Design and research of a new type of electromagnetic vacuum circuit breaker

Lili Xu [1,a], Yuting Yu [1,b,*], Chunmian Chen [1,c]

[1] Hunan Railway Professional Technology College, Zhuzhou, China;

[a] 327314381@qq.com, [b] 643515608@qq.com, [c] 38742832@qq.com

Abstract. The vacuum circuit breaker is the main switch of electric locomotive, controlling the on and off of the main circuit of electric locomotive. Existing vacuum circuit breaker of electric locomotives generally the air-driven, electromagnetic retention, this vacuum circuit breaker structure is simple and stable performance is high, but large mass, high air tightness requirements, the shortcomings of the noise. The design of this design according to the actual situation of electric locomotives, the design of a vacuum circuit breaker does not require compressed air drive, electronic control of mechanical manipulation mode of the circuit breaker, the new vacuum circuit breaker using electromagnet drive device to realize the vacuum circuit breaker opening and closing operation, while increasing the energy storage device for the vacuum circuit breaker closing operation to provide the necessary energy. This new type of electromagnetic vacuum circuit breaker has the characteristics of small size, simple structure, low cost and high reliability performance.

Keywords: Circuit breaker; Solenoid driver; Energy storage device.

1. Introduction

The low-voltage control part of the main type vacuum circuit breaker of electric locomotive adopts the principle of electropneumatic design, such as BVAC.N99 series vacuum circuit breaker. When the electric locomotive is in normal operation, it receives current from OCS through the pantograph, and the circuit breaker receives the instruction from the driver to make the connecting and disconnecting action quickly. When the electric locomotive has a short circuit, pantograph failure, short circuit grounding, the control circuit of the circuit breaker will be disconnected, thus cutting off the total power supply of the locomotive. With the high-speed development of rail transit vehicles, the degree of integration of vehicle high-voltage electrical appliances and the reliability of the product requires more and more high performance. Designed a small size, low cost, low noise, high reliability performance of the vacuum circuit breaker is research hot spot.

2. Proposed approach

At present, electric locomotives are mostly used in air-driven vacuum circuit breaker, in addition there are a small number of permanent magnet drive vacuum circuit breaker, permanent magnet vacuum circuit breaker adopts double-coil bistable structure, lossless precision electromagnetic components, such circuit breaker mechanism is simple, long-term action of the reliable and high, and the moving parts of the permanent magnet mechanism does not require mechanical release device, but the opening capacity is small, so the application of the railroad transportation equipment in the However, the opening capacity is small, so it is not much used in railway transportation equipment.

The last one is electromagnetic vacuum circuit breaker, Secheron, Alstom and other foreign companies are also being developed and gradually applied a railroad locomotive with electromagnetic vacuum circuit breaker. According to the different opening methods and characteristics of the three different driving methods of vacuum circuit breakers, the following comparisons are made.

Table 1. Comparison of the three drive types

Driving method	Characteristics	Applications
Air Drive	Reliable performance, mature technology, large size, high noise level	BVAC.N99 series
Electromagnetic drive	Simple structure and few parts	New type circuit breaker with large capacity
Permanent magnet drive	Lower magnetism, less suction force	Medium and low voltage power system

From the comparative analysis of the above table, the electromagnetic type drive is characterized by good closing performance and stable electromagnetic holding function. Therefore, the proposed circuit breaker in this paper will choose the electromagnetic holding type drive.

In addition to BVAC.N99 series vacuum circuit breakers, TDV10(01) series vacuum circuit breakers are also widely used in China's mainline high power electric locomotives, which have reliable operation performance. This kind of vacuum circuit breaker with the base plate as the boundary is divided into a high-voltage part above the base plate and a low-voltage part below the base plate. The two insulators of the high-voltage part with large electrical gaps are connected vertically, abandoning the right-angle connection of the high-voltage insulators of the BVAC.N99 series vacuum circuit breakers. The double insulators are connected vertically with higher strength and better reliability. Meanwhile, TDV10 series vacuum circuit breaker adopts Siemens vacuum switching tube with high reliability performance, which greatly improves the insulation performance of vacuum circuit breaker. In view of the good high-voltage performance of TDV10(01) vacuum circuit breaker, the high-voltage part of the new electromagnetic vacuum circuit breaker will be borrowed from the high-voltage part of TDV10(01) vacuum circuit breaker structure.

