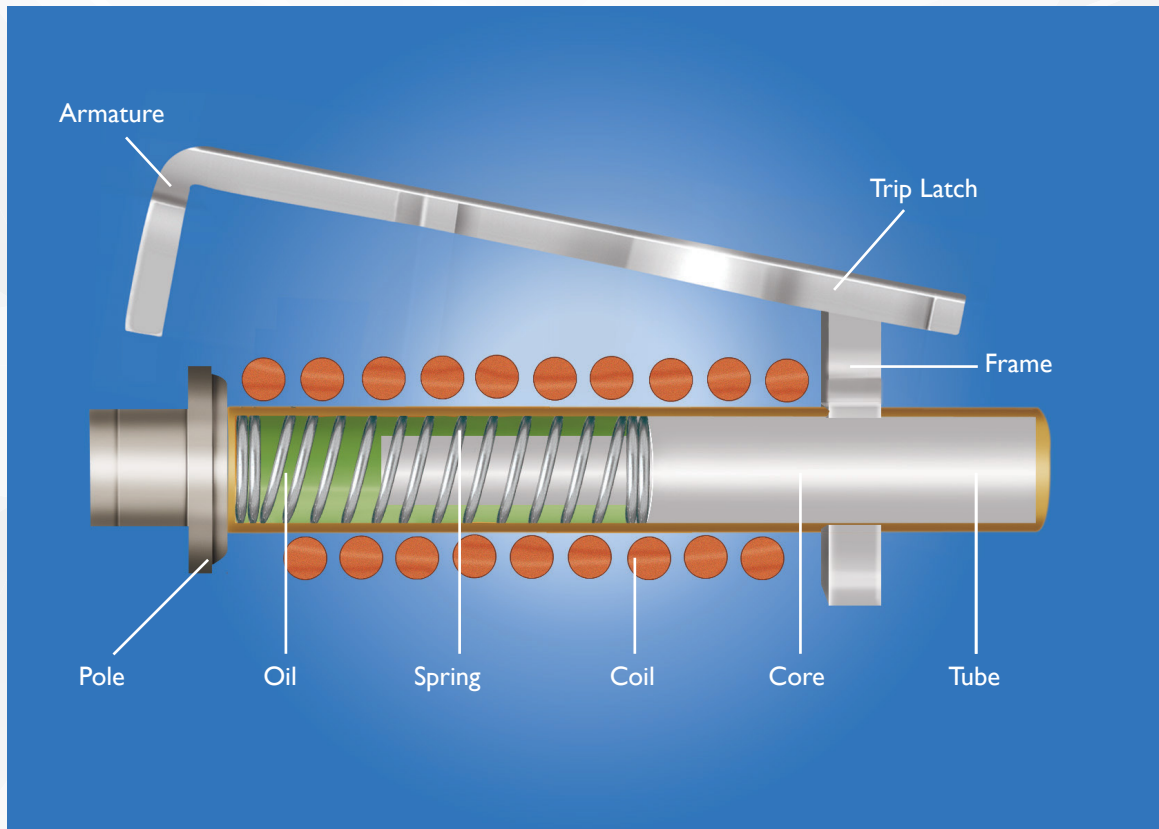
1. Handle
2. Mechanism assembly
3. Line terminal
4. Fixed contact
5. Contact tips
6. Moving contact
7. Arc runner line side
8. Hermetically sealed tube
9. Magnetic frame
10. Solenoid coil
11. Armature
12. Load terminal
13. Pole piece
14. Arc runner load side
15. Arc grids
16. Clip-in springs

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## Principle of Operation

### Hydraulic-Magnetic Technology

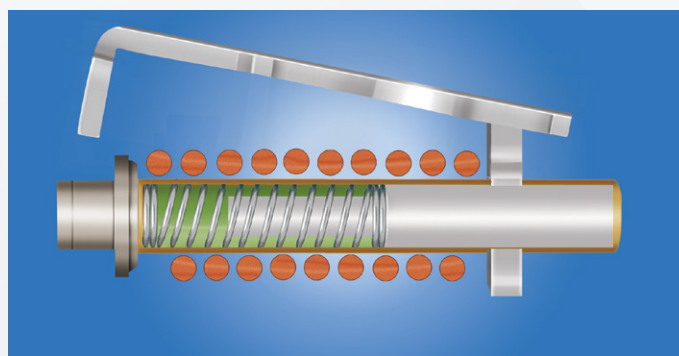
Hydraulic-magnetic circuit breakers operate on the magnetic force produced by a load current flowing through a series-connected solenoid coil that is wound around a hermetically sealed tube containing an iron core, a spring and dampening fluid, as shown in Figure 1.



