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Mitsubishi Electric

ADVANCE

Latest Factory Automation Products, Technologies, and Systems

MITSUBISHI ELECTRIC
Changes for the Better

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Latest Factory Automation Products, Technologies, and Systems

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CONTENTS

Precis

Mitsubishi Electric Corporation has been contributing to global manufacturing and working to be an “OnlyOne” FA supplier that satisfies customers by providing the e-F@ctory FA integrated solution, which is based on advanced technologies focusing on the highest quality. This issue introduces the latest FA technologies and systems that support e-F@ctory.

(1) “MELSERVO-J5 series” AC servo amplifier: The function for linking with solutions with the CC-Link IE TSN industrial network as the core has been remarkably improved. Basic performance and functions have also been enhanced to the highest levels in the industry.
(2) “HK series” servo motor with improved basic performance: This series is equipped with batteryless encoders, and the number of product types was greatly increased.
(3) Magnetic contactors with spring clamp terminals: The contactors eliminated the need for high skill level, as was required for conventional screwing—which is now made easy. And more-secure wiring is also now possible. In addition, the products eliminate concern that joints will become loose when they are used for an extended period of time, making it possible to reduce additional tightening in inspections.

Overview

Author: *Yoshikazu Miyata**

Mitsubishi Electric's Smart Manufacturing Initiatives

In FY2020, Mitsubishi Electric Corporation celebrated the 100th year since its foundation. By drawing on technologies that we have cultivated for many years, we have been working to create values in the four sectors: life (living); industry for producing the essentials; infrastructure that supports society; and mobility that connects these items, aiming to realize Society 5.0 and achieve the SDGs. Our FA Systems business helps customers to make their factories smarter (smart manufacturing) by providing products and services that combine FA and IT as "e–F@ctory" integrated solutions for industry.

The Japanese manufacturing industry has traditionally depended on human intuition and know-how of experienced workers. However, the working population is decreasing due to the declining birthrate and aging population, and so conventional manufacturing that depends on humans can no longer be relied upon. To cope with the changing business environment, manufacturers around the world have been making their factories smarter using the Internet of Things (IoT), including Japan's "Connected Industries."

The business environment is also becoming harsher due to the globalization of companies, fiercer competition among companies, and the unclear situation of global politics and economic situations. In response, value creation and quick decision-making through digital transformation (DX) are crucial. Furthermore, business models also need to be changed, for example, in addition to the conventional provision of products, it is now also necessary to provide services and solutions.

Mitsubishi Electric was a pioneer by proposing that manufacturing be changed by e–F@ctory in 2003, before the terms "IoT" and "DX" were even invented, and has been supporting smart manufacturing. In manufacturing-oriented Japan, to cope with the intensifying global competition and to provide both goods and solutions, it is important to embrace technologies, expertise and know-how acquired at actual manufacturing sites that are specific to Japan, unlike in Europe and the U.S. where IT and digital technologies are used as the main tools.

Going forward, e–F@ctory will encompass the latest IoT, AI, control, and communication technologies, in addition to information linkage between manufacturing sites and IT systems, and will combine expertise acquired at manufacturing sites, data technologies, and edge computing for smart manufacturing.

This special issue introduces edge computing, compact AI, and time sensitive networking (TSN) as examples of advanced technologies for realizing smart manufacturing, and our latest FA products and solutions incorporating these technologies.

For edge computing, the open software platform Edgecross that goes beyond the boundaries of companies and industries was adopted. The platform makes it easy to communicate with various units installed at manufacturing sites with different FA networks, realizing ecosystems that link with various types of software on the IT side.

Regarding compact AI, our AI technology "Maisart" was used to develop "Kotsumon," which is a system that automatically detects specific behavior from camera images to make operation analysis more efficient. We also have developed a testing technology that detects errors in equipment highly accurately to reduce equipment downtime.

Regarding TSN, we were one of the first companies in the world to apply TSN to industrial open networks*[1] and have contributed to the standardization of "CC-Link IE TSN" that combines FA and IT and high-speed and high-accuracy control, providing many related products.

This special issue also describes the creation of solutions using software and the application package product "iQ Monozukuri," which was developed using our manufacturing knowledge cultivated to date. iQ Monozukuri supports data analysis and equipment testing at manufacturing sites and makes it possible to introduce, expand, operate, and maintain systems efficiently.

We will keep taking the initiative toward smart manufacturing by advancing our e–F@ctory while placing priority on manufacturing sites at all times. We aim to attain Society 5.0 and the SDGs by providing products that help alleviate the labor shortage.

[1] As of November 27, 2018, according to our research

**Senior Vice President, Group President, Factory Automation Systems*

CC-Link IE TSN Compatible AC Servo Amplifier "MELSERVO-J5 Series"

Author: *Satoshi Ohdaira**

1. Introduction

AC servo systems are used for drive control of various types of industrial machines such as semiconductor manufacturing equipment, lithium-ion battery (LiB) manufacturing equipment, injection molding machines, food packaging machines, printing presses, conveying equipment, robots, and machine tools. Market needs have also been diversifying; high functionality, ease of use and maintenance, and energy saving are demanded in addition to higher performance and accuracy.

Mitsubishi Electric Corporation has developed the MELSERVO-J5 series of AC servo amplifiers (hereafter "MR-J5 series") to satisfy such diversifying requirements under the concept of "maximizing the performance of equipment and systems by total drive solutions," while ensuring heritage and compatibility with the widely acclaimed MELSERVO-J4 series of AC servo amplifiers (hereafter "MR-J4 series").

This paper describes the advantages of the MR-J5 series.

2. Dramatically Improved Fundamental Performance

2.1 Ultrahigh speed, high response, and high accuracy

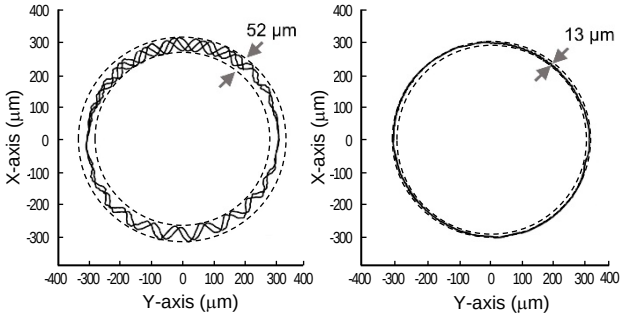
The MR-J5 series offer ultrahigh speed, high response, and high accuracy that are among the best in the industry. For this series, the dead time in various types of arithmetic processing was reduced by approximately 50% by adopting a special LSI featuring our proprietary high-speed servo architecture, reducing the computing time of encoders, and increasing the encoder communication speed. These improvements have increased the speed frequency response to 3.5 kHz from the conventional 2.5 kHz.