3. Proposed system design

The new electromagnetic vacuum circuit breaker is mainly composed of high-voltage part, electromagnet driving device, energy storage device and key parts of control unit. The high-voltage part is mainly composed of vacuum packages, insulators and other components to realize the opening and closing of the high-voltage part of the vacuum circuit breaker; the electromagnet driving device mainly realizes the driving function of the opening and closing operation of the vacuum circuit breaker; the energy storage device provides the necessary energy for the closing operation of the vacuum circuit breaker; and the control unit realizes the acceptance of the opening and closing manipulation instructions of the vacuum circuit breaker and the closing action control. The three-dimensional structure of the electromagnetic vacuum circuit breaker design is shown in Figure 1 below.

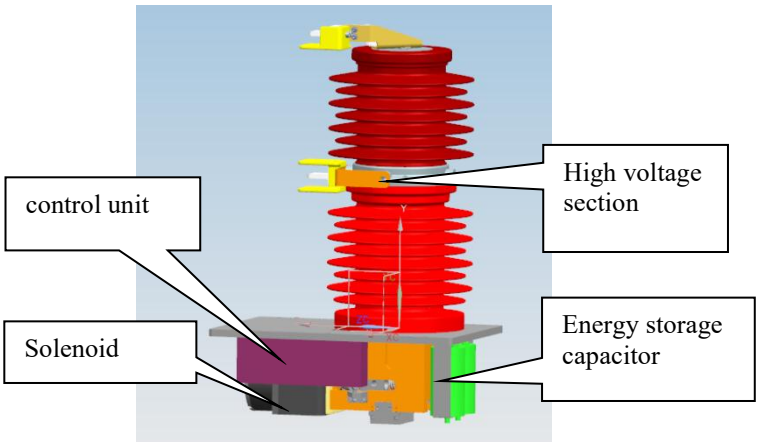


Fig. 1 Design of the proposed electromagnetic vacuum circuit breaker

The electromagnetic drive mechanism of the new vacuum circuit breaker (as shown in Fig. 2) mainly consists of closing solenoid 4, transmission mechanism 5, breaking spring 8, contact spring 9, cam 6, auxiliary interlocking 7, etc.[2], and there are also important supporting components such as control unit for controlling the opening and closing operation (as shown in Fig. 3), energy storage capacitor (as shown in Fig. 4), and so on.

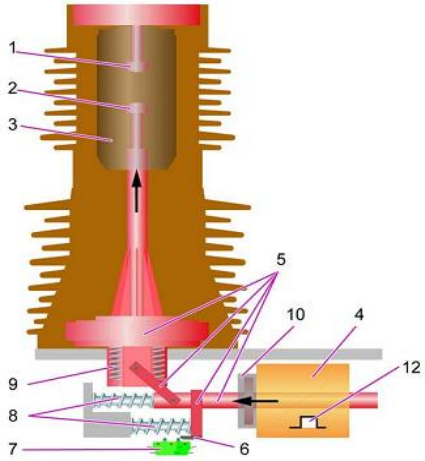


Figure 2 Structure of electromagnetic drive mechanism of electromagnetic vacuum circuit breaker

The new electromagnetic vacuum circuit breaker is characterized by the use of electromagnetic drive to replace the transmission of the pneumatic drive, the key components of the electromagnetic drive for the electromagnet device, compared with the traditional pneumatic drive has a simple structure, fewer parts and components, the advantages of high reliability performance[3].

3.1 Solenoid drive

The function of the solenoid device can be decomposed into closing drive and closing hold, when the solenoid device electromagnetic drive coil passes the closing current, the closing operation of the vacuum circuit breaker can be realized; when the movable and static contacts of the circuit breaker are in full contact, the control unit provides a certain delay effect to ensure that the circuit breaker is fully closed, and at the same time, it switches the closing circuit to the holding coil circuit, and the holding coil passes the smaller holding current to realize the closing and holding state of the vacuum circuit breaker [4]. The holding coil is energized with a smaller holding current to realize the closing and holding state of the vacuum circuit breaker [4].

