# *Low-Voltage Air Circuit Breakers "World Super AE V Series C – class"*

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## 1. Introduction

More than 10 years have passed since Mitsubishi Electric Corporation released the Low-Voltage Air Circuit Breaker World Super AE Series (hereafter "AE-SW Series"), which are the existing models of our low-voltage air circuit breakers. During that period, rival companies in Europe improved their products' performance through model changes and also released low-end series to increase their product models targeting the middle- to low-end markets. In addition, in recent years, there are demands for compatibility with measuring and networks (e.g., centralized monitoring and control) due to increasing needs for saving energy and labor in buildings and production sites.

In response, we developed new models of the Low-Voltage Air Circuit Breaker World Super AE V Series C-class (hereafter "AE V Series C-class") (Fig. 1). These low-end models, which adopt remote closing operation as standard, are intended for markets such as commercial buildings, hotels, and condominiums overseas which used to be difficult for us to enter with our existing models.


Fig. 1 Low-voltage air circuit breaker "World Super AE V Series C-class"

In addition, new models have received the Winner of the 2021 R&D 100 Award from U.S. publication R&D World. The R&D 100 Awards program identifies and celebrates the top 100 revolutionary technologies of the past year.

This paper describes the main characteristics of the AE V Series C-class and the technological development of the electromagnetic solenoid-type closing mechanism, which is the first in the industry on low-voltage air circuit breakers,*[1] as well as an analysis technique that realized short-time withstand current performance.

## 2. Models and Characteristics of AE V Series C-class

### 2.1 Characteristics of AE V Series C-class

#### 2.1.1 Provision of remote closing operation as a standard function

There is strong demand for remote closing operation as a standard function on low-voltage air circuit

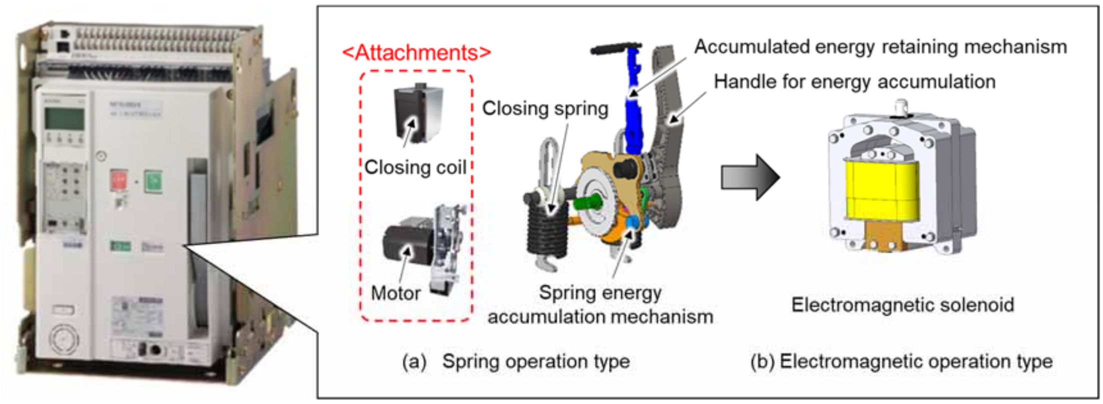


Fig. 2 Former and new remote closing operation mechanisms

[1] As of February 1, 2022, researched by Mitsubishi Electric Corporation

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breakers to be used on power receiving and distribution panels. For the existing models, in addition to a spring operation mechanism with a closing spring, spring energy accumulation and opening operation are separately required. For this purpose, as shown in Fig. 2, a motor for energy accumulation and a closing coil for opening are used as attachments. To provide remote closing operation as a standard function, it was necessary to combine the aforementioned functions including the spring operation mechanism into one component. Accordingly, we developed an operation mechanism involving an electromagnetic solenoid, which enabled remote closing operation to be provided as a standard function.

#### 2.1.2 User-friendly design

(1) Horizontal / vertical universal terminals

To cope with sudden changes to specifications of power receiving and distribution panels, we developed horizontal / vertical universal terminals structured so as to make it easy to switch main circuit connection terminals between the horizontal and vertical types.

(2) Easier installation of attachments (auxiliary switch (AX), shunt trip device (SHT), and under voltage trip device (UVT))

To save labor in the manufacturing of power receiving and distribution panels, attachments (AX, SHT, and UVT), which are often modified in low-voltage air circuit breakers, have been brought together in the upper section of the main body; the structure allows the cover of only the main body in the applicable section to be separately removed and installed.