In addition, CC-Link IE TSN is supported as a method of communicating with controllers, achieving 1-Gbps full-duplex transmission which is eight times faster than before and a minimum communication cycle of 31.25 µs, reducing the system's command response time by approximately 70%. Transmission Control Protocol/Internet Protocol (TCP/IP) is supported for communications, greatly increasing suitability for the Internet of Things (IoT).

Furthermore, the corresponding HK series of servo motor have 67-million-pulse (67,108,864 p/r) batteryless absolute position encoders as standard equipment. The resolution of the HK series is 16 times that of the conventional HG series. Thus, the HK series are highly accurate and stable at low speed.

2.1.1 Improved trajectory trackability

Figure 1 illustrates the results of roundness measurement performed to verify the trajectory trackability as examples. In these measurements, two-axis ball screw equipment imitating an X-Y table was used at load, and circular interpolation drive was performed at constant speed. Variation in the trajectory tracking was reduced by up to 75% for the MR-J5 series compared to the MR-J4 series. This shows the effects of the higher gain (improved by approximately 40%) thanks to the reduced dead time in various mathematical operations and the shorter command communication cycle and encoder communication cycle time. These improvements in performance will help customers get the most out of their equipment and systems.



(a) MR-J4 series (b) MR-J5 series

Fig. 1 Roundness measurement results

2.2 Flexible combinations of servo motors

In the past, the combination of a servo amplifier and servo motor was limited depending on their capacity; for example, a 200-W servo amplifier was used to drive a 200-W servo motor. For the MR-J5 series, the current sensing circuit was reviewed to increase the current sensing resolution to approximately four times that of the conventional models, enabling flexible combinations. These flexible combinations make it possible to increase the maximum torque of servo motors (Fig. 2), thus reducing the cycle time of equipment. They also enable

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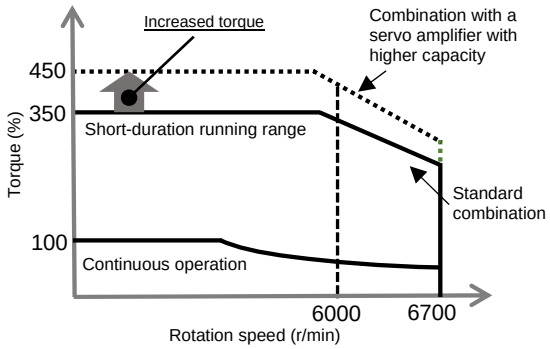


Fig. 2 Freedom of combination with servo motor

servo motors with different capacity to be driven by one servo amplifier, helping to reduce the number of maintenance parts.

3. Diagnostic Functions

3.1 Machine diagnosis

For industrial machinery involving a servo mechanism, ball screws, linear motion guides, bearings, guiding mechanisms, reduction gears, and belt driving mechanisms are often used as drive mechanisms. If an error occurs in these drive mechanisms, the functions and performance of the equipment deteriorate and the drive mechanisms become damaged and may malfunction. If an error occurs in the servo amplifiers due to an abnormality in the drive mechanisms, the error often cannot be reproduced, which makes it difficult to identify the cause of the error when analyzing the returned equipment. Therefore, Mitsubishi Electric has developed a machine diagnostic function that detects age-related deterioration of driving parts and that makes maintenance before breakdown (predictive maintenance) possible. Some of the MR-J4 series have ball screw diagnosis. The MR-J5 series have new belt and gear diagnosis in addition to more accurate ball screw diagnosis.

3.1.1 Ball screw diagnosis

The ball screw diagnostic function predicts failures in the ball screw mechanisms connected to servo motors. The ball screw diagnosis estimates the friction torque and vibrational amplitude based on the internal data (current and speed) of the servo amplifiers, predicts the service life from changes in the friction torque, and judges the service life from the vibrational amplitude. One problem with the ball screw diagnostic function of the MR-J4 series is that the friction torque estimation accuracy changes due to operation patterns. For the MR-J5 series, the estimation accuracy was improved and so this improved ball screw diagnosis is not affected by operation patterns of customers. For the MR-4 series, customers need to set judgment criteria, whereas for the MR-5 series, they are automatically set, which makes it easier to use (Fig. 3).

3.1.2 Belt diagnosis

The belt diagnostic function predicts a failure in the belt mechanisms connected to servo motors. Two types of belt diagnostic method were developed: static friction estimation and tension estimation. In the static friction estimation method, the internal data (current and speed) of the servo amplifiers is used to estimate the static friction and changes in the friction are used to estimate the decrease in belt tension. The judgment criterion for static friction can be automatically set, making it easier for customers to use. However, because only a static friction decrease is detected, the accuracy of detecting a decrease in belt tension is low and the function may misjudge elongation of the belt in the early stage as a failure. On the other hand, in the tension estimation method, the belt tension is directly estimated based on the internal data (current and speed) of the servo amplifiers and whether the tension has decreased is judged. Although customers need to enter a parameter for the relationship between the belt tension and static friction in advance, a decrease in belt tension can be detected highly accurately (Fig. 4).

3.1.3 Gear diagnosis

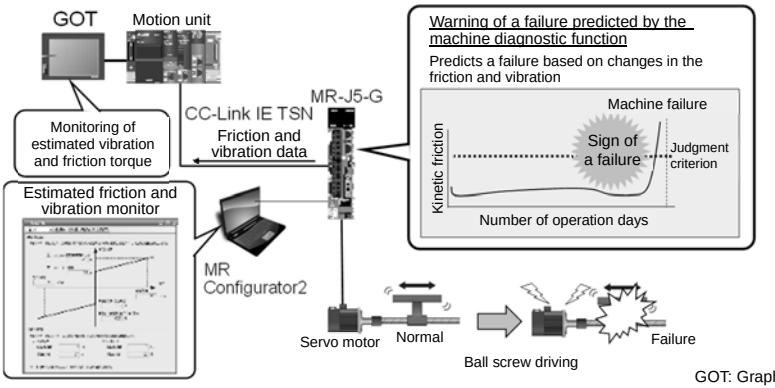
The gear diagnostic function predicts a failure in the gear mechanisms (e.g., reduction gears) connected to servo motors. In gear diagnosis, the backlash amounts of the gears are estimated based on the internal data (current and position) of the servo amplifiers in to-and-fro positioning operation and changes in the amounts are used to predict a failure (e.g., wear of the gears). A failure in the gears is judged by comparing the estimated backlash amount to the backlash amount (threshold) that the customer entered in advance as a parameter (Fig. 5).