**Figure 1: Series Connected Coil**

### Normal Operation

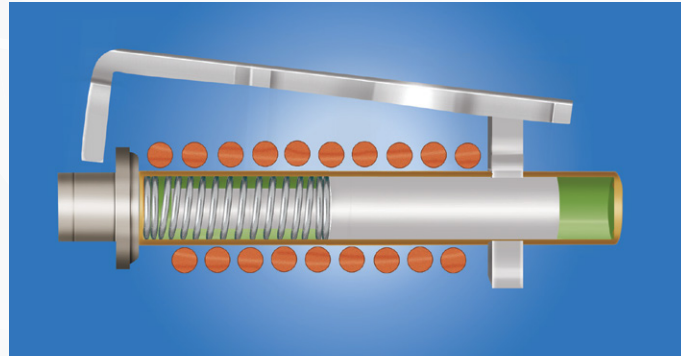
At the circuit breaker's rated current or below, the magnetic flux in the solenoid is insufficient to attract the core towards the pole piece, due to the spring force shown in Figure 2. Therefore the circuit breaker remains loaded and the circuit is energised.



**Figure 2: Rated Current or Less**

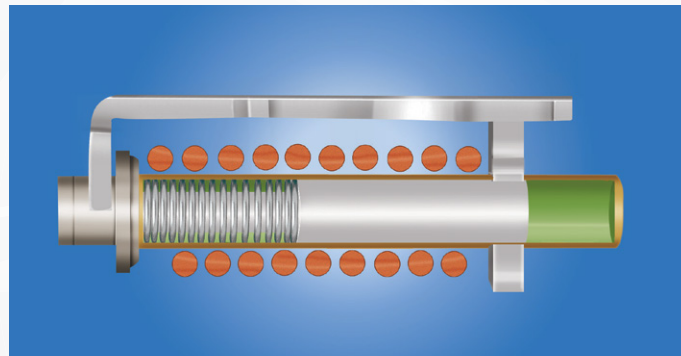
## Overload

When an overload occurs, i.e. current  $I_s$  greater than the circuit breaker's rating, the magnetic flux in the solenoid produces sufficient pull on the core to start its movement towards the pole piece. During this movement, the hydraulic fluid regulates the core's speed of travel, creating a controlled time delay inversely proportional to the magnitude of the current. This time delay is useful in that if the overload is of short duration, e.g. start-up of motors etc., the core returns to its rest position when the overload disappears (Figure 3).



**Figure 3: Overload Current (Time Delay)**

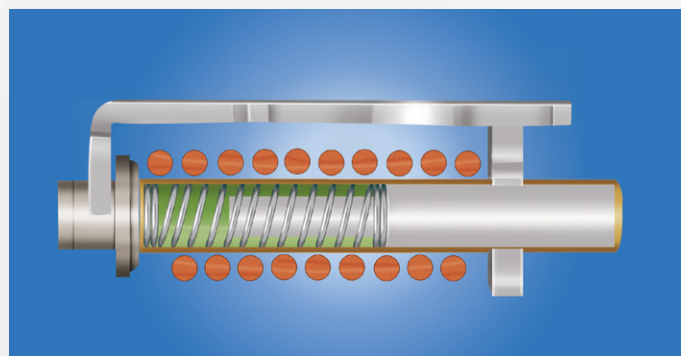
If the overload persists, the core reaches the pole piece. As a result the reluctance of the magnetic circuit is reduced, so that the armature is attracted to the pole piece with sufficient force to collapse the latch mechanism (toggle), and trips the breaker (Figure 4). The contacts separate, the current ceases to flow and the core will then return to its rest position.



**Figure 4: Overload Current (Trip)**

## Short Circuit

With high values of overloads or short circuit, the magnetic flux produced by the coil is sufficient to attract the armature to the pole face and trip the breaker even though the core has not moved. This is called the instantaneous trip region of the circuit breaker characteristic (Figure 5). Unlike thermal circuit breakers, the hydraulic-magnetic circuit breaker's trip point is unaffected by ambient temperature. After tripping, the breaker may be re-closed immediately since there is no cooling-down time necessary. By the nature of the principle of operation, it is possible to obtain any variation of time / current characteristic.



**Figure 5: Instantaneous Trip**

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## Application Guide

### Circuit Breakers



While circuit breakers are generally applied for the protection of cables and installations, it is important to choose the correct circuit breaker to protect critical equipment so that essential services are maintained while protecting the equipment. Careful selection of appropriate circuit breakers with specific characteristics will ensure that critical equipment is protected against electrical faults.

The fixed electrical installation is generally covered by a country's electric code and has at its core the protection of cable and cable installation. This code generally does not cover the variety found in equipment. The environment in which the equipment operates, or to which it is exposed, may differ from fixed installations.

Various technical authorities, such as the International Electrotechnical Commission (IEC), Underwriters Laboratories (UL) and China CCC, have generated specific circuit breaker specifications for the types and applications.

CBI's Circuit Breakers for Equipment (CBE) comply with various international standards and are built to the highest quality standards. They are specifically designed with the capability to be configured to the requirement of the designer of the end-product or system equipment. CBI's technical and sales staff often work with the design engineers to select the most appropriate product for the requirement. CBI also works with its customers to develop specific customer solutions.

Generally the CBE products are either front mounted, rail mounted, terminal mounted or surface mounted, and available for both AC and DC applications. The products are built to suit the environment in which they operate and to comply with strict environmental specifications.