When the solenoid coil passes the closing current and the control unit opens the holding circuit at the same time, the movable iron core travel 43.5mm direction in horizontal inside the solenoid under the action of electromagnetic force, and at the same time drives the movable contact connected to the movable iron core to complete the travel of 20mm in the vertical direction to realize the closing operation. When the movable and static contacts of the circuit breaker are in full contact and the closing process is completed, the control unit disconnects the driving circuit and the coil realizes the holding function under a smaller holding current.

The closing drive and closing hold functions of the electromagnetic drive can be realized by one coil or by two coils separately. As the closing drive force is as high as several thousand N, the closing coil needs a large number of excitation turns, and at the same time, it needs a large closing power, which requires a large current and small resistance of the driving coil [5]. In the process of closing and holding, the locomotive requires a smaller closing current to reduce line electromagnetic interference and coil heating, then the closing coil resistance is larger. Comprehensive analysis, a coil at the same time to achieve the closing drive and hold function, in the original closing coil current does not change the premise of difficult to achieve. Therefore, this program adopts the closing drive coil and holding coil to realize the driving and holding functions respectively.

The closing time of the electromagnetic drive device has a certain relationship with the current passing through the drive coil, and its closing speed can be adjusted according to the control voltage so as to meet the closing technical requirements of the supporting circuit breakers.

The closing speed of the electromagnetic drive device can be adjusted by the regulator body of the buffer end cover, so as to meet the technical requirements of the supporting circuit breaker.

Solenoid electromagnetic force and coil ampere-turns into a certain proportion, large ampere-turns require solenoid coil volume is too large, the overall volume and mass of the solenoid will be large. Comprehensive consideration of the coil drive current, the number of coil turns and electromagnet volume, the proposed development of the electromagnetic drive device shown in Figure 3:

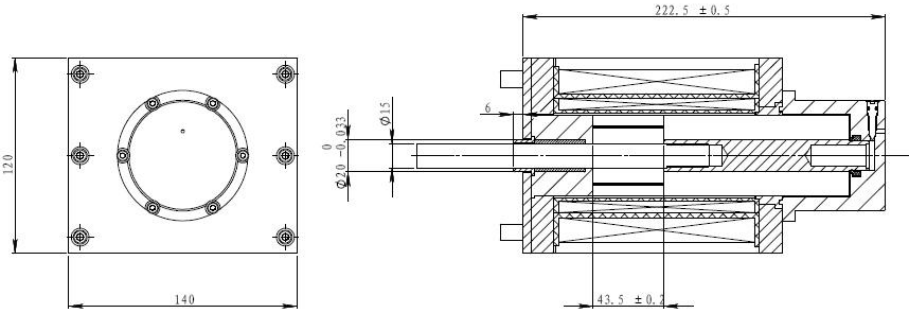


Fig. 3 2D structure of solenoid device

3.2 Energy storage devices

Solenoid device closing coil must reach a certain excitation ampere-turns, in order to meet the vacuum circuit breaker closing speed requirements. In a shorter period of time to obtain a large pulsating current, purely by the design of the power supply is not economical, and the power line is complex, bulky and the locomotive line does not allow. Therefore, the power supply must be improved from the efficiency of the comprehensive consideration.

In a shorter period of time to obtain a large pulsating current, there are two programs to choose from. One is the use of capacitors; the second is the use of batteries. Battery as a power supply needs to consider over-voltage, over-discharge and other issues, charging lines and protection circuits are more complex.

Considering the capacitors need to have a short charging time, can be used with filtered or non-filtered, regulated or unregulated DC output of any kind of conventional power supply device to charge it, do not have to consider the risk of overcharging; capacitor charging and discharging, the power cycle is unlimited; capacitors in the process of using the capacitors do not have chemical contamination or electrode oxidation problems, can withstand the test of the short-circuit, and can be discharged to any level will not be damaged; Capacitors can also be easily used in parallel [6]. Therefore, capacitors can be used for energy storage in electromagnetic drives.