3.2 Open-phase detection

If any of the phases of the main circuit power sources (L1/L2/L3) of servo amplifiers is interrupted, causing a large load on the motors, an error that is not directly related to the phase interruption may be issued. In addition, if any of the phases of the servo motor power sources (U/V/W) is interrupted, an overcurrent or overload error may be issued. Identifying the causes of these failures takes time. For the MR-J5 series, Mitsubishi Electric has developed input open-phase detection that detects phase interruption in the main circuit power sources of servo amplifiers and output open-phase detection that detects phase interruption in servo motor power sources. These functions that can discriminate phase interruption from other types of errors (e.g., overload) can reduce the time required for recovery operations (Fig. 6).

3.3 Encoder communication circuit diagnosis

Encoder communication errors are often caused by



GOT: Graphic Operation Terminal

Fig. 3 Ball screw diagnosis

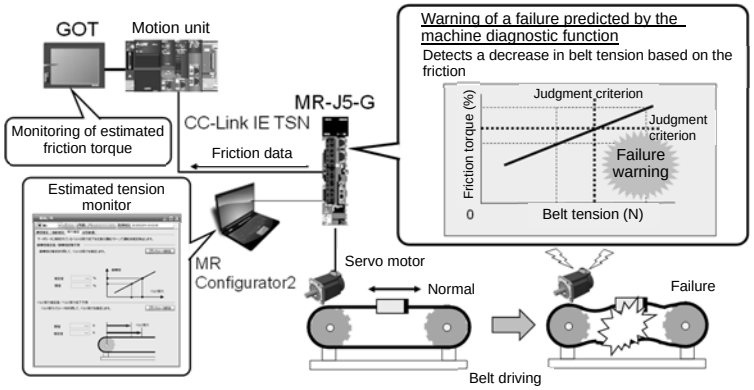


Fig. 4 Belt diagnosis

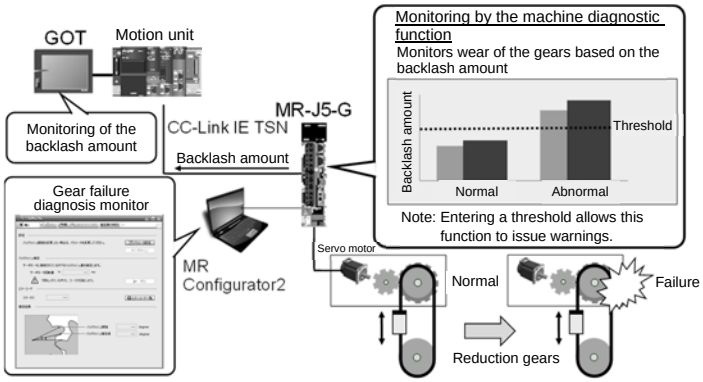


Fig. 5 Gear diagnosis

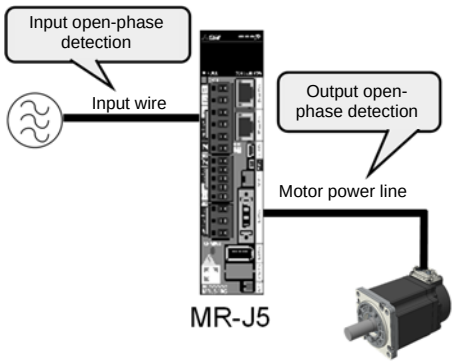


Fig. 6 Open-phase detection

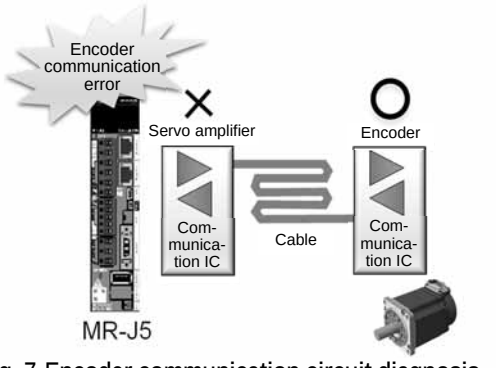


Fig. 7 Encoder communication circuit diagnosis

failures in servo amplifiers and encoders, breaks in encoder cables, and communication data errors due to noise. Identifying such causes takes time. The MR-J5 series have a function to diagnose failures in differential drivers and receivers used on the encoder communication circuits in the servo amplifiers and that can reduce the time from when a failure is detected in the servo amplifiers to when the cause of the failure is identified (Fig. 7).

4. Adjustment Functions That Immediately Improve Performance

4.1 Quick tuning

To improve the performance of equipment and systems, various control parameters need to be adjusted depending on the mechanical properties and operation specifications. For example, machines for which high-speed and high-accuracy operations are required (e.g., semiconductor mounting equipment and die bonders) require high-level adjustments. The one-touch tuning function provided on the MR-J4 series can realize high-speed and high-accuracy operations automatically, which is popular in the market. Meanwhile, servo systems are often used for simple transfer and other similar applications that do not require high response and accuracy. For such applications, ease of use is crucial, for example, servo systems that require only wiring to start working. In addition, for machines for which extremely high loads are applied to the servo motors, the control systems may be unstable if the servo amplifiers are used with the factory settings. In such an unstable state, various adjustment functions cannot be applied and high-level adjustment operations cannot be performed. Therefore, there are increasing demands for a function that requires only wiring to stabilize the control systems and that makes it possible for the machines to operate even when the response is low. To satisfy such needs, the MR-J5 series have a newly developed quick tuning function. This function eliminates the need for adjustments by customers, stabilizes the control systems instantaneously, and ensures the response is not too slow.