### Selection and Application of Circuit Breakers for Equipment Protection

The critical operational requirement of the equipment demands selection of high quality circuit breakers offering close protection, with tripping characteristics suitable for the specific application. Circuit breakers are by definition safety devices and must comply with appropriate specifications and approvals. Many of these are legal and / or regulatory in nature.

Major considerations in the selection of these circuit breakers are the total cost of ownership of the installed system, life-cycle cost of the equipment, mounting footprint, termination and handle styles and actuator design. When operated with auxiliary switches, trip alarm, shunt and remote trip capabilities, CBI's circuit breakers assist the customer's design engineers in their quest for a high quality design.

## Voltage and Frequency

CBI Circuit Breakers' specifications generally refer to the nominal system voltages, typically 120 V AC, 120 / 240 V AC, 240 / 415 V AC, 277 / 480 V AC, 24 V DC, 32 V DC, 48 V DC, 65 V DC, 80 V DC, 125 V DC etc. The voltage referred to is the nominal system voltage, typically 240 Y / 240 V, 277 Y / 480 V or 480  $\Delta$  V. Products with a rated voltage higher than the nominal system voltage may be applied, since if the product handles a higher voltage, applications with lower voltages will function just as well. Circuit breakers are not recommended for use in systems below 2 V, because the impedance of the circuit breaker may influence the function of the system in which it is used, causing voltage drops. Contact resistance at very low voltages, particularly in harsh environments, may adversely affect the circuit breakers' performance.

The rated insulation voltage, the voltage at which the product's insulation is deemed to be functional, helps to determine the voltage at which the dielectric tests are conducted. The clearance and creepage distances are calculated for this voltage.

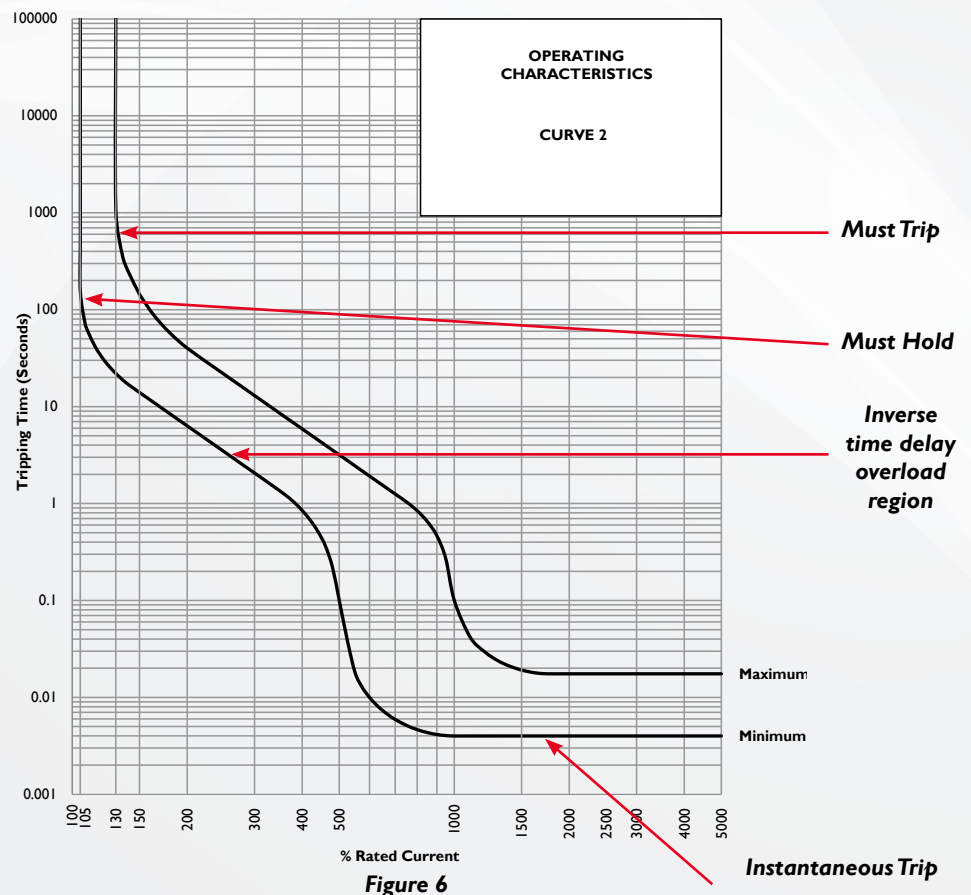
Most of CBI's products are certified for use in 50 / 60 Hz AC and in DC applications. CBI also has a specific range of products that can be applied to 400 Hz. Overheating of the breaker may occur at higher frequencies. Use of the circuit breakers under frequency conditions other than those for which the product is approved, or under harmonics, requires careful consideration as the breaker performance may vary. In such applications it is necessary to evaluate the performance of the circuit breaker for reliable performance. CBI's technical staff work with the customers in the selection of the appropriate product.

## Current Rating and Time Delay

CBI Hydraulic-Magnetic Circuit Breakers are designed to hold 100% of the rated current, unaffected by the ambient temperature. While specifications allow for slight variation on the must-trip point, CBI's circuit breakers are generally designed to trip at 125% of the rated current. The must-hold and must-trip points operate on the magnetic force generated by the load current and hence no de-rating is required. It is possible to design a circuit breaker to any current rating, thus offering close protection for the overall system and lowering the cost of the total system design.