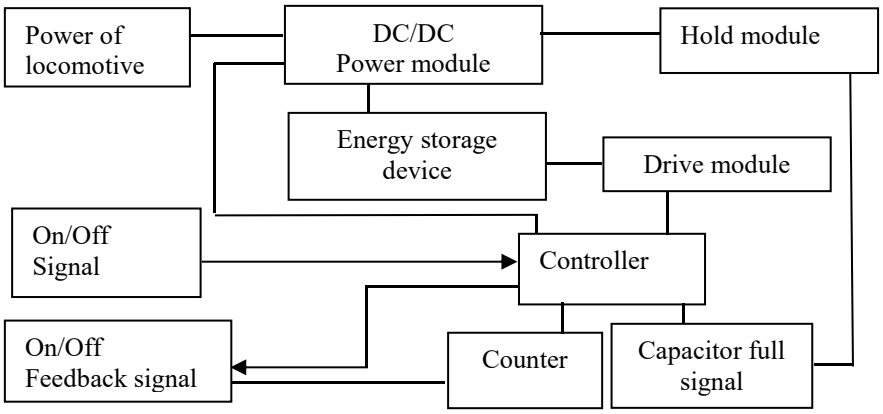
According to the mechanical power of the circuit breaker closing process, as well as the closing time to determine the capacity of the energy storage capacitor and the charging and discharging time of the capacitor, so as to select the appropriate capacitor to realize the vacuum circuit breaker closing operation.

3.3 Control Unit

Intelligent and highly reliable performance of the control circuit determines the accuracy and stability of the circuit breaker action. Therefore, in order to realize the control function of the new electromagnetic drive device, the intelligent control unit is mainly composed of power supply module, controller, drive module, holding module, energy storage device, counter module, etc. The schematic diagram of the structural principle is shown in Figure 4.

The power module provides charging power to the capacitor. The withstand voltage of the capacitor must be considered, as well as the power supply voltage required for the actual closing

operation. At the same time, the power module provides stable voltage for the controller and holding circuit.



The controller is mainly responsible for collecting the opening and closing signals of the circuit breaker, making judgments based on the signals, switching the opening and holding circuits to realize the opening, closing and holding functions, and controlling the charging and discharging time of the energy storage device.

The drive module realizes the closing drive function of the electromagnetic drive device.

The holding module realizes the closing holding function of the electromagnetic drive device.

The energy storage device is mainly used to provide the energy required for the closing drive of the drive coil.

Fig. 4 Principle diagram of the control unit

The counter module is mainly used to record the number of closing times of the electromagnetic drive device.

The control unit with this design idea eliminates the air storage cylinder, pressure regulating valve, pressure switch, air circuit and other components of the traditional pneumatic vacuum circuit breaker, reduces the volume of the low-voltage part of the vacuum circuit breaker, and removes the base plate of the vacuum circuit breaker from The existing 840mm×380mm is reduced to 550mm×380mm, which greatly reduces the cost of the vacuum circuit breaker and improves the reliability of the circuit breaker.

As shown in Figure 5, the control unit retains the counter, main break logic control and other functions of the transmission product, and also integrates functions such as capacitor energy indication, component working status display, and capacitor temperature adjustment.

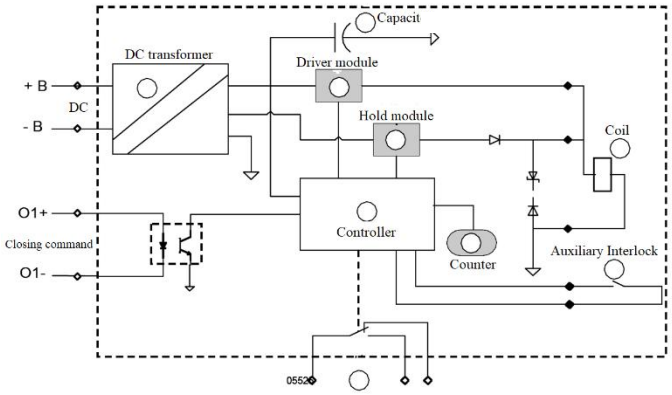


Fig.5 Schematic diagram of the new electromagnetic vacuum circuit breaker control unit