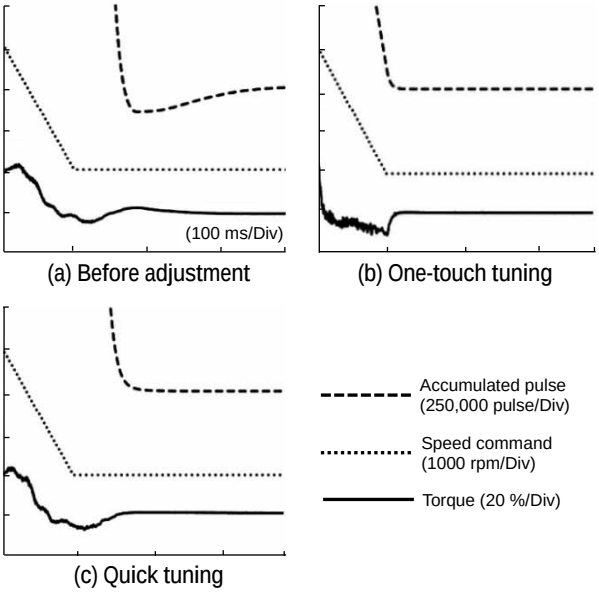


Fig. 8 Adjustment results by various tuning functions

Table 1 Adjustment results by various tuning functions

Item	Before adjustment	One-touch tuning	Quick tuning
Adjustment time (s)	–	60	0.3
Settling time (ms)	247.04	11.09	91.72
Overshoot amount (pulses)	243,200	110	110

Figure 8 and Table 1 show the results of applying the one-touch tuning and quick tuning to ball screw equipment as examples. Regarding the quick tuning, adjustment of the overshoot amount of 110 pulses and the settling time of 91 ms could be made instantaneously (0.3 second) after the servo was turned on.

5. Energy Saving, Space Saving, and Simple Wiring

5.1 Simple converters

In recent years, there are growing demands for energy saving, space saving, and simple wiring. For the MR-J4 series, a single servo amplifier is used to drive multiple servo motors (multiple-axis integrated servo amplifier). However, the system configuration is rather inflexible. For example, servo motors for which the capacity greatly varies cannot be combined and the maximum number of axes is limited to three. A new simple converter MR-CM developed for the MR-J5 series has made it easier to configure common bus systems. Regarding the specifications of the simple converter, the maximum number of connectable amplifiers is six and the rated output is 3 kW or less.

Common bus systems can reuse the regenerative energy of a servo motor to power another servo motor. In addition, the regenerative cooperative control, which is described later, enables maximum use of the regeneration resistances built into the servo amplifiers. In addition, reducing the number of protective devices and regeneration resistances can reduce the footprint of control boards (Fig. 9). As an example, when a single-axis MR-J5 common bus system with MR-CM is used in place of a 6-axis system, the number of circuit breakers and electromagnetic contactors can be respectively reduced by five (the footprint is reduced by approximately 38% even considering that of MR-CM) and the number of cables can be reduced by 31.

5.2 Regenerative cooperative control

One problem with conventional common bus systems is that regenerative loads are concentrated due to variation in the bus voltage detection circuits of the servo amplifiers and variation in the timing of turning on regeneration. To solve this problem, the regenerative cooperative control can disperse regenerative loads to all the servo amplifiers in the system. This control achieves the ideal system: the processable regenerative energy becomes the total of the regenerative capacity of the servo amplifiers in the system. Figure 10 shows the

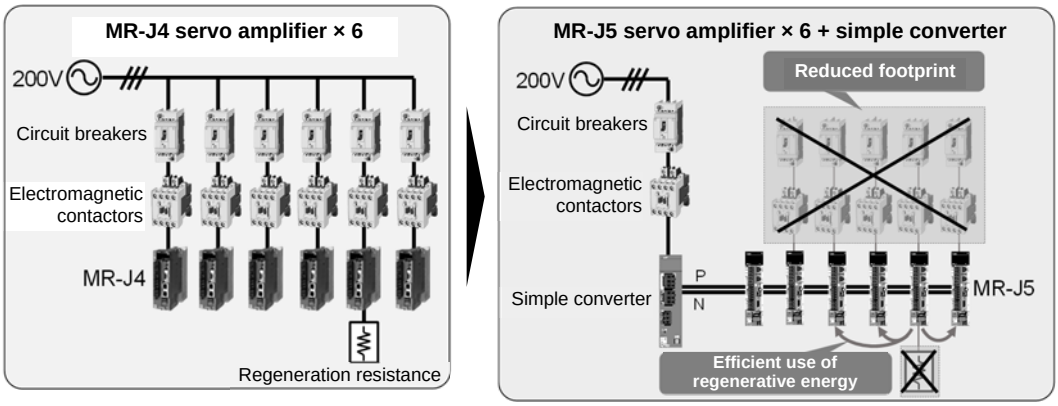
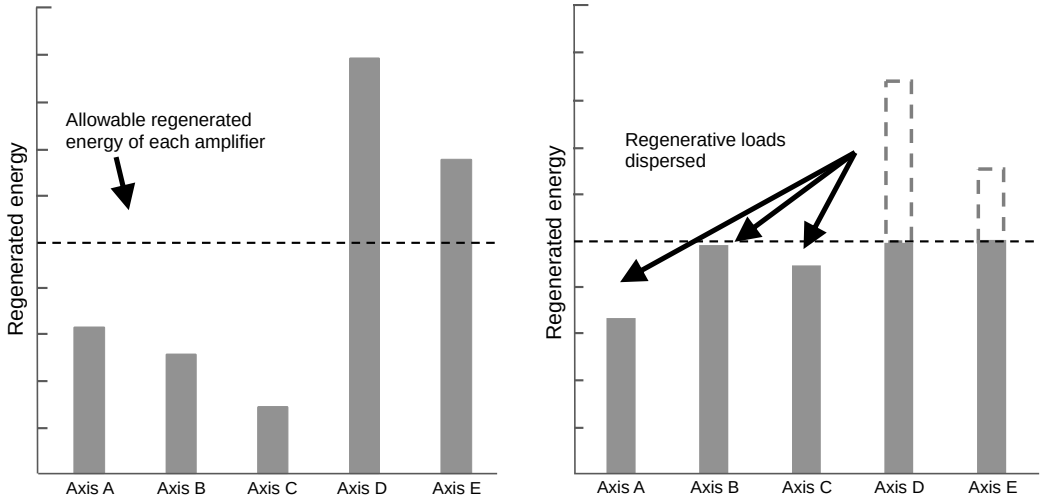


Fig. 9 Configuration example of common bus system by utilizing MR-CM



(a) Without regenerative cooperative control (b) With regenerative cooperative control

Fig. 10 Effects of regenerative cooperative control

test results using a 5-axis system as an example. Thanks to the regenerative cooperative control, the regeneration resistance in the system was enough to process the regenerated energy and thereby external regeneration resistance could be reduced.