#### 2.1.3 Reduction of power consumption and the number of parts requiring maintenance and inspections

The existing AE–SW Series has spring operation mechanisms with closing springs and therefore, before the closing operation, it is necessary to charge the closing spring with a motor (energy accumulation). In comparison, the AE V Series C-class models have electromagnetic solenoid-type operation mechanisms and so do not require charging, reducing power consumption. Furthermore, the new design used for the mechanism section reduces the interruption time during maintenance and inspection, and also the number of parts requiring maintenance and inspection.

## 3. Technical Characteristics of the AE V Series C-class Breakers

### 3.1 Development of the electromagnetic solenoid-type operation mechanism

In developing the electromagnetic solenoid-type operation mechanism, it was necessary to minimize the mechanical reaction force applied to the electromagnetic solenoid (optimizing the closing mechanism) and to increase its output. To do this, we developed a robust minimization technique to optimize the closing mechanism and a new structure to increase the output of the electromagnetic solenoids.

#### 3.1.1 Optimization of the closing mechanism

The closing mechanism was optimized by using a new particle swarm optimization (PSO) method. In this method, for the behavior and balance of forces of the mathematically modeled mechanism, function J, which evaluates the errors from the requirements shown in formula (1), is defined to automatically minimize them. In other words, the method automatically searches for the mechanism layout that matches the requirements. Because there are multiple requirement terms, evaluation function J becomes a multidimensional waveform as shown in Fig. 3. However, this method can search for a minimal solution for the whole instead of a

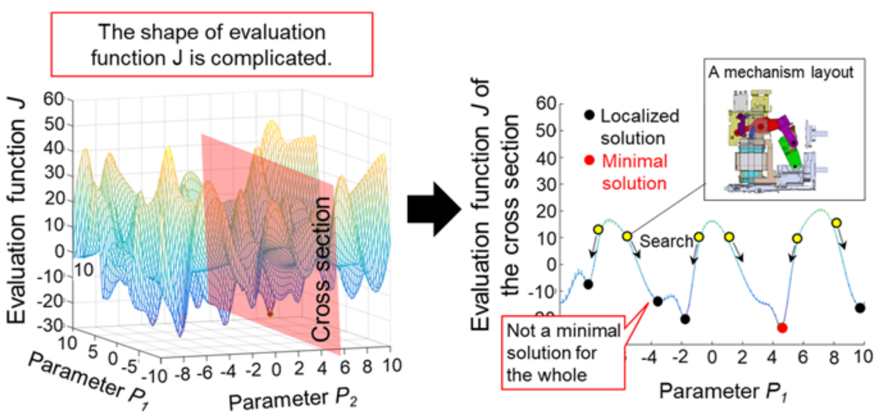


Fig. 3 Evaluation function

localized solution. In addition, evaluation function J includes a term for the mechanical reaction force that is applied to the electromagnetic solenoid; as a result, variations can be reduced including all the requirements compared to general methods.

$$J = \alpha_1(L_1 - L_{1\max})^2 + \alpha_2(L_2 - L_{2\max})^2 \cdots + \alpha_n \sum \left( \frac{\partial F}{\partial P_n} \right) \quad (1)$$

$\alpha_i$ : Weighting factor of each requirement parameter

$L_i$ : Design value of each requirement parameter

$L_{i\max}$ : Maximum value of each requirement parameter

F : Mechanical reaction force

$P_n$ : Location of each mechanism element

### 3.1.2 Increase in the output of electromagnetic solenoids

To increase the output of the electromagnetic solenoids, operation in the high coil current region is required. Figure 4 shows typical coil current waveforms. When an electromagnetic solenoid starts operating, the current decreases due to the counter electromotive force of the coil. For example, assuming that the operation start of an electromagnetic solenoid having fast initial motion is A, its operation completion is B, the operation start of an electromagnetic solenoid having slow initial motion is A', and its operation completion is B', then when the iron cores are not magnetically saturated, the output is roughly proportional to the square of the coil currents. Therefore, to increase the output, it is important to increase the current at the time of initial motion (initial motion current).

Figure 5 illustrates a general electromagnetic solenoid and the developed electromagnetic solenoid. A common feature is the tapered adsorption faces of the moving and fixed cores. Compared to flat adsorption faces, the tapered form reduces distance b between the moving and fixed cores, thus reducing the magnetic resistance. Accordingly, when the coil current is at a constant level, the output at the initial location can be increased. However, in this configuration, the coil current gradually increases as shown in Fig. 4, making the initial motion current lower in the case of the tapered form than the flat form.

To solve this problem, new projections have been provided between the moving and fixed cores. These give magnetic adsorptive power to the moving core at the initial location in the direction opposite to the output direction, which reduces the output and increases the initial motion current. After the moving core starts operating, the clearance between the projections expands, which increases the magnetic resistance and then the magnetic adsorptive power disappears, which increases the output. Figure 6 compares the output at the rated operation voltage of 110 VDC between a general solenoid and the developed solenoid. This structure increases the initial current to approximately 1.7 times (3.0 to 5.2 A), increasing the output by approximately 50% from that of general electromagnetic solenoids.

