AN ASYMMETRICAL MAGNETIC ACTUATOR FOR M.V. CIRCUIT-BREAKERS

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0. SYNOPSIS

Keywords : magnetic, actuator, low energy tripping, reliability, communication

In the recent past, magnetic actuators have been introduced in the switchgear technology. In particular, some manufacturers propose reclosers fitted with this kind of drive, and more recently, substation circuit-breakers have been presented. The advantages of magnetic actuators are obvious, and have already been described : simple system, very few moving parts, direct link between tripping order and moving contact. Meanwhile, classical magnetic actuators present some disadvantages which are not important for reclosers, but can be of great importance for substation circuit-breakers. Classical magnetic actuator require a high energy pulse for closing and for opening, that means that a powerful battery and/or a capacitor is requested for both operations. In the asymmetrical magnetic actuator described in this paper, the total energy for closing and opening is stored in the system just before closing. So, a low energy pulse can be sufficient to get the circuit-breaker open. Besides, through the asymmetrical drive, the circuit-breaker can always open, even when the local auxiliary supply is shut down, what is essential for security. Thanks to this system, a local manual opening operation is easy to include, as well as a minimum voltage release coil, or a self powered protection feature. The asymmetrical actuator enables a step further in the circuit-breaker technology, including a higher reliability and a higher security, as well as new communication possibilities.

1. INTRODUCTION

The switching technology of medium voltage circuit breakers have seen constant improvements.

The vacuum switching technology has now been perfectly mastered. Its excellent performance has been made possible thanks to a better understanding of vacuum switching and the development of new contact materials, particularly copper-chrome contacts. [1]

All vacuum circuit-breakers are currently equipped with conventional spring mechanisms, the basic workings of which have remained unchanged for several decades.

Manufacturers are now working to take one step further by developing a simpler, lower cost mechanism, particularly for the vacuum interrupter operation, which is characterised by low mass movement, small contact travel and the need to ensure a significant level of pressure of the contacts. Many producers see the electromagnetic actuator as the ideal replacement for the spring mechanism. [2] [3]

Why now ?
The materials used for permanent magnets have evolved greatly in recent years. The price of rare earth magnets, in particular, has fallen considerably thanks to improved manufacturing technologies. Furthermore, modern calculation methods mean that the dimensions of magnetic circuits can now be optimised without the need to develop numerous prototypes.

ALSTOM T&D – EIB S.A. has recently taken decisive step forward with the development of a system which allows for the circuit breaker to open with a very low level of electrical or mechanical energy.

The principle of the magnet actuator is not new. It has been used for many years in the operation of vacuum contactors. Magnet actuators are chiefly characterised by their simple construction and the greater number of operations possible in comparison with spring mechanisms.

ALSTOM T&D – EIB S.A. has carried out in-depth research into a low-cost, reliable magnetic actuator perfectly adapted to the operation of medium voltage circuit breakers. This article looks into the main features of this actuator, but we can already mention the main advantages.

The significant reduction in the actuator's parts has a direct effect on production costs, while savings are also made on the cost of use given that no maintenance is required. The number of moving parts, moreover, is kept to the bare minimum. Due to the axisymmetrical design, all the internal parts are well protected against the environment.

The absence of a charging motor eliminates the effects of peak demands when switching on, which means that the size of the back-up battery can be kept to a minimum. Moreover, it is perfectly feasible to charge manually.

All the operations remain comparable to those of a spring mechanism. The possibility to open manually remains highly simple, regardless of the circumstances in which it is used. It is also still possible to open even when the main capacitor is not charged. The opening circuit is traditional, so it is still possible to check the continuity of this circuit. Moreover, this actuator can be used on a circuit breaker with a self-powered protection device.

2. DESCRIPTION OF THE ALSTOM T&D – EIB S.A. VACUUM CIRCUIT-BREAKER WITH MAGNETIC ACTUATOR TYPE AMD

2.1 Functionalities

The magnetic actuator type AMD is intended to operate vacuum circuit-breakers.