6. Conclusion

This paper described the MR-J5 series that deliver the high speed and performance required of servo systems, and that were developed under the concept of "maximizing the performance of equipment and systems by total drive solutions." We will continue to anticipate future needs and develop products that satisfy many customers.

New Servo Motors "HK Series"

Author: *Hiroki Kobayashi**

1. Introduction

Servo motors, which are one kind of FA product, are used to drive various types of industrial machines. Mitsubishi Electric Corporation put the HG series of servo motors on the market in 2012. The series are highly compatible with conventional models, inheriting their functionality. Although the HG series are now our main products, requirements for servo motors have been diversifying due to the globalization of manufacturing in recent years. To satisfy such needs, in addition to improving the functions and performance and inherited functionality, which are still required as before, the number of product types also needs to be increased. In addition, regarding encoders, there is a need in recent years for systems that can detect multiple rotational positions even when the power source is turned off. Typically, batteries are used to detect and record multiple rotational positions when there is no power source. However, when the batteries go dead or after they are replaced, the origin needs to be adjusted and it is difficult to transport encoders with batteries connected due to air transportation regulations.

In response, Mitsubishi Electric has developed the new HK series of servo motors. For the HK series, the existing basic performance was improved by optimizing the magnetic design and reducing the loss, while the product types were greatly increased by common use of parts through modular design. The HK series come with batteryless absolute position encoders as standard, thus helping to reduce total cost of ownership for users.

2. Technologies for Smaller and Higher-Performance Motors

The HK series are up to 20% smaller than the conventional models. To reduce the size of motors, improving the heat dissipation and reducing the loss (iron loss and copper loss) are effective. For the HK series, iron cores without caulking were used to reduce the iron loss (eddy-current loss) on the motors, while the magnetic gap between the stator and rotor was decreased to reduce the copper loss. At the same time, the influence on the motor characteristics due to the decreased gap was minimized by optimizing the magnetic design. These improvements have realized smaller, higher-performance motors.

2.1 Adoption of iron cores without caulking

The adoption of iron cores without caulking reduced the iron loss by 25% on average compared to the conventional fixing by caulking. Caulking (Fig. 1(a)) is commonly used for fixing magnetic steel sheets. However, at the fastened sections, short circuits between the laminated layers cause eddy currents, which increase the iron loss. For the HK series, we developed a method to secure magnetic steel sheets only by winding, thus eliminating the caulking (Fig. 1(b)).

2.2 Smaller magnetic gap

The magnetic gap was reduced to 0.5 mm from the conventional 1.5 mm (Fig. 2), reducing the copper loss by approximately 30%. When the magnetic gap between the stator and rotor is reduced, the magnetic efficiency improves and the copper loss can be reduced while the cogging torque becomes larger. Because servo motors have permanent magnets in the rotors, cogging torque (torque pulsation) exists even when no current is supplied. Because cogging torque is a disturbance factor, it needs to be minimized to improve the performance of servo motors. Cogging torque is caused by multiple

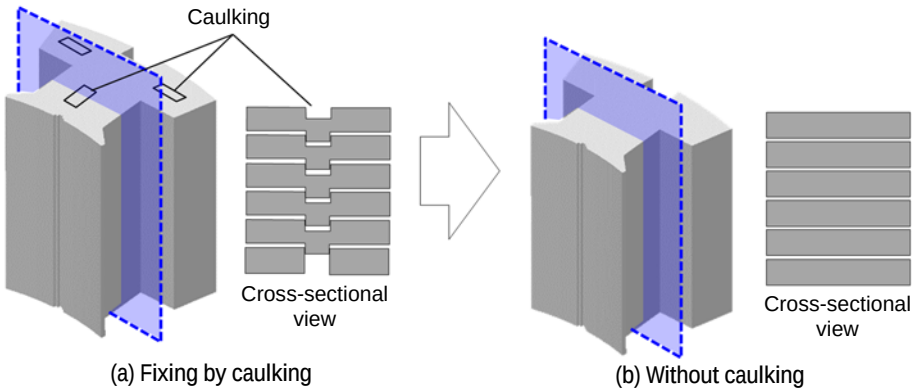


Fig. 1 Comparison of method of fixing magnetic steel sheets

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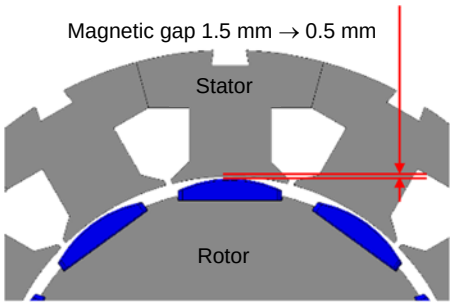


Fig. 2 Cross-sectional drawing of a servo motor

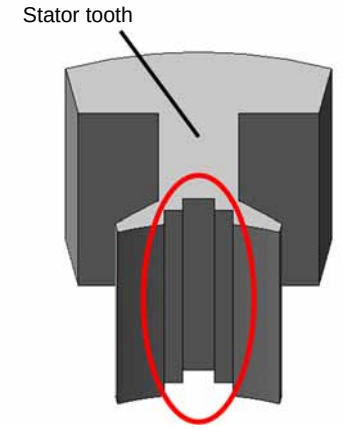


Fig. 3 Two-stage dummy slot

factors, such as the combination of the number of rotor magnetic poles and that of stator slots and variations in magnets and stators.

For the HK series, to solve the problem of an increase in the cogging torque due to reduction of the magnetic gap, the two-stage dummy slot shown in Fig. 3 was adopted to reduce both cogging torque and copper loss. Providing a dummy slot (notch) at the end of a stator tooth is a common method of reducing cogging torque. However, for usual dummy slots, the design parameter is only their width, making it difficult to cope with multiple factors at once only with the single parameter. On the two-stage dummy slot, the width of the first stage was designed separately from that of the second stage, which made it possible to address multiple factors and further reduce cogging torque.

3. Modular Design Technologies

The number of parts used for the HK series was reduced by modular design, while the number of product types was increased to 78 from 58 of the previous series. In addition, increased combinations with servo amplifiers and wide-range motor driving (200 V/400 V class servo motors) produced approximately 270 patterns of torque characteristics in total.