The selection of the appropriate tripping characteristic for the circuit being protected is one of the most critical decisions. The circuit breaker must adequately protect the equipment and operate with the rest of the system components in the most cost-effective manner during the life cycle of the equipment and the systems being protected.

CBI offers a range of published tripping curves in products designed to meet these characteristics. Should the customer require a specific tripping characteristic to be developed for their application, CBI will work with the customer to achieve precision protection characteristics for the specific application.



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The region between the must-trip point and the point at which the circuit breaker is designed to trip instantaneously is known as the overload region of the curve. In this region, the tripping characteristic of the circuit breaker is inversely proportional to the percentage of overload current in amps. The tripping characteristics follow a predetermined time delay of the curve as determined statistically and published. This time delay is created by the damping effect of silicon oil in the tube. This damping effect sustains the circuit breaker from nuisance tripping due to momentary overloads such as start-up currents.

Figure 6 shows a typical curve for a hydraulic-magnetic circuit breaker. By virtue of its design, flexibility is a key advantage on the hydraulic-magnetic circuit breaker.

The instantaneous point (defined as a trip time of 0.1 second) is that point at which the circuit breaker will trip instantaneously due to a short circuit current, as the current here is a higher magnitude than the rated current. CBI's circuit breakers generally exhibit a 2 millisecond (ms) delay in the trip response time.

An important factor to consider is the discrimination and coordination with other protective devices in the system, to achieve the most appropriate protection regime. The selection of the different tripping characteristics enables the designer to choose the appropriate curve required at the point of protection. With CBI's hydraulic-magnetic circuit breaker technology, it is possible to discriminate between series-connected circuit breakers both by the selection of appropriate current ratings and by time-delay characteristics.

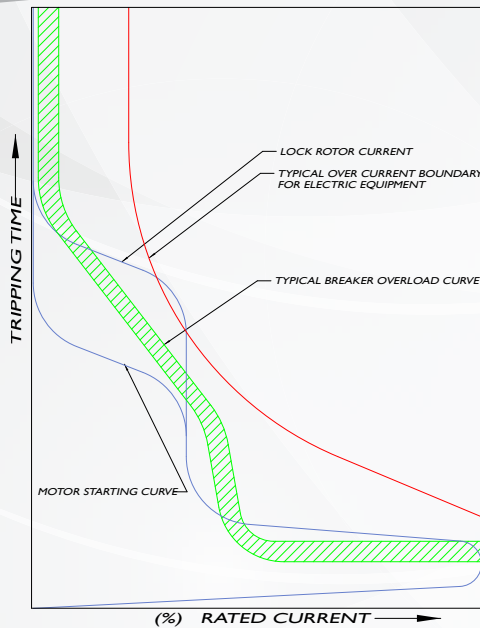
One of the major advantages of the hydraulic-magnetic circuit breaker is that the must-hold point and must-trip point of the breaker are independent of ambient temperature. This allows close protection of components, which in turn allows savings, as the components may be rated correctly and do not have to be overrated for a particular application.

Choosing the correct tripping characteristic for the circuit being protected is critical. The protection equipment must adequately protect the system components, work harmoniously with other protection devices in series with the protector and do so in a cost-effective manner for the lifespan of the installation.

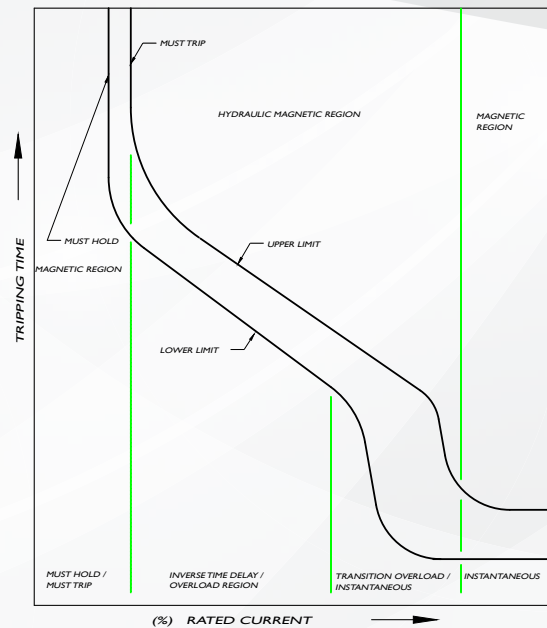
Important current ratings when choosing a curve fall into three main categories: normal load currents, overload conditions and short circuit conditions. The overload protection device should fulfil the following requirements:

- Allow normal currents (below or equal to rated current of the system or equipment) to flow continuously.
- Allow temporary overload conditions, such as those associated with motor starting or capacitor switching, without unnecessary tripping.
- Be able to detect and trip the circuit breaker in overload conditions that because of their current magnitude and time duration would damage the equipment insulation or the equipment itself.
- When the insulation of equipment breaks down, short circuit currents of many times the rating of the breaker may flow. To reduce the thermal and dynamic stresses that can occur in system components or equipment, the short circuit should be interrupted as quickly as possible.