The actuator has been developed to fulfil the same functions as a conventional spring charged mechanism, that is :

Accumulation of energy for a CO cycle :
- either manual local
- or electrical from an auxiliary voltage supply (automatic after a closing)

Closing operation :
- either manual local
- or by voltage emission from an auxiliary voltage supply (shunt closing release) with anti-pumping

Opening operation :
- either by voltage emission from an auxiliary voltage supply (shunt opening release)
- or manual local with push-button
- or by under voltage release from a reference voltage source with the possibility of adjustable time delay
- or by current emission (series release) from current transformers
- or by self-powered protection (capacitor discharge) from low energy current transformer and self-powered relay

2.2 Operation principle

2.2.1 Magnetic actuator

The magnetic actuator consists in an electromagnet with one coil to control the closing operation and two coils to control the opening operation.
The magnetic circuit of the actuator shows an axisymmetrical geometry.
It includes :
- an external fixed part, consisting in a flow head and an 0 upper cover;
- an internal moving core, mechanically coupled to the rod that actuates the moving contacts of the vacuum interrupters through the transmission;
- a second internal moving part, not coupled to the rod that actuates the moving contacts, called magnetic shunt;
- a compressed spring tends to move it, but it is latched in its position by a conventional mechanical latch. Due to this second internal moving part, the actuator has an asymmetrical design.

Open position (Fig. 1). In open position, the moving core is maintained in its lower stable position, corresponding to the position « open interrupters », by the magnetic force of the permanent magnets, and by the residual mechanical force (pre-strength) of the opening springs, that is without electrical consumption.

Energy accumulation for a closing. The energy for a closing of the breaker is stored in a capacitor. The charge is controlled electronically. The capacitor charge is possible whatever the position of the breaker is.

Closing operation. The manual or electrical closing command allows the discharge of the capacitor in the closing coil of the electromagnet. This discharge modifies the magnetic flow in the magnetic circuit, and the resulting flow induces a force that tends to move the core upwards. During its stroke upwards, the core drives along the closing of the vacuum interrupters contacts and next the compression of the pressure springs. Simultaneously, it charges the opening springs that store part of the energy necessary for the opening.
The transmission is featured by a varying ratio that allows the shape of the driving force to fit in an optimal manner the shape of the resistive force.

Closed position (Fig. 2). The moving core is maintained in its upper stable position **-** corresponding to the position : interrupters closed, pressure springs charged, and opening springs charged **-**, by the magnetic force of the permanent magnets, that is without electrical consumption.

Opening operation. The energy for opening is stored in both the opening springs and pressure springs that were charged at closing.
The opening is caused by modifying the flow generated by the permanent magnets : the resulting magnetic force on the core then becomes lower than the force of the pressure and opening springs that pull the moving core downwards, what leads to the opening of the breaker.
There are two ways to modify the magnetic flow due to the permanent magnets and cause the opening :
- the first one consists in injecting a current in one of the opening coils of the electromagnet;
- the second one consists in actuating the mechanical latch to release the magnetic shunt, the movement of which then modifies the magnetic circuit (Fig. 3).