## 3.2 Analysis technique to realize short-time withstand current performance

### 3.2.1 Short-time withstand current performance

Short-time withstand current performance refers to the performance of stably passing a short-circuit current from when the short-circuit current occurs to when it is

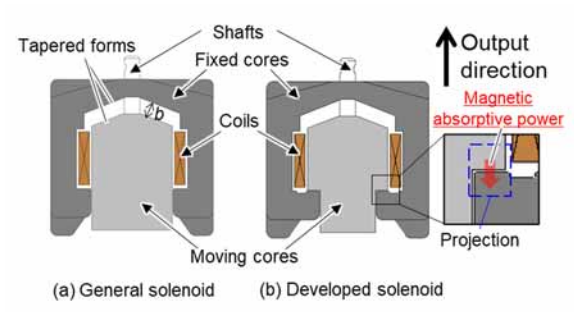


Fig. 5 Schematic diagrams of electromagnetic solenoids

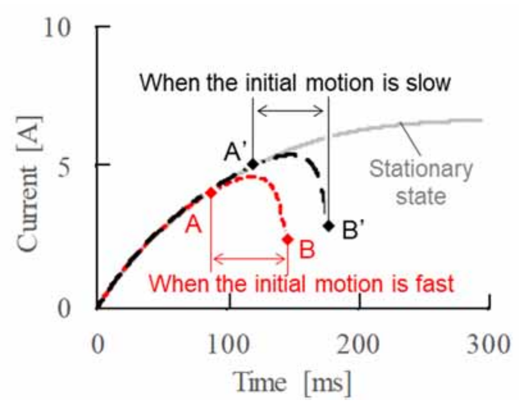


Fig. 4 Current waveforms of electromagnetic solenoid coils

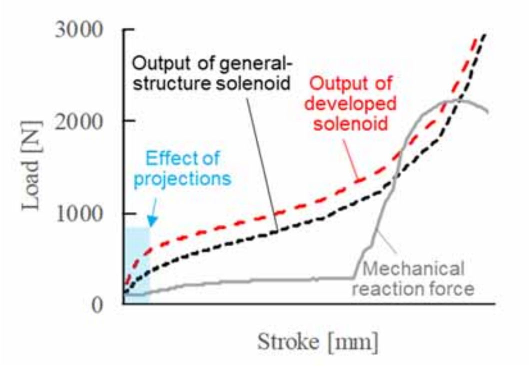


Fig. 6 Comparison of output of electromagnetic

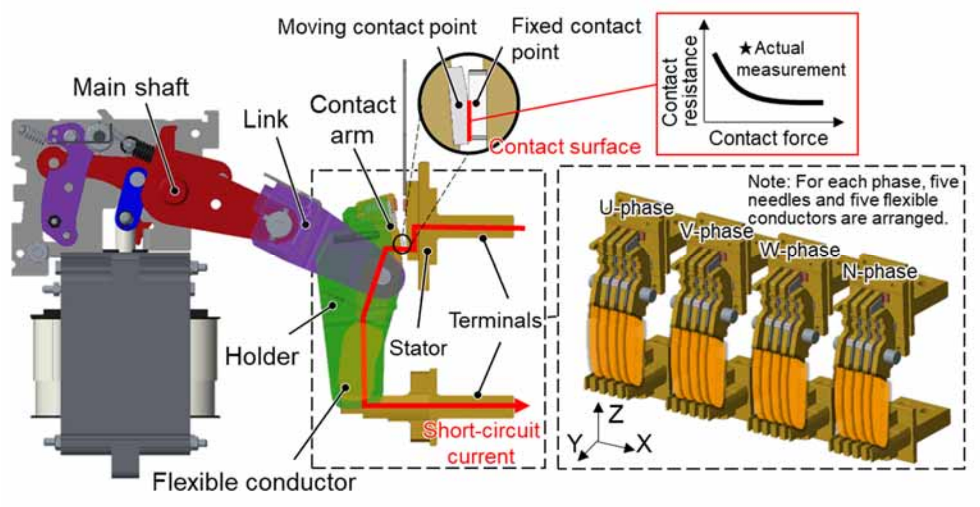


Fig. 7 Electromagnetic field analytical model

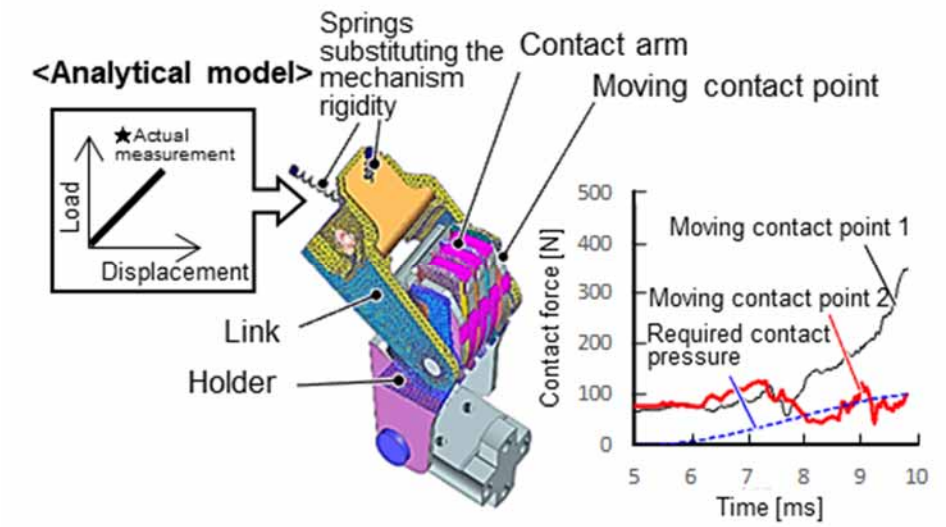


Fig. 8 Analytical model of mechanism

cut off by a breaker, etc. The AE V Series C-class models have a short-time withstand current performance of one second when the short-circuit current is 50 kArms. During this period, the Lorentz force of several hundred to several thousand N that is generated on the energized conductor needs to be controlled to prevent arc flashing caused by improper contact between the contact points, damage to resin parts due to stress concentration, and other factors.

To achieve this, electromagnetic field analysis and mechanism analysis were linked to quantify the behavior of parts when a short-circuit current was passed, and also the generated stress. By controlling these, the short-time withstand current performance was realized.

### 3.2.2 Electromagnetic field analytical model for short-time withstand currents

Electromagnetic field analysis software was used to quantify the Lorentz force when a short-circuit current was passed. Figure 7 shows the analytical model. A flexible conductor is joined to a contact arm; for each phase, five sets of them are arranged in series for each pole. As input conditions, the three-phase short-circuit current was set at 50 kArms considering the transient current. The distribution of the current (shunt) branched out to each flexible conductor was analyzed and time-series data on the Lorentz force generated in the X, Y, and Z directions was output. Each flexible conductor receives Lorentz force in the Y direction in the magnetic fields on the current paths at the terminal sections. In addition, for each flexible conductor, Lorentz force in the X direction (direction to attract each other) is generated by the branched shunt current. The magnetic fields of the short-circuit currents carried by the other phases also influence the Lorentz force in the X direction.

