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Precision power protection and shock buffering in a rail environment

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The rail industry is highly competitive, and rail operators are under pressure to make their trains safer, more reliable, cost-effective and attractive to travellers. Choosing hydraulic-magnetic circuit breakers for circuit protection can help in meeting these objectives, as they perform reliably under the harsh conditions of a rail environment while eliminating nuisance tripping and its associated problems. In this White Paper Jean-Christophe BARNAS, senior engineer at Eaton explains the technology and details the advantages that it offers.

Railways have long been recognised as particularly harsh environments, placing extreme demands on the equipment installed into their rolling stock and trackside applications. However, simply meeting these challenges, though essential, isn't sufficient – while doing so the equipment must also play its part in helping operators' drive for an ever safer, more reliable, attractive and cost effective environment. They work under intense competition where global safety standards are increasingly stringent and railways are just one transportation option for travellers.

Electrical equipment and circuits are particularly important in these considerations. Protecting them is critical to ensure passenger and staff safety and minimise downtime, costs and delays arising from any malfunction or failure. Eaton's line of hydraulic-magnetic circuit breakers offers operators a powerful tool for improving circuit protection on board trains. In this paper we look at why these devices are especially resilient in rail operating conditions, and why they offer a more reliable, trouble-free, safe and cost-effective solution than thermo-magnetic circuit breakers.

The nature of the rail challenge

Conditions on board a train are harsh for equipment mechanically, electrically and environmentally. Additionally, the equipment is expected to endure these conditions throughout near-continuous operation over very long lifetimes.

Due to space limitations, the electrical equipment is usually tightly packed into small enclosures, cabinets or compartments, with units operating in very close proximity to one another. This can increase the incidence of spikes, transients and bursts in the power lines that circuit breakers have to protect. Within applications such as metros and tramways, track distances and time intervals between stops are short, with multiple journey breaks and traction step changes. These, together with heavy passenger door usage, cause hard repetitive switching which subjects the equipment and circuit breakers to constant voltage fluctuations.

Additionally, there are often long wiring runs between the circuit breakers and the equipment they protect, because the circuit breakers are usually assembled onto panels within the driver's cab or into electrical cabinets located in the coaches. Alternatively they may be housed within low voltage boxes on the carriage's underframe or even on its roof.

Sudden, fast temperature fluctuations can occur during a journey as the train enters different geographies or goes through tunnels. These can affect equipment operation and may impact their electrical and/or mechanical performance. Current fluctuations in the electrical circuits can arise as a direct result. The circuit breakers can also be subjected to hard mechanical shock, , vibrations, accelerations and jerking movements transmitted directly from the body shell of the train. The severity of these will depend on the location of the circuit breaker panels. The potential impact of these environmental issues can be summarised as follows:

- Breakers may be subjected to extreme electrical and physical disturbances
- Circuit protection may not be optimised to actual power supply and load requirements
- There are several factors that could lead to nuisance triggering
- In the worst case, protection provided may not be effective

The hydraulic-magnetic circuit breaker solution

Hydraulic-magnetic circuit breakers lend themselves naturally to solving these issues, and accordingly they have become well-established in the sector after being introduced by the different rail manufacturers. They provide a better circuit protection solution than thermo-magnetic devices for the rail environment. Overall, they can be seen as energy buffers that absorb abrupt and sudden mechanical and

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magnetic variations. Additionally, as we shall see, many detailed advantages arise from both the functional and physical aspects of their design.

To understand why hydraulic-magnetic circuit breakers are functionally so much better-suited to the rail environment and its challenges than the alternative thermal-magnetic approach, we can start by reviewing the operating and fault conditions that any circuit breaker must handle, and then compare the hydraulic magnetic and thermal-magnetic solutions to these conditions.

During normal operation, the current drawn by the load through its protecting circuit breaker is within the breaker's nominal current limits, and under these conditions the device will allow current to flow indefinitely. In most installations, however, an overload current is likely to arise at some point, either because a fault condition has developed, or, more usually, because equipment such as a motor or transformer has been turned on. Starting inductive equipment such as this draws a heavy inrush current, creating a power surge through the supply circuit and circuit breaker.