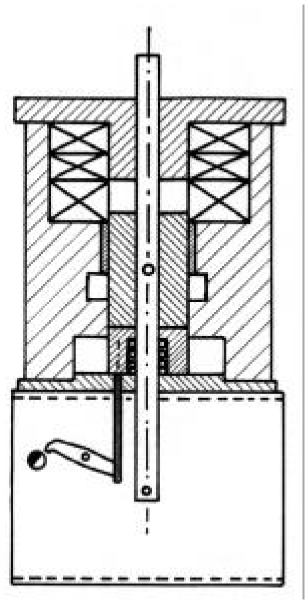

Fig 1 - Circuit-breaker open

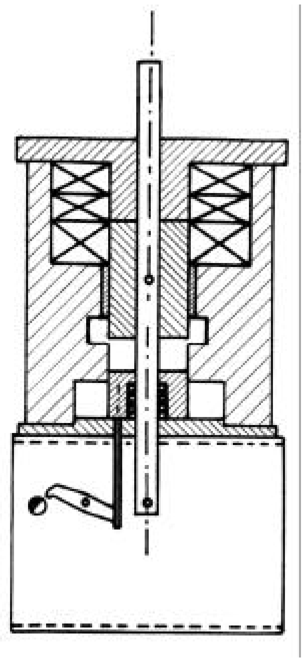

Fig 2 - Circuit-breaker closed

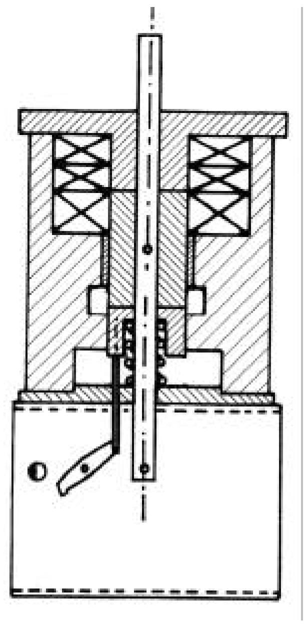

Fig 3 - Circuit-breaker closed with shunt up

2.2.2 Control of the operations of the actuator

The functions related to closing, that is the storage of energy and the closing command, are ensured by an electronic device with microprocessor. This device requires a power supply, either auxiliary, or emergency.

It controls the charging of the capacitor at the voltage value specified to ensure closing.
The normal way is to charge from an auxiliary voltage supply. The charge duration is less than 15 s.
Note : the power required is regulated, what avoids every over-design of the battery, necessary for example in the case of a motor-driven spring mechanisms during motor starting.

The second way is to charge from an emergency supply. In this emergency case, it is possible to use :
- either an accumulator or batteries
- or a manual generator (dynamo), for a manual operation.

Besides, it also indicates when the breaker is ready to close.

It controls the execution of a closing command by allowing the discharge of the capacitor in the closing coil of the electromagnet :
- either from a voltage impulse (shunt closing release)
- or from a push-button (local manual closing)

Besides, it latches the execution of a closing command when some conditions are not fulfilled :
- the capacitor voltage must be sufficient
- the circuit-breaker must be open
- the former closing sequence must be over (anti-pumping)
- the input signal « closing allowed » must be active (in case of fitting with under-voltage release)

The supply of the microprocessor electronic device is done through one of the supplies (auxiliary or emergency) used for the capacitor charging. However, the execution of a closing command remains possible 200 seconds after the loss of auxiliary supply, or after manual charging when there is no auxiliary supply.

Except for the control of the opening by under voltage release, all the types of opening control are made in a conventional way (mechanical or electrical), without using electronics :
- the voltage emission control (shunt opening release) is made by applying a voltage impulse through a single rectifier to one of the opening coils of the actuator electromagnet.
- the other types of opening control use the mechanical latch that release the magnetic shunt :
  * manual opening with a push-button
  * current emission opening with a conventional series release
  * self-powered protection opening with a striker supplied by the discharge of the capacitor of a self-powered relay.

The control of the opening by under voltage release, optional, is made with a second optional microprocessor electronic device that controls the discharge of a capacitor also in a striker which actuates the mechanical latch to release the magnetic shunt, when the reference voltage goes down.

The figure 4 shows the different ways to control the actuator.

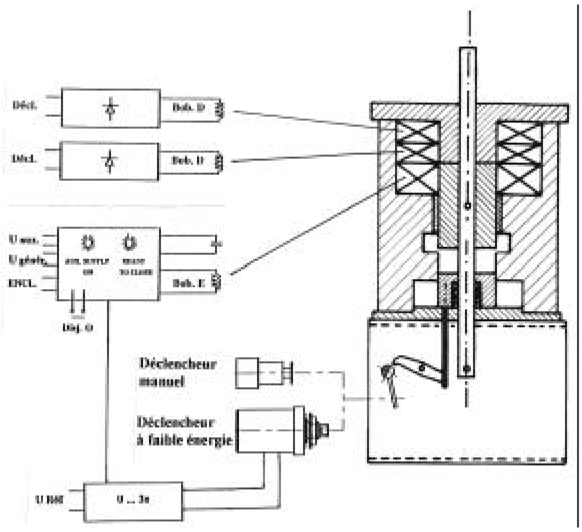

Fig 4 - Ways of actuator control

Fig 5 - Vacuum CB with magnetic actuator and self protection

Thanks to the opening energy storage in springs, the opening is possible even when the main capacitor is discharged. That point is essential for the safety.
Besides, thanks to the opening mechanical latch, the opening is always possible, even without auxiliary voltage supply. It is effectively possible to use a manual push-button for emergency trip, or to use the striker by the way of self-powered protection.
By comparison with some other actuators, these characteristics of this asymmetrical actuator offer important advantages for the operator and improve the safety.