For this analysis, in order to analyze the distribution of the current in the flexible conductors accurately, the skin effect was considered and the contact resistance occurring on the contact surface between the moving and fixed contact points was measured and incorporated.

### 3.2.3 Analytical model of mechanism for short-time withstand currents

In the mechanism analysis, the time-series Lorentz force on each flexible conductor in the X, Y, and Z directions was input and the transitional elastic deformation of the parts and their transitional motion quantities were analyzed. Figure 8 illustrates the analytical model of the mechanism. Although the stator is not illustrated, it is completely restrained in the analysis. In this analytical model, in order to reduce the calculation cost, the mechanism parts including the main shaft were represented by springs, and actually measured values were incorporated as the spring constants.

This analysis can quantitatively evaluate the stress generated on the link and holder and also the time-series contact force between the moving and fixed contact points. Figure 8 also shows an example of analyzing a case in which arc flashing occurred between the contact points when an accident current was passed. As analysis conditions, the current was 50 kArms and the closing phase (V-phase) was zero degrees. Two moving contact points were extracted from the five points in the U-phase in which the arc flashing occurred and the time-series contact force was shown. The required contact pressure was calculated from the melting voltage and contact repulsive force as a threshold value in which when the contact force falls below the required contact pressure, the contact becomes poor. The analysis results show that at approximately 8 ms, the contact force of contact point 2 falls below the required contact pressure and the time matches that when arc flashing occurs on an actual device, confirming the appropriateness of the analysis results.

By using this analysis technique, it was possible to design taking into consideration the dimensional tolerance of each part and variations in assembly, and thus to establish the short-time withstand current performance quickly and secure high reliability.

## 4. Conclusion

This paper described the characteristics of the new models of our low-voltage air circuit breakers along with the technological development of their electromagnetic solenoid operation mechanism, as well as an analysis technique to realize the short-time withstand current performance. We will actively use the technology to increase the output of electromagnetic solenoids and the analysis technique for linking electromagnetic field analysis and mechanism analysis established in this development when developing new models in the future.