Because these surges represent transient overloads, they usually pose no threat of damage to the line or equipment. Therefore, interrupting the supply when they occur is not necessary or even desirable. In fact, such interruptions are referred to as 'nuisance tripping'. Nevertheless, because the overload current may be caused by a genuine fault condition rather than a start-up transient, power must be interrupted if it persists for too long the heavier the current, the shorter the allowable trip time delay.

In more extreme circumstances, a fault may cause or may be seen as a short-circuit current. This is much heavier than an overload, with the potential to damage equipment or injure people very quickly. Any circuit breaker must open as fast as possible to minimise the energy it lets through.

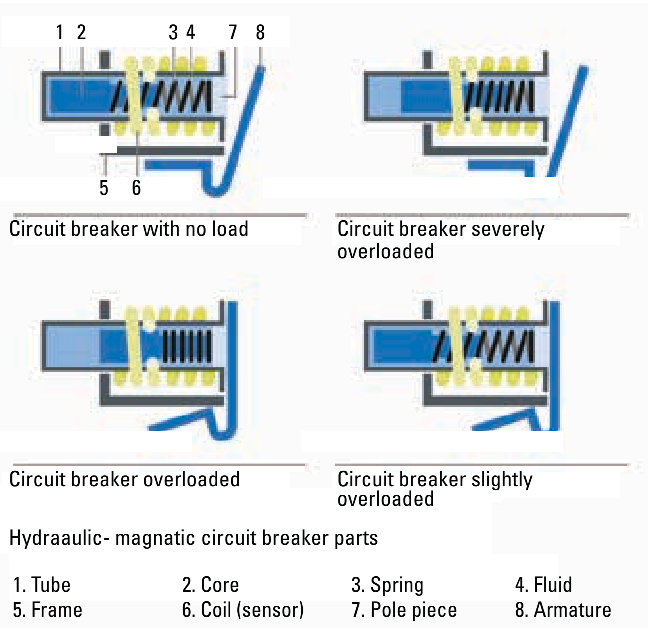

Figure 1. Hydraulic-magnetic circuit breaker principle

Thermo-magnetic circuit breakers meet the diverse challenges of overload and short circuit currents using two core components; a bimetallic element in series with a magnetic core. An overload current causes the bimetallic element to heat up and deform, thus opening the contacts and breaking the power circuit. The bimetal has thermal inertia, which provides a useful time delay for overload transients, but renders it too slow to safely limit short circuit energy. Therefore, the thermo-magnetic breakers also have an electro-magnetic system which quickly trips the breaker on short circuit or high current levels; a reaction within 2 ms is possible. Electro-magnetic tripping generally occurs at six times the circuit breaker's nominal current.

However these devices have a couple of major weaknesses. First is their dependence on ambient temperature which leads to significant variations – of up to 50% - of the tripping point. Taking this temperature parameter into account when selecting the circuit breaker's nominal current is absolutely mandatory.

Secondly, compared with hydraulic-magnetic circuit breakers, the thermo-magnetic devices might have relatively high internal resistance; this generates a voltage drop across their terminals. Switching on capacitive loads may immediately trip a sensitive breaker, making it impossible to start the equipment.

By contrast, hydraulic-magnetic circuit breakers deliver precision protection and a controlled response to changes in load current. They provide reliable, consistent protection characteristics in all environments. Fig. 1 below shows their operating principle. A load current is passed through a coil of wire wound around a hermetically-sealed non-magnetic tube containing a spring-loaded, moveable iron core and silicone oil fill. With the load current either at or below the breaker's nominal rating, the magnetic flux produced lacks the strength to move the core, which remains at the end of the tube furthest from the armature.