3.1 Common magnet designing

The conventional HG series provide seven main models depending on the capacity and inertia levels. Their higher performance was obtained by individual optimization design. When this technique is used, the design varies from model to model. Therefore, as the number of product types is increased, the number of parts also increases, which is a problem. On the other hand, total optimization design, which was used for all models in the HK series, both reduced the number of parts and increased the number of product types.

Regarding magnets, which are key parts in motors, a common magnet design was adopted and the number of types was reduced to 9 from the conventional 20. In the design, the same type of magnet is commonly used for different models by using differences in the inertia levels. The outer diameters of the rotors in our servo motors were varied when the output was the same in order to realize different inertia levels. When comparing with models with different capacity levels, for two particular models with different inertia and capacity levels, the outer diameter values of the rotors are close. However, with the conventional separate optimization design, even when the outer diameters of the rotors are close, different types of magnets are used model by model. For the HK series, as shown in Fig. 4, these factors were commonly designed to reduce the number of magnet types while also increasing the number of product types. For example, as shown in Fig. 5, for a small-capacity and low-inertia model and a medium-capacity and ultra-low-inertia model, the outer diameter of the rotors was designed to be the same and the same type of magnet is used.

3.2 Increased combinations with servo amplifiers

The maximum torque can be increased by combining the HK series with larger-capacity servo amplifiers. The motors' torque characteristic depends on the current value and so is limited by the allowable current values of the combined servo amplifiers. Conventionally, there was only one kind of combination of servo motors and servo amplifiers, which uniquely determined the torque characteristic. The HK series can be combined with larger-capacity servo amplifiers, which can increase the maximum torque. Thanks to this advantage, when a single type of motor is combined with different types of servo amplifiers, two patterns of torque characteristics can be obtained (Fig. 6).

3.3 Wide-range motor driving (200 V/400 V class servo motors)

Wide-range motor driving that allows a single model to support power source voltages of both 200 and 400 VAC (200 V/400 V class servo motors) has realized multiple torque characteristics. In the high-speed range of servo motors, there is a voltage saturation area in which the voltage of the motor terminals reaches the input voltage. Therefore, the torque characteristic is restricted by the input voltage. Because the voltage of

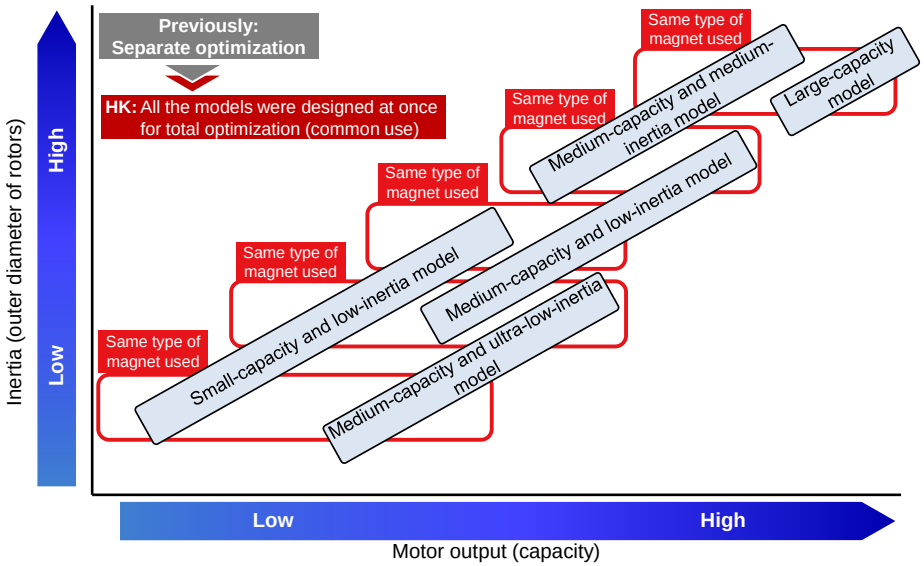


Fig. 4 Common magnet designing

motor terminals is determined by the electric design of the motors, an electric design based on the input voltage (= power source voltage − voltage drop on the servo amplifier) is required. Therefore, for a single torque characteristic, two types that were designed for each of two power source voltage values (200 and 400 VAC) (A) are available. Previously, a single model could only support either of the power source voltage values (voltage designed in (A) above) and insulation was also separately designed for the voltage value. A single type in the HK series supports the two power source voltage values, enabling the operation area to be expanded (higher speed) or reduced (smaller-capacity servo amplifiers) for a torque characteristic. In addition, a thin insulation design using insulation analysis technologies enabled common use of the insulation structure for both 200-V and 400-V power sources (Fig. 7).

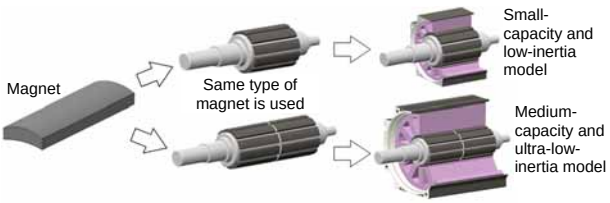
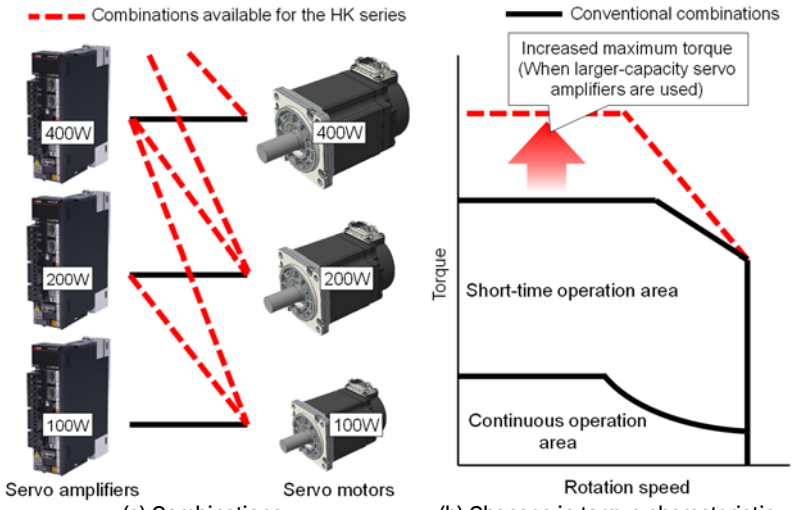