The rated current of a circuit breaker is the ampere rating appearing on the front of the product. The tripping characteristic or time delay curve is generated based on a percentage of this value.



**Figure 7: Overload Boundary of Typical Electrical Equipment, Breaker Curve and Motor Characteristic Curve**



**Figure 8: Typical Hydraulic-Magnetic Curve**

The tripping curve of the protection device must track the overload boundary of the protected equipment or system. Figure 7 shows the overload boundary of electrical equipment. The tripping curve of the ideal protection device will track the curve of the protected equipment, but as a safety margin should be slightly below the overload boundary to avoid damage to the system. Figure 8 shows a typical trip curve for a hydraulic-magnetic breaker. Note the upper and lower limits of the curve are a function of the variation within the construction of the circuit breaker. The trip point will fall within these limits. Flexibility regarding the curve is an advantage of the hydraulic-magnetic principle.

The characteristic curve for the breakers is generated with the breaker mounted in the wall mount position at 25 °C (ambient temperature) from cold (i.e. no current flowing before the current is suddenly applied) at rated frequency. The test is conducted at a convenient voltage (in CBI's test equipment at 2V or higher).

The first points to consider are the must-hold and must-trip points. Hydraulic-magnetic circuit breakers always carry 100% of rated current, independent of ambient temperature. This is a distinct advantage over the normal thermal and thermal-magnetic devices that have to be de-rated if the temperature is above the calibration temperature of the circuit breaker. The must-hold point is usually 100% (this could also be 105% or other, depending on the specification). According to IEC specifications, a circuit breaker must hold the rated current for one hour. Hydraulic-magnetic circuit breakers will hold the rated current indefinitely, independent of the ambient temperature.

The must-trip point is the percentage of rated current at which the product is guaranteed to trip. The percentage of the rated current of the must-trip point is usually 125% (though it can differ depending on specification and construction). A hydraulic-magnetic circuit breaker is guaranteed to trip at the must-trip point independent of the ambient temperature.

The must-hold point is above the normal current drawn by the equipment during operation. A safety factor of 5% is usually used i.e. the normal current drawn is 95% of the rating of the circuit breaker. The must-trip point is associated with the overload boundary of the equipment. The must-trip point must obviously be below the point where damage to the equipment would start. It is up to the designer to add a safety factor to take care of variations in the environment and equipment.

From the must-trip point to the point where the breaker trips instantaneously (defined as a trip time of 100 ms or less) is known as the overload region of the curve. The time delay in this region is caused by the damping effect of silicon oil in the tube. As silicone oil viscosity changes with temperature, the time delay will also become faster or slower as the temperature increases or decreases. In some circles this is considered to be an advantage. This region of the curve will allow normal transients to pass and thus prevent nuisance tripping, while interrupting the current when the over-current persists.

A good example of the phenomenon is motor starting, where the start-up current may be as high as six to eight times running current and the phenomenon may last for several hundred milliseconds. This current (motor start current) must not be confused

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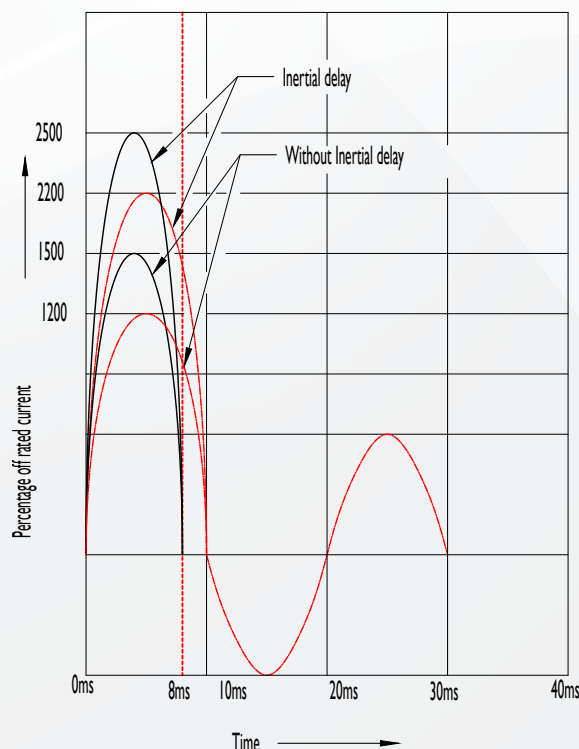
with the inrush current that is a magnetic phenomenon (will be discussed under instantaneous point). A typical cure for motor starting and locked rotor condition may be seen in figure 7. Here the inrush current and the locked rotor condition will trip the breaker. The time delay curve must be changed to accommodate the motor start-up characteristics.