On overload, the magnetic flux force increases, pulling the iron core into the coil and towards the pole piece and attracting the armature. -. The silicone oil regulates the core's speed of travel, creating a controlled trip delay that is inversely proportional to the magnitude of the overload. If the overload current subsides before the core reaches the pole piece, the spring returns the core to its original position and the breaker does not trip. However if the magnetic flux reaches a predetermined value, the armature is attracted to the pole piece and the breaker trips. The breaker may even trip before the core reaches the pole piece if the critical flux value is reached first.

On very heavy overloads, or short circuits, the flux produced is sufficient to pull in the armature regardless of the core position. This provides immediate circuit interruption with no intentional delay – a very desirable characteristic. Fig. 2 compares the response curves of the two technologies and shows how a proportion of the thermo-magnetic curve is temperature dependent.

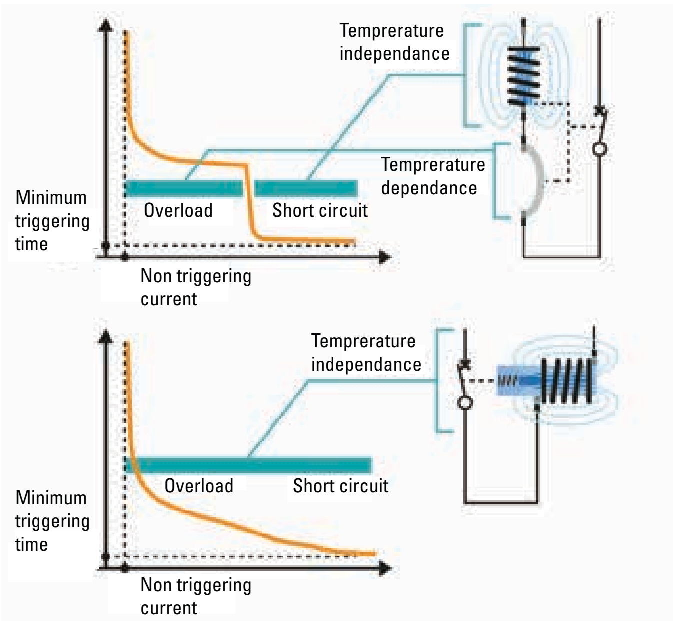

Figure 2. Comparison of trip mechanisms and response curves of thermos-magnetic vs hydraulic-magnetic breaker technology

Hydraulic-magnetic circuit breakers – key advantages for the rail environment

The hydraulic-magnetic design has a number of key advantages. Nuisance tripping caused by high ambient temperatures is eliminated, as the breaker responds only to current variations, not temperature changes. Another cause of nuisance tripping transient current surges – can also be eliminated with precision, and without reducing the overload protection. As described above, surges occur mainly when a machine such as a motor is turned on.

The larger the machine, the greater the surge. The breaker's hydraulically-controlled time delay is inversely proportional to the size of the overload, so response is faster on large overloads where greater potential danger exists, and slower on smaller overloads.

In all cases, however, the breaker can be accurately optimised for its application - responding fast enough to avoid dangerous overloads, but not so fast as to cause nuisance tripping. This precision is possible because the device's current rating is set by the number of wire turns in the load sensing coil. By altering this number and the wire size, Eaton can provide a breaker of virtually any rating within the unit's overall current capacity. This agility is enhanced by the hydraulic-magnetic technology's use of a single mechanism to encompass both the overload current and short-circuit regions. In addition to providing safe, predictable protection this also allows cost-effective, compact installations as hydraulic-magnetic circuit breakers do not have to be oversized during specification.