3. COMPARISON BETWEEN A CONVENTIONAL SPRING DRIVE AND A MAGNETIC ACTUATOR

After this magnetic actuator principle explanation, it can be interesting to compare, for each function of a circuit-breaker, how an usual spring mechanism works and how a magnetic actuator works.

Function	Spring mechanism	Magnetic actuator
Electrical charging	Power supply + motor	Power supply + charger
Manual charging	Manual charging lever	Dynamo or accumulator + charger
Storage of the energy for CO operation	Spring	Capacitor + spring
Transmission of energy	Lever cam system	Magnetic circuit + variable transmission
Electrical closing	Closing coil + mechanical lock	Electronic circuit + closing coil + magnetic lock
Manual closing	Mechanical button and lock	Electrical push button + closing coil + magnetic lock
Electrical opening	Opening coil + mechanical opening lock	Opening coil + magnetic opening lock
Manual opening	Manual button of the opening lock	Manual push-button + mechanical lock
Self-powered low energy tripping	Striker + mechanical lock	Striker + mechanical lock
Main contacts position holding	Mechanical latches	Magnetic latches
Interlocking	Mechanical lever	Electronic circuit
Main contacts optical signalling	Mechanical indicator	Mechanical indicator
Main contacts electrical signalling	Auxiliary switch	Auxiliary switch
Operations counter	Mechanical	Mechanical
Anti-pumping	Relay	Electronic circuit
Minimum voltage release	Electro mechanical + mechanical lock	Electronic circuit + mechanical lock

For the operator, all the operations are possible and similar with the actuator as with a spring mechanism.

4. IMPORTANT FEATURES RELATED TO MAGNETIC ACTUATOR

4.1 Rare earth magnets

During the last 20 years, considerable progress have been done related to the development and the manufacture of rare earth magnets. They present the advantage to have an energy density unit about 4 to 8 times higher than ferrite magnets or alnico magnets.

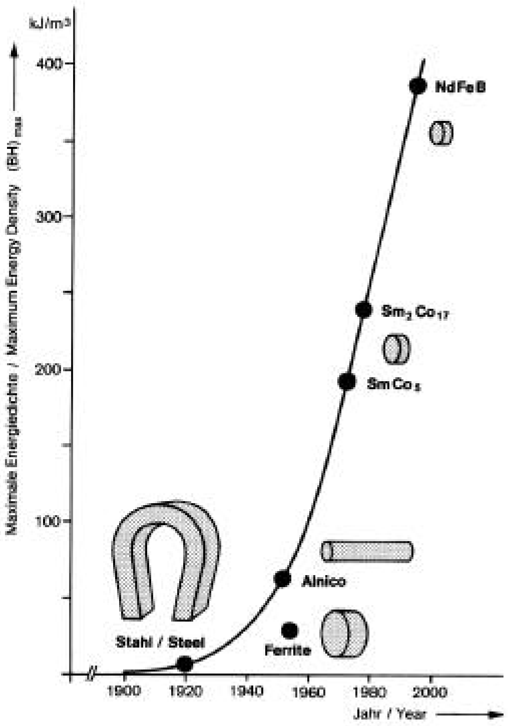

Fig 6 - Development of energy densities in the coursof the 20th century

It is therefore possible to considerably reduce the necessary volume to obtain the required magnetic characteristics. In the case of a vacuum circuit breaker, an important characteristic is the high force required to press the main contacts together, to prevent a separation during short-circuit.

The magnets type NdFeB are particularly interesting, in a technical and economical point of view. They offer the highest energy density and in the same time, they offer excellent magnetical and mechanical properties. They can be protected against corrosion and are time-stable. They are submitted to irreversible losses only with temperatures higher than 120 °C. They are protected against an accidental demagnetising by a very high coercivity.

With such advantages, they are used in many applications : electrotechnics (motors), automotive industry (ABS, airbags), informatics and electronics (hard disk drive for example).