Depending on, among other factors, the application and the need to discriminate with other protection devices in series, the instantaneous trip point is chosen. This is the point where the circuit breaker trips at 100 ms. For the instantaneous trip point, a minimum and maximum as percentage of the rated current is given to cater for manufacturing tolerances. When the minimum current value is applied, the breaker must not trip within 100 ms. At the maximum level the breaker must trip within 100 ms. This instantaneous trip point may be chosen between three to 20 times rated current. The area forms the limit between the time delay region and the non-time delay (purely magnetic) trip region of a hydraulic-magnetic circuit breaker. With hydraulic-magnetic circuit breakers it is possible to discriminate between series connected breakers not only via the instantaneous trip point, but with a longer time delay during normal overloads.

A note of caution is necessary here, especially if discrimination is required between a circuit breaker and a fuse. The fuse is a device that essentially measures  $I^2t$  (let through energy). Since a hydraulic-magnetic circuit breaker measures current and has an additional time delay due to the mechanism, it is not recommended to establish the limits of discrimination theoretically. Physical tests have to be conducted.

A high instantaneous point is also used to take care of effects such as motor inrush current, which may last a couple of cycles and may not all be at the maximum current. The initial inrush may be as high as three times the locked rotor value and up to 24 times rated current. IEEE 242 recommends: "For many smaller squirrel-cage induction motors, it is usual to set the instantaneous pickup at 10 to 11 times the motor full load current."

For other short-term phenomena that last less than one cycle, the use of an inertial delay current breaker is recommended. The inertial delay is characterised by the high-inrush current and is defined as the maximum current the product can withstand without tripping for half a cycle (10 ms 50 Hz and 8 ms 60 Hz). This phenomenon is shown in figure 9. The inrush tolerance may be as high as 35 times the rated current (the value for 60 Hz obviously is higher than 50 Hz), but is normally between 12 and 20 times. The inrush given in the CBI catalogue is for a 50 Hz system. The B, C and DD Frame have a DC Inrush Tolerance (10 ms pulse). The inrush that can be expected for a specific curve is quoted in the detailed technical section and varies depending on the specific construction. Typical application areas are capacitor switching (can be anywhere from below 1 ms to several milliseconds up to 25 times rated current), switching incandescent lamps (10 to 15 times rated current for even several milliseconds) or even for motor inrush.

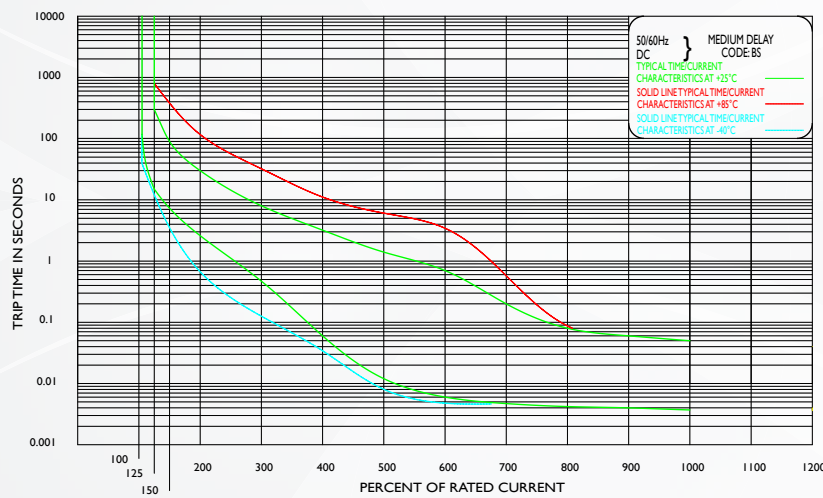


**Figure 9: Influence of Frequency on Inrush Withstand**

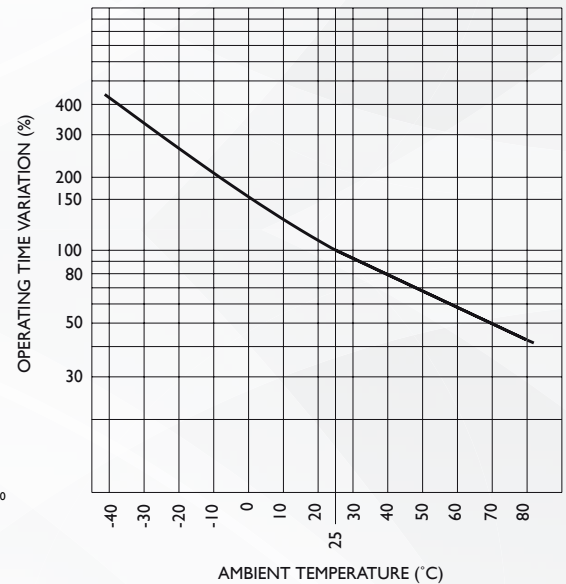


Although the breaker may be switched back on immediately after the fault has been cleared, the time delay mechanism may take a little time to reset. Normally if the current in the circuit is less than 80% of the rated current, the time delay mechanism will reset and tripping will not occur. For curves such as the OP (instantaneous) and CS (fast curve), the resetting time of the time delay mechanism is a matter of seconds. For longer curves (AS and AH) the reset time for time delay mechanism may take longer. Resetting in this sense means that the time delay characteristic as per published curve has been regained. This is not the case with other protection devices.