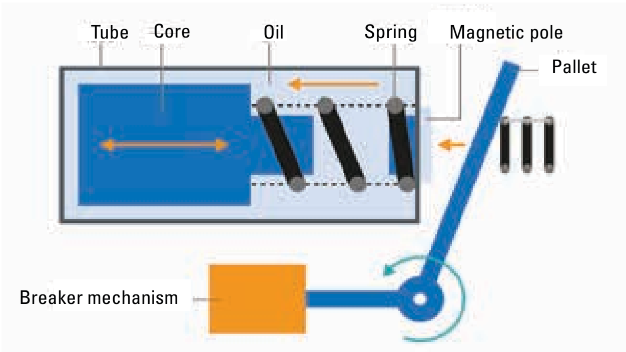

Figure 3. Mechanical arrangement of hydraulic-magnetic device, showing inbuilt resistance to physical shock and vibration

Hydraulic-magnetic circuit breakers offer a number of other advantages that are particularly beneficial to rail applications. Fig. 3 gives a more detailed view of their mechanical design, showing how the core's position is controlled by the oil's viscosity and two main operating springs. This arrangement has good ability to absorb amplified physical shock and vibration from the body of the train; during normal operation, the core is maintained in its rest position even if subjected to continuous shock and vibration frequencies.

Equally, the devices have excellent ability to absorb line current fluctuations such as bursts and fast transients, and avoid nuisance tripping. This is partly due to the time delay imposed by the oil viscosity as discussed above, but also helped by the natural magnetic gap existing between the magnetic pole and the pallet (armature). Fig. 4 below shows how this operates. If a fast current transient occurs, the magnetic frame channels the induction field H towards the air gap e1; this normally operates with a second air gap, e2 as shown, for a high-inrush circuit breaker. Together, they act as a transient energy storage sink that prevents the magnetic circuit from becoming saturated and attracting the pallet and breaker mechanism.

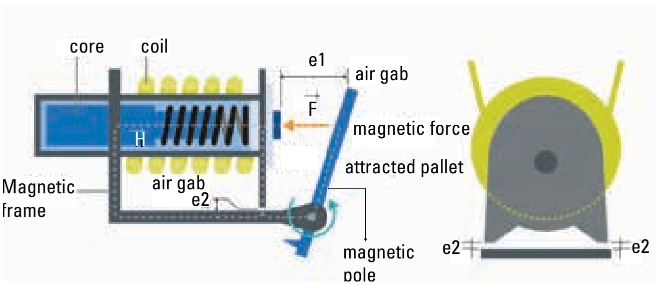

Figure 4. Role of air gaps in absorbing transient energy

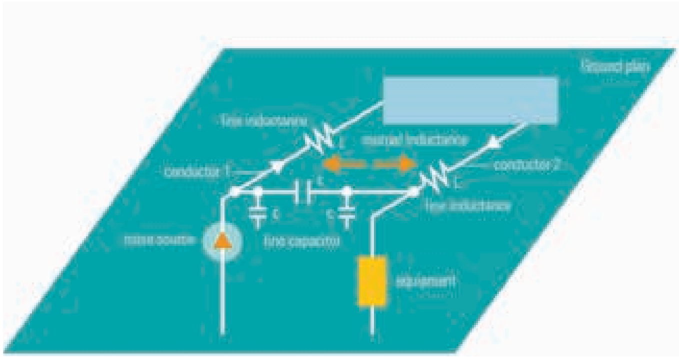

Figure 5. Long wire field schematic

Long wiring runs are another issue that frequently causes problems in the rail environment. Wires can cross or overlap, and wire pairs may be split across different looms, leading to loop surfaces acting as antennae. All of these circumstances are associated with long distance cables involving mutual inductances and capacitances and, mostly, carrier wave frequency currents.

These have a potential to affect circuit breakers and cause nuisance tripping. However hydraulic-magnetic circuit breakers avoid this by the large size of their air gap e1 as shown in Fig. 4; this helps to ensure that the breaker's magnetic circuit reluctance is not influenced by these factors, irrespective of the load current being drawn.

Unlike thermo-magnetic devices that must be de-rated at higher temperatures, hydraulic-magnetic breakers will always carry their full rated current, with no need for any form of temperature compensation. Additionally, long wire runs mean that short circuit currents are usually limited by high impedance values. Designers can use hydraulic-magnetic circuit breakers' precision of response set-up and freedom from temperature de-rating to take advantage of this limitation and specify circuit breakers that are not oversized for any short circuit current they would have to carry in practice.