4.2 Electronic device

The electronic device in the circuit-breaker with magnetic actuator fulfils the functions related to closing operation, that is energy storage, execution of a closing order and signalling "ready to close".
At power on or after a closing operation, the capacitor is charged at nominal voltage in 7s approximately. Capacitor is kept charged until next closing.
When the electronic device receives a closing order, the capacitor is discharged in the coil and the main contacts close. These conditions are not severe for a capacitor as permanent current is nearly zero, discharge peak current is about 40 amps and equivalent series resistance is not critical. Therefore, lifetime is more than 30 years at maximum temperature.

An important reason to introduce electronics is the reduction of the global cost of a system during its lifetime for a defined level of reliability. The global availability of the system is improved because an eventual problem can be detected before and not after operation. And that, without need of preventive maintenance.

The integration of several functions in a single unit which were previously provided by spared dedicated units is also an advantage. This increases the operational safety and reduces the costs. A single unit allows to diagnose the complete logic of the CB from the sensors related to energy storage, input/output data and operations them selves. And that, without difficult communications between separated equipments.

Finally, the use of electronics allows to reduce the number of options necessary to satisfy the requirements. In consequence, the required stock of options can be reduced, and some optional choices can be managed only by parameters modifications.

4.3 Design calculation

The development and design of this actuator is the result of intensive research. Different calculation methods, related to electro-magnetical and mechanical phenomena simulation have been largely used. Magnetic circuit design, permanent magnets dimensions choice, coils characteristics : many parameters necessary to be controlled to reach the desired global behaviour were optimised.
The magnetic actuator has this advantage too : it is completely calculable. That allows to optimise each individual parameter without many expensive prototypes. Furthermore, the coupling between actuator and vacuum circuit-breaker can also be simulated to reach the speeds, the forces and the other physical values required.

The quality of the models obtained during this development allows today to calculate quickly and precisely all the adaptations required by the circuit-breaker designer.
The use of models allowed to a better comprehension of phenomena appearing during operations. This way, important efforts have been made to reduce the required energy. And the cost of an actuator is very dependent on the energy it can supply.

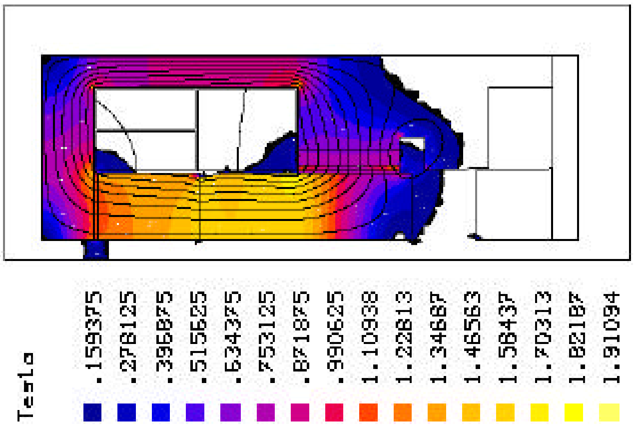

Fig 7 - Example of flux density calculation in magnet actuator

5. SIGNIFICANT TESTS PERFORMED ON CB

A complete type test certificate has been performed in the KEMA Laboratory on a vacuum circuit-breaker type VBL 800A / 17.5kV / 25 kA.
The magnetic actuator behaviour has been totally satisfactory. Particularly, the peak and short-time current did not lead to opening by magnetic unlatching due to either vibrations or magnetic field proximity.
The electronic control device has not been influenced by the short-circuit current effect.
During a closing operation on short-circuit, the capacitor energy was sufficient to close fully and latch. During an opening on short-circuit, the force in the spring is sufficient to break an eventual welding.

Different cycles of mechanical endurance tests have been also performed, which confirm the reliability of this magnetic actuator, and of its electronic control device.
EMC tests, in accordance with UNIPEDE specification 230.05 have also been performed to check the system immunity.

6. CONCLUSIONS

The vacuum circuit-breaker with its asymmetrical magnetic actuator presented in this paper offers many interesting characteristics and advantages. The magnetic actuator is particularly adapted to the operation of vacuum circuit-breaker, and this principle appears now as an ideal successor of the conventional spring mechanism.
For the user, the circuit-breaker above-mentioned offers all the usual possibilities.
The closing and opening operations are easily performed.
Particularly, manual emergency opening with a push-button or, self powered low energy tripping are always possible.

7. ACKNOWLEDGMENTS

The researches of EIB, in relation with the University of Liège, are financially supported by the Walloon Region Ministery.

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