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Electrically actuated vacuum circuit breaker with spring accumulator

The following article introduces a vacuum circuit breaker (CVB) with fail-safe and load isolation functions that fulfils all requirements on power switches, while avoiding the disadvantages of pneumatic circuit-breaker actuators.

Modern high-speed trains – whether the drive concept is locomotive or coupled unit – make the highest demands of all electric vehicles, because the power consumption can exceed 10 MVA. In direct-current (DC) networks, this order of power is almost impossible, because of the operating voltages of 1500 VDC_{NOM} or 3000 VDC_{NOM} (as defined in European railway standards, UIC standards). Even in alternating-current (AC) networks with 15 kV, 16 2/3 Hz or 25 kV, 50 Hz, this kind of power means considerable currents of ≈670 A (at 15 kV) and ≈400 A (at 25 kV), respectively.

1. REDUCTION OF WEAR

Power of this order is handled either with traditional compressed-air switches that mechanically extend the occurring electrical arcs, thus cooling them down until they break off, or with modern-type “vacuum switching tubes”, in which no significant arcs occur, and which therefore suffer significantly less wear.
To avoid unnecessary electrical arcs (= wear), both types of contact breaker need a spring function, or rather a defined acceleration curve, on both opening and closing. If one were to generate this dynamic movement directly, e.g. from the vehicle’s battery, this would mean an admittedly short but very intense current requirement.

Depending on the magnitude of the surge of current, this could damage the battery, and at any rate overload it, if its charge state is not optimal. The charge state of a battery depends on various factors, such as the surrounding temperature, the charge, the degree of permanent discharge and self-discharge, number of charge/discharge cycles hitherto, state of maintenance, etc. So right from the beginning of the electrification of rail vehicles, alternatives were looked for that could generate the opening/closing movement with energy that is not stored in the battery.
Because of the height of the voltage, which is always in the range above 60 V which is dangerous to persons, and because the insulation of the system plays just as important a role as the switching behaviour, fluid-dependent (hydraulic) systems were out of the question.

2. HIGH RELIABILITY

Early on, recourse was taken to pneumatic systems, as these offer a number of advantages. These are:

- → Good technical manageability
- → Reasonable price
- → Compactness
- → Ease of storage, and
- → Capability of delivering easily controlled spring energy

However, these systems cause problems in actual practice, e.g.:

- → Pollution of switches due to impurities (almost solved by filter systems)
- → System-immanent dependence on air pressure (solvable only in part, due to current altitude above sea level)
- → Cooling of the switches by fast airflow, associated with condensation on the switches and, depending on the temperature of the surroundings, a tendency for the systems to ice up, even at temperatures well above freezing point (only fixes, no solutions)

Up to now, problems of these kinds have been solved only with reservations, and in some cases the susceptibility has only been reduced.
Add to this the demand for a double, non-redundant energy supply concept. The reason for this is that, due to the requirement of fail-safe operation, a holding mechanism for the contact-breaker in the “On” position is needed that falls into the “Off” position, not only when definitely switched (as in pneumatic systems), but also when the power supply, e.g. the battery network, fails or a cable breaks.
In rail vehicles, pneumatic operation of the main electrical switch, which is immediately behind the pantograph as the connection to the power wire, has therefore become the tradition. The drive loads its return mechanism in the form of a spring accumulator at power-on time. The switch is held in the “On” position directly or indirectly by an electromagnet. The direct holding alternative does require more energy (from the battery, which is then charged from the mains), but it is significantly more reliable than the indirect alternative. Here, only the holding air pressure is maintained through an electromagnetic valve, which blows off when required; this valve is liable to ice up, and is then unable to release the air.

3. ROOM FOR IMPROVEMENTS

An improvement in the status quo can be achieved in principle through:

→ Use of a vacuum switching tube to reduce wear
→ Reduction of susceptibility to faults by supplying power from only one source (without further auxiliary actuators) with one main actuator
→ Very low energy consumption for switching on, so as to be ready for operation even when the vehicle's battery is low
→ The capability to switch On/Off repeatedly in quick succession
→ Loss-free storage of the necessary auxiliary energies, maintenance-free and over a prolonged period
→ Storage of the switch-off energy when switching on
→ A holding mechanism that leaves the "On" status when the supply of energy for holding is switched off or fails (fail-safe principle)
→ Minimisation of routine maintenance

In recent years, alternative solutions have been presented at the relevant trade fairs. Some of these appear not to have reached series-production status; others seem to have been developed for the internal use of a system manufacturer; and yet others do not fulfil all the demands on an alternative actuator because an active pulse is required to switch off, or an electrical energy store (condenser) must be actively used.

4. VACUUM SWITCHING TUBES

The above-mentioned demands are met by the CVB vacuum switching tube (Figure 1), an alternative actuator concept developed by the Schaltbau company. How does this unit work, and how is it capable of fulfilling all the listed requirements?