The lack of response control features within thermal-magnetic circuit breakers is exacerbated if the current drawn is close to their magnetic current region. As Fig. 6 shows, this is because at this point the circuit breaker triggering time is suddenly and drastically reduced – an effect known as 'curve crack'.

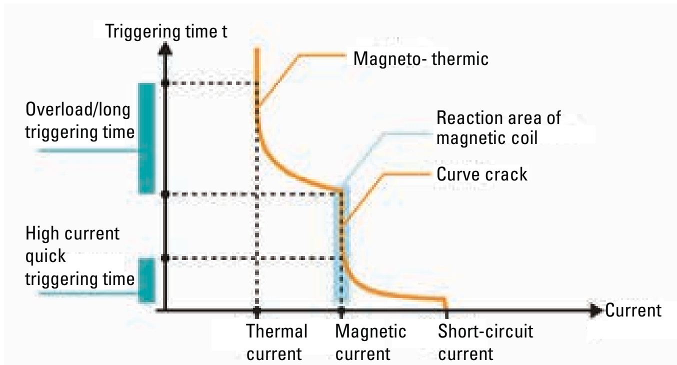

Figure 6. Showing sudden sharp decrease in triggering time at start of magnetic region

Hydraulic-magnetic circuit breakers also provide useful compensation for the elevated ambient temperature levels often encountered on a train. As temperatures rise, equipment usually becomes more vulnerable to transient damage and need faster protection. The hydraulic-magnetic devices provide this, because the viscosity of their oil reduces as temperatures increase, allowing the core to move more quickly towards breaking the circuit. Note that elevated temperatures do not affect the tripping current level, but only decrease the trip response time. Therefore, the breakers offer faster protection at higher temperatures without increase of nuisance tripping.

These devices offer physical advantages in addition to the functional benefits described above. They are compact devices that are mainly front face mounting via small inserts.

The back plate is free to accommodate power terminals and auxiliary switches. This feature greatly benefits manufacturers, as they can simplify cable looms by assembling them near to the bottom of the housing cabinet. Reducing the distance between two adjacent circuit breaker lines also becomes possible.

Hydraulic-magnetic circuit breaker electrical power terminals are well-suited to rail applications, as they are usually implemented as studs that allow closed lug connections – an approach frequently specified by rail standards. These very safe and reliable connections minimise hazard, heat generation and increases to electrical line resistance.

Conclusions

In this paper we have seen how circuit breakers and the equipment they protect face many challenges particular to rail environments; physical shock and vibration due both to travelling and frequent starts and stops (and also that generated by other equipment itself such as motors, compressors etc.), as well as electrical transients caused by equipment starting and induction onto long cable runs. Sudden temperature changes can also create problems, especially for sensitive electronic equipment. Circuit breakers must not only survive these hazards throughout a long life with high usage, they must also prevent these factors leading to nuisance tripping and loss of equipment availability.

We have seen how circuit breakers meet these challenges by using hydraulic-magnetic technology. They can absorb mechanical and electrical disturbances and manage the factors that potentially cause nuisance tripping. They can also be specified with great precision, so that accurate, compact and cost-effective solutions without unnecessary oversizing can designed in.

To ensure making the best choice in terms of safety, performance and cost-effectiveness, designers will benefit from consulting with a large international partner such as Eaton Electrical. Eaton distributors worldwide offer local support and advice on specifying from the extensive range of products available. Wide choices of current rating, timing curves and other parameters together with options for internal switching circuits and switches, handles and terminations mean that most application requirements can be met with great precision and efficiency. The hydraulic circuit breakers are available in both AC and DC ratings in accordance with UL, CSA and VDE standards, allowing their design into applications worldwide and meet the most requested railway standards and certifications.

If you are considering circuit protection design for your next rail project or upgrade, visit us online at

www.eaton.com/rail contact your nearest local distributor or contact us via **alexandrezint@eaton.com** or with Eaton's comprehensive knowledge and stockholding of all circuit breaker technologies, you will be assured of an unbiased discussion of the best approach for your particular requirements.

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