It may be a requirement in the specified application to have a circuit breaker that can withstand the effects of high inrush currents. Such high inrush currents may be many times the rated current (sometimes up to 25 times or more) and if the appropriately designed circuit breaker is not chosen, nuisance tripping of the system may result. CBI offers specific long delay characteristics specially designed for such applications. On certain products, CBI offers additional inertial delay that enables them to withstand spikes of up to 35 times the rated current. Duration of the pulse is generally under 10 ms. An example of inrush / pulse is shown in figure 9.



**Figure 10: Influence of Temperature on Time Delay**



**Figure 11: Temperature Variation Chart for the Time Delay Region of a Hydraulic-Magnetic Circuit Breaker**

## Compensation Curve for Temperature on the Time Delay Portion

While the must-hold, must-trip and instantaneous points of the tripping curve are unaffected by temperature, the time delay portion, because of the hydraulic fluid viscosity, varies with temperature. This portion of the curve has a variation as shown in Figure 10. Hence, while the circuit breaker current rating is unaffected by temperature, the time delay portion varies with temperature. This is shown in Figure 11.

## Dielectric Strength and Insulation Resistance

CBI's products are designed for a minimum of 1500 V dielectric strength normally applied for 60 seconds between line and load, adjacent poles and all poles and earth, after any destructive testing such as short circuit, overload and endurance test sequences. This is to avoid breakdown at rated voltage due to carbon build-up, which could be a potential fire and safety hazard. CBI's products are tested to various international standards and comply with third party approvals.

The products also comply with an insulation resistance of at least 2 MΩ at 500 V DC to ensure proper insulation properties to protect the user against electric shock.

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## Short Circuit Interrupting Capacity

It is critical to select a product that can safely interrupt the short circuit that may occur in a system. In selecting the appropriate circuit breaker it is important to determine the fault level (in kA) to which the system may be subjected. CBI offers various products complying with various short circuit interrupting capacities, as confirmed by the various specifications and approvals it holds. The reliability of the design is regularly evaluated and ensured by compulsory follow-up testing as required by various authorities, such as UL. This ensures the integrity of the design and maintains the production process within specifications.

Using a circuit breaker with a higher than necessary short circuit interrupting capacity may seem to pose no risk, but the use of a circuit breaker may become uneconomical or impractical if products with a higher interrupting capacity are used for the application. It also makes no sense to have a very high interrupting capacity circuit breaker when the rest of the system is not designed for such fault levels.

### Branch Protection

The National Electrical Code of the United States defines a branch circuit as “the circuit conductor between the final over-current device protecting the circuit and the outlet”. The UL 489, IEC 60947-2 covers the requirement for circuit breakers that may be used in branch circuit protection. UL 489 requires a circuit breaker to pass a minimum of 5 kA short circuit current. Circuit breakers complying with UL 489 are capable of branch circuit protection, are known as UL listed products and can be used as service entrance circuit breakers.

### Supplementary Protection

Supplementary protectors are devices installed in circuits where branch protection already exists. UL 1077 covers the requirement of such devices, which may be used for supplementary protection and are labelled as UL-recognised.

IEC 60934 defines the requirements for circuit breakers to be used in equipment protection. Generally such devices are used in electrical equipment that is plugged into a socket outlet protected by the branch circuit breaker, which is a listed product.

### Temperature Rise

CBI's circuit breakers are certified to the relevant UL, IEC and other national standards. As specified in these standards, tests are carried out in most instances at an ambient temperature of 25 °C. UL, IEC, AS and other certifications ensure that the product complies with these standards.

To establish the operational temperature range for the trip time delay of a CB at temperatures higher or lower than 25 °C, as is the norm, in-house tests may be carried out by the manufacturer of the circuit breaker. The test set-up and conditions can be agreed between the manufacturer and the user of the product and such tests are not covered by UL, IEC or any other national standards.

After requests from the market, CBI has performed various tests at -40 °C and +85 °C in line with the above standards to establish that the circuit breaker can be operated without problems at such ambient temperature. Relevant tests were completed successfully and therefore CBI's circuit breakers can be used safely at -40 °C to +85 °C ambient temperature.

### UL Requirements and Labels on Circuit Breakers

The marking “60 / 75 °C CU only” on the UL label of CBI's circuit breaker refers to the temperature rating of the wire used in the test installation with that circuit breaker and is prescribed by UL for the product certification testing at 25 °C. This is not related to the circuit breaker's operational temperature range.

When the circuit breaker is installed in applications where the ambient temperature can go up to 85 °C, for instance, the user or installer has to ensure that the wire used complies with the National Electric Code or any other applicable national code or standard, and to apply the necessary cable de-rating factor, i.e. use a 90°C cable or a cable with a higher current carrying capability.

CBI has performed various tests on the temperature rise on the terminals of the circuit breakers for the operating range of the product and recorded a temperature rise between 23°C and 26°C, an actual terminal temperature of 49 °C at 25 °C ambient and 109 °C at ambient 85 °C. CBI performs the required tests for UL 489 and UL 489A at the prescribed temperature requirement of 25 °C or at 40 °C as required.