Fig. 5 Use of common magnet for several models

For the HK series (200 V/400 V class servo motors), in order to discriminate the two voltage levels, when the power source voltage (voltage designed in (A) above) that can obtain the standard characteristic is 200 VAC, the model names have the "W" suffix; when it is 400 VAC, the names have the "4W" suffix. These are called "□W type" and "□4W type," respectively. When the □W type is used with a 400-VAC power source by wide-range driving, a higher voltage than the original design can be applied. Therefore, the operation area for the torque characteristic expands, and although the servo amplifiers' capacity increases, the speed can be higher. On the other hand, when the □4W type is used with a



(a) Combinations (b) Changes in torque characteristic

Fig. 6 Expanding combinations of servo amplifiers and servo motors

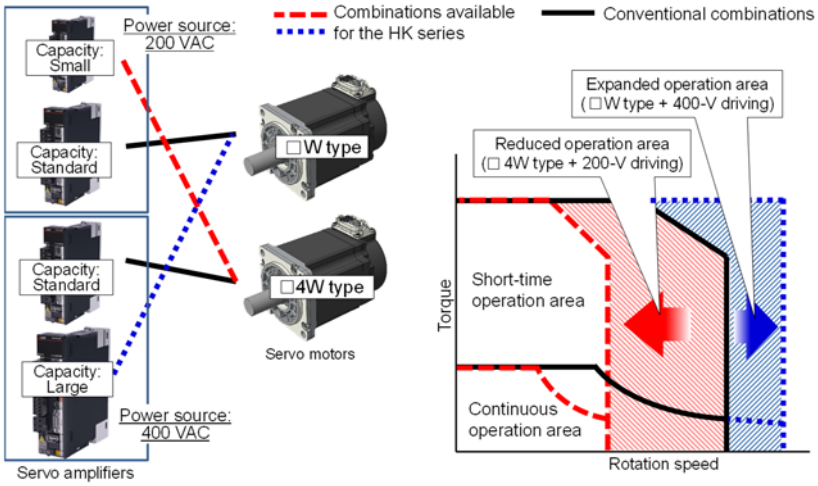


Fig.7 Driving of 200 V/400 V class servo motors

Table 1 Variations of torque characteristics

Servo amplifiers combined	□W type (Conventional 200-V class)		□4W type (Conventional 400-V class)	
	200-VAC power source	400-VAC power source (wide-range driving)	200-VAC power source (wide-range driving)	400-VAC power source
Standard servo amplifier	Standard	Expanded operation area	Reduced operation area	Standard
Larger-capacity servo amplifier	Higher torque	Higher torque Expanded operation area	Higher torque Reduced operation area	Higher torque

□: New torque characteristics realized by the HK series

200-VAC power source, although the operation area and rotation speed decrease because the voltage that can be input is smaller than the original design value, smaller-capacity servo amplifiers can be used. Both increased combinations with servo amplifiers described in 3.2 and the wide-range driving described in this section can be selected at the same time and hence a single type can realize four patterns of torque characteristics (Table 1). These variations make it possible to select optimum servo motors and servo amplifiers that match the operation patterns of machines.

4. Technologies for Encoders

The HK series come with batteryless absolute position encoders as standard. Optimized batteryless and optical detection schemes reduced the increase in size resulting from the batteryless configuration. In addition, the motors were downsized and the basic performance was improved (e.g., higher resolution).

4.1 Batteryless scheme

Generally, to realize a batteryless configuration, mechanical (gear) and generation schemes are used. Compared to the generation scheme, when the mechanical scheme is used, the service life is shorter due to wear of the sliding sections, the detectors are larger, and the countable number of revolutions when the power source is off is smaller. Therefore, our proprietary self-generation scheme was used as encoders for the HK series.

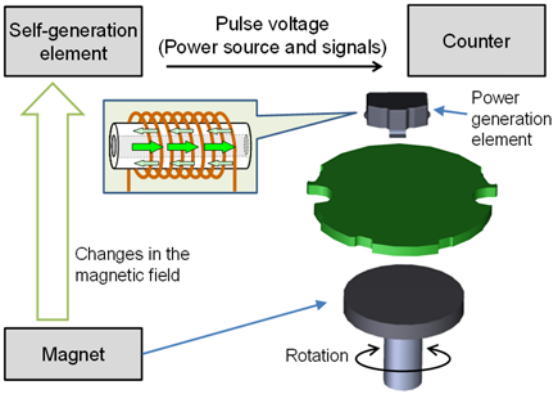


Fig. 8 Principle of batteryless absolute position encoder

In the self-generation scheme, as shown in Fig. 8, the pulse voltage that is generated on the power generation element due to changes in the magnetic field that is produced when the magnet at the end of the motor shaft rotates is used to detect the position, and the voltage that is generated by changes in the magnetic field is used to record the position into nonvolatile memory.

In this scheme, there is the concern that when the rotation speed and the frequency of driving are low, the position data may vanish. However, the pulse voltage to be generated was optimized, the circuit was configured considering the voltage at low speed, and special ASICs were developed to make it possible to detect and record positions for approximately 10 years regardless of the driving conditions.

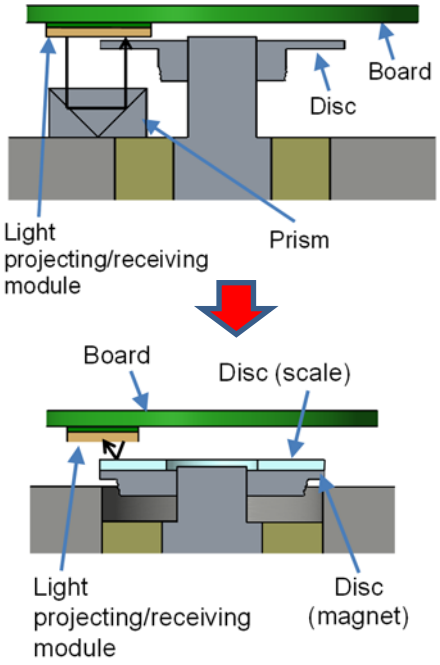


Fig. 9 Optimization of optical detection

4.2 Optimization of the optical detection scheme

Compared to the gear scheme, the self-generation scheme described in 4.1 makes the size smaller. However, because power generation elements are installed on boards, the total length of motors becomes longer, which is a problem. To solve this problem, a single board/disc with higher resolution was realized by the following improvements: (1) The optical detection scheme was changed to the reflection scheme from our conventional loopback scheme to reduce the total length (Fig. 9), (2) a structure design linked to motor parts was adopted to reduce the total length, and (3) composite discs of magnetism and optics are used to process both signals with the special ASIC. These improvements enabled the batteryless configuration, increased the resolution to 26 bits from 22 bits, and reduced the size by up to 20% compared to the conventional models.