1. On commissioning, an electric motor winds up a mechanical spring accumulator, locking it just short of the tipping point.
2. The unit can remain in this position for any length of time without any kind of power supply.
3. A short, weak power pulse drives the electric motor past the tipping point of the spring accumulator, which can then discharge its energy via a free-wheel coupling.
4. With this spring energy, the switching tube is closed in a precisely defined movement via a cam disc, and the return spring is loaded. An electromagnet holds the switch in this position with a very low energy consumption. Immediately after switching on, and independent of all other states (unit remains switched on, or switches off immediately because of a short-circuit), the spring accumulator is loaded again within about 4 seconds.
5. If the energy supply of the holding magnet is switched off, or if it fails for some other reason, the return springs open the switch very quickly (typically in 40 ms, at maximum in 60 ms). The vehicle controls can thus use the switch as a genuine load isolator, should excess current be detected. Because the energy accumulator for switch-on operation has been loaded after the previous switch-on, the switch is ready for the next switch-on operation immediately.

All of this means that there is a fundamental difference that is relevant to actual practice: pneumatic systems can store the energy for several on/off switching operations in very quick succession, and are therefore ready for the next attempt at once. By contrast, a spring storage system such as the one presented by Schaltbau takes at least 3 – 4 seconds between the first and second switch-on attempts (though switching off is possible at any time, because of the return springs), because the spring accumulator has to be loaded first.
What at first sight appears to be a disadvantage is advantageous for the lifetime of the system, and is thus a positive characteristic in actual practice. Each switch-off operation stresses an electromagnetic switch (even a vacuum switch). For this reason, several seconds should be allowed to elapse between two full-load switch-off operations (e.g. because of a short-circuit) to let the switching element cool down. Furthermore, there are only two real reasons for the failure of a switch-on operation:

- → There is a genuine short-circuit that cannot be rectified. Repeated switch-on operations on this short-circuit will also fail.
- → There are different energy accumulators at the input to the system (e.g. condensers) that can cause a short-circuit on switching on if the pre-charge circuit is not working properly. This means that switching on may well be successful after a short wait.

This means that the wait between two successive switch-on operations is an advantage, in that it reduces wear and prolongs the lifetime of this kind of component.
So we have here a circuit breaker with fail-safe and load-isolation functions that avoids all the serious drawbacks of pneumatic actuators and meets all the positive requirements on such components.

5. MAINTENANCE EFFORT

Finally, this technically advanced system must be subjected to economic considerations. It must be taken into account that the operators and the system manufacturers regard the cost situation from different standpoints.
New vehicles and reconditioning services are offered by specialised railway works and system manufacturers, and bought by the operator's system purchasing department. The latter consider a vehicle for only a very short part of its lifetime: the construction, commissioning, warranty and possibly life-cycle cost (LCC) phases, and the penalty period. For system manufacturers, by contrast, the price of the components is the determining factor.
For operators, the LCC is decisive. Reductions in costs for routine maintenance and overhauls can compensate for a higher purchase price in a short time, and generate lower overall costs when viewed across the life-cycle.
In the type inspections carried out on vacuum circuit breakers and competitors' pneumatically actuated units it was ascertained that, in the course of the lifetime test under the relevant regulations (200,000 switching cycles, including equivalent power cut-offs), pneumatically actuated units required a significantly greater maintenance effort, whereas the CVB vacuum circuit breaker needed no maintenance, not even the usual greasing.
This maintenance-friendly design is complemented by a system for automatic compensation of contact erosion (wear on the vacuum tube) that allows operation

without adjustments, so that the maintenance costs will be significantly less than for competitors' models, as experience has shown.
The CVB vacuum circuit breaker is equipped with a diagnostic system that acquires and stores the most important operating data and error messages. The data can be read out for evaluation via USB connection. This unit is thus a technical evolution at market prices with significantly reduced life-cycle costs.

6. CONCLUSION

The field tests that are at present in progress and will be concluded shortly corroborate these statements. CVB vacuum circuit breakers have been in failure-free use with the Central German Railway Company, MEG (15 kV version) and the Hungarian State Railways, MAV (25 kV version) for a year, and have proved their practical suitability and reliability. To round off the field tests, there are two further CVB vacuum switches in use in Russia. For this purpose, the CVBs were qualified for a temperature range down to -50°C, their functionality being certified in a test laboratory in Prague.

7. SUMMARY

Electrically activated spring-loaded vacuum circuit breaker

The field tests, which are currently running, and are due to be completed soon, have confirmed claims that were made beforehand regarding CVB-type vacuum circuit breakers. These have been operating fault-free on the Mitteldeutsche Eisenbahngesellschaft (MEG, 15kV version) and the Hungarian State Railway (MAV, 25kV version), and their suitability for use in practice and their reliability have been documented in both locations. In order to round off the field tests, two further CVBs have been undergoing testing in Russia since September 2009. Beforehand, these "circuit vacuum breakers" were found to qualify for use within a temperature range down to -50°, and their correct functioning was documented in a test laboratory in Praha (Prague).

CVB vacuum circuit breaker by the
Schaltbau company