4. Design description

The developed vacuum circuit breaker electromagnetic drive device is intended to be used with TDV10(01) upright vacuum circuit breaker, and the technical parameters of the drive device shall

be based on TDV10(01) circuit breaker as the standard. Wherein the electromagnetic drive device stroke for TDV10 upright vacuum circuit breaker air drive device horizontal direction on the stroke; open and close time for the TDV10 circuit breaker technical parameters; in order to ensure that the development of the electromagnetic drive device to meet the TDV10 closing process of the driving force requirements, the early for the TDV10 (01) circuit breaker closing process to carry out a detailed analysis of the force, the preparation of the "TDV10 (01) upright vacuum circuit breaker," the "TDV10 (01) Upright Vacuum Circuit Breaker Counterforce Characteristic Analysis", and accurately calculate the maximum driving force of the electromagnetic driving device; in order to ensure that the energy stored in the energy storage device can meet the requirements of TDV10(01) circuit breaker closing, the maximum driving power is calculated according to the speed at the point of the maximum counterforce; the rated holding current, the rated holding force, and the maximum holding force are all referenced to the technical requirements of the TDV10(01) circuit breaker.

5. Summary

The rail transport industry is developing rapidly and the technology is changing day by day. This paper conforms to the market development, designed an electromagnetic vacuum circuit breaker. At present, the electromagnetic drive technology is advanced, mature and reliable, and the energy storage technology is also commonly used. The technical core of electromagnetic vacuum circuit breaker lies in electromagnetic drive technology, low voltage control technology and energy storage technology. The research content of this paper is summarised as follows:

(1) The structure and advantages and disadvantages of the current common main type circuit breaker are analysed, and the working mechanism of the electromagnetic circuit breaker is clarified.

(2) Propose the key technology of electromagnetic type vacuum circuit breaker, and design the electromagnetic circuit breaker which adopts electromagnetic driving device and has the function of energy storage device at the same time.

(3) Innovatively put forward the logical composition of the control unit of electromagnetic vacuum short circuit breaker.

References

[1] DIN EN 60077-1:2003 Railway applications-Electric equipment for rolling stock - Part 1: General service conditions and general rules (IEC 60077-1:1999, modified); German version EN 60077-1:2002.

[2] DIN EN 60077-2:2003 Railway applications-Electric equipment for rolling stock - Part 2: Electrotechnical components; General rules (IEC 60077-2:1999, modified); German version EN 60077-2:2002.

[3] DIN EN 60077-3:2003 Railway applications. Electric equipment for rolling stock. Part 3: Electrotechnical components Rules for DC circuit-breakers (IEC 60077-3:2001); German version EN 60077-3:2002.

[4] DIN EN 60077-4:2003 Railway applications - Electric equipment for rolling stock - Part 4: Electrotechnical components; Rules for AC circuit-breakers(IEC 60077-4:2003); German version EN 60077-4:2003.

[5] AI Shaogui, LI Xiuguan, DU Wei, et al. Study on high speed vacuum switch based on permanent magnetic repulsion mechanism[J]. High Voltage Apparatus, 2017 53(2)：54-60(in Chinese).

[6] ZHANG Licai, YANG Kun, LIU Zhiyuan, et al. Influence of design parameters on electro-magnetic repulsion mechanism performance [C]//2016 27th International Symposium on Discharges and Electrical Insulation in Vacuum. Suzhou: IEEE, 2016.

[7] SUN Liqiong, WANG Zhenxing, HE Sainan, et al. A permanent mag netic actuator with separated magnetic circuit for 126 kV vacuum circuit breakers[J]. Transactions of China Electrotechnical Society, 2015, 30(20): 49-56.

[8] HOU Yushan, SHI Zongqian, LI Sheng, et al. Co-simulation on the optimization design of high-speed electromagnetic repulsion mechanism of vacuum circuit breaker[C]//2016 27th International Symposium on Discharges and Electrical Insulation in Vacuum. Suzhou: IEEE, 016.

[9] ZHOU Xiaojiong, YAN Xianglian, LIU Beiyang, et al. Phase- coherent closure scheme of 10kV capacitor bank by fast-speed mechanical switchgear[J]. High Voltage Engineering, 2019, 45(2): 533-540(in Chinese).