CBI has performed various tests on the temperature rise on the terminals of the circuit breakers for the operating range of the product and recorded a temperature rise between 23 and 26 °C, that is an actual terminal temperature of 49 °C at 25 °C ambient and 109 °C at ambient 85 °C. CBI performs the required tests for UL 489 and UL 489A at the prescribed temperature requirement of 25 °C or at 40 °C as required.

## Internal Resistance of Circuit Breakers

The internal resistance of circuit breakers is measured as a DC resistance at the rated current of the circuit breaker. The short circuit protection offered by circuit breakers uses an electromagnetic principle whereby higher current ratings will require fewer coil windings to generate sufficient magnetic flux to trip the circuit breaker than will a lower current rating product. Thus the effective coil resistance will be less for higher current ratings than for the lower rating products.

Due to the low internal resistance of breakers it is imperative that a four-wire or Kelvin measurement is performed to measure the DC resistance, and that the measurement wires are securely attached to the sample under test. This will ensure that no additional resistance is introduced through the measurement wires or probe contacts. Finally the measurements must be performed at the rated current for a particular circuit breaker. A typical internal resistance measurement graph is shown in figure 12.

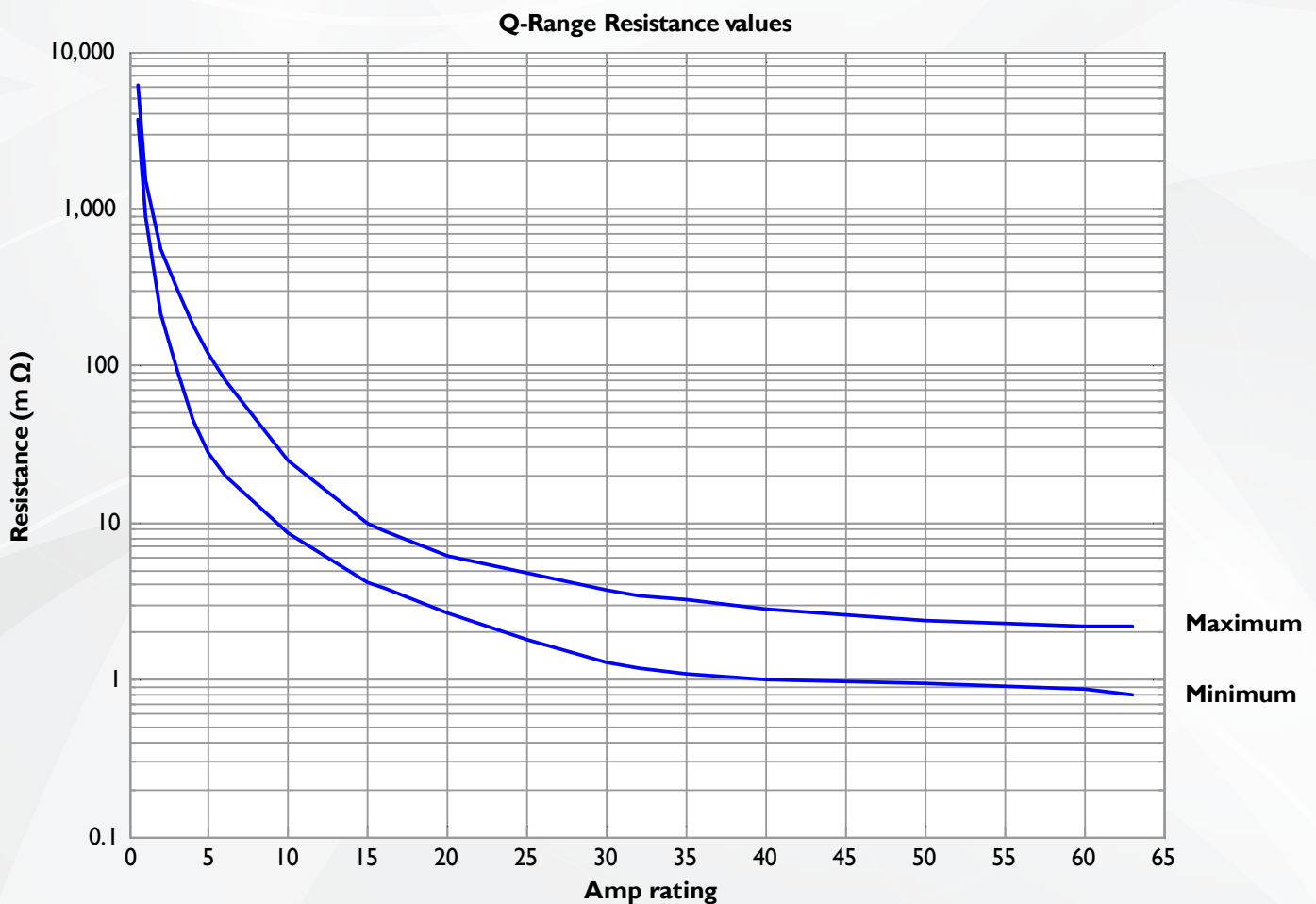


Figure 12