5. Conclusion

The new small, high-performance HK series of servo motors provide more product types and have new functions, reducing the total cost of ownership for users.

We will continue developing servo motors based on advanced technologies focusing on the highest quality, thus contributing to manufacturing around the world.

Magnetic Starters and Relays with Spring Clamp Terminals

Author: *Tohru Hayashi**

1. Introduction

When electrical apparatus is installed on control boards and equipment, connecting wires to the screw terminals is laborious and workers require skill to maintain high quality. In addition, when electrical apparatus is delivered and inspected, it takes much time to ensure quality (e.g., additional tightening and other operations) and also other costs are incurred.

The declining birthrate, aging population, and other similar problems in recent years have caused labor shortages and reduced the number of skilled workers. Therefore, to reduce time and cost, there is strong demand for products with spring clamp terminals as screwless terminals featuring simple wiring and less maintenance. Spring clamp terminals are commonly used in Europe and many products to be exported to Europe contain parts that utilize these terminals.

Mitsubishi Electric Corporation has developed magnetic starters and magnetic relays with spring clamp terminals that satisfy such requirements, in addition to the conventional magnetic starters and magnetic relays with screw terminals. Small frames which sell in large quantities were developed; as shown in Table 1, 12-A and 20-A magnetic contactors and 5-pole magnetic relays are available.

This paper describes the advantages of the products developed this time.

2. Advantages of the Developed Products

2.1 Wiring[1]

The advantages of wiring to our newly developed magnetic starters and magnetic relays with spring clamp terminals are described below.

2.1.1 Solid conductors, stranded conductors, flexible stranded conductors, and ferrules supported

Our magnetic contactors with spring clamp terminals support solid conductors and stranded conductors, whether plated or not, for the first time in Japan.[*1] Although ferrules prevent stranded conductors from spreading out, they do not save as much work. The main wiring method used overseas does not involve ferrules, and so stranded conductors are important for global business. In addition, solid conductors are often used when installing electric facilities in buildings and they can be flexibly used for installing the growing number of electric vehicle (EV) chargers as well as for vehicle-to-home (V2H) equipment.

2.1.2 Methods to insert and remove various types of wires

Solid conductors and ferrules can be connected to our products with spring clamp terminals simply by pushing in unsheathed wires in one action, while stranded conductors can be connected in two actions using a tool. These methods eliminate the risk of losing screws and save work.

2.1.3 Higher usability thanks to 15° wiring direction

The tilted wiring direction reduces swelling in wires in ducts. In addition, the tool is operated perpendicular to the mounting surface of a control panel, which makes it easier to apply force to manipulate the springs. The

Table 1 Specifications

Models		Magnetic contactors		Magnetic relays
Operation coils	AC	S-T12SQ	S-T20SQ	SR-T5SQ
	DC	SD-T12SQ	SD-T20SQ	SRD-T5SQ
Rating (AC200V) (Same as products with screw terminals)		13A (AC-3)	18A (AC-3)	3A (AC-15)
Size of applicable wires (Main and auxiliary/operation)	Solid conductor	ϕ0.8–2		
	Stranded conductor	0.5–4 mm^2		
	Ferrule	0.25–2.5 mm^2		
External dimensions (W × H × D (mm))	AC operation	44 × 76.7 × 78 (similar to products with screw terminals) (Reference: Products with screw terminals: 44 × 75 × 78)		
	DC operation	44 × 76.7 × 100 (similar to products with screw terminals) (Reference: Products with screw terminals: 44 × 75 × 100)		
Screw installation dimensions (mm)		35 × 60, etc. (same as products with screw terminals)		

1 As of November 1, 2019, researched by Mitsubishi Electric Corporation

**Nagoya Works*

method also avoids the need to change the direction of the tool between the power source side and load side. Any terminal can be inserted and removed in a uniform direction, which greatly improves workability.

2.1.4 Wire insertion indicator

For ferrules with insulation collars, when the insulation collar section is inserted deeper from the surface of wire slots, the connection is complete. By tilting the wire insertion direction by 15° it is easier to see the insulation collar section, which speeds up checking the connection visually.

2.1.5 Push-in CAGE CLAMP*2 made by WAGO

As spring clamp terminals, the reliable Push-in CAGE CLAMP, which is made by the German spring terminal block manufacturer WAGO and has been used for many years around the world, was selected. The cage in the Push-in CAGE CLAMP holds an inserted wire firmly as if cooped up in a cage. Solid conductors and stranded conductors can be connected without crimp terminals. Specifically, a wire is surrounded with a spring on one side and with an electric conductor on the other three sides. The area of the section that is in contact with the electric conductor is reduced, which increases the pressure per unit area, ensures better contact and reduces the contact resistance.

2.2 Other advantages

2.2.1 Product types

12-A and 20-A frame types of magnetic contactors with spring clamp terminals and 5-pole magnetic relays were developed. Two types of operation coil (AC and DC) are provided for all types, making six types available in total. Regarding performance, the voltage of the operation coils, main circuit and auxiliary circuit ratings, and screw installation dimensions are similar to those of products with screw terminals. Products with spring clamp terminals have the “SQ” added to the end of the model names of products with screw terminals. They can be ordered in the same way as ordering conventional BC types of wiring streamlining terminals with screw holders. Table 1 lists the product specifications.

2.2.2 Wide range of wire types and standard wire sizes for all terminals

The developed products are compatible with a wide variety of wire types and sizes as shown in Table 2. As solid conductors, ϕ0.8 wires commonly used for communication lines up to ϕ2.0 wires often used for indoor vinyl wires in buildings are supported. As stranded conductors, 0.5-mm^2 wires often used for signal wires up to 4.0-mm^2 wires to be used on the primary side from the circuit breakers when wires are routed across multiple magnetic contactors are supported. As ferrules with insulation collars, thinner 0.25-mm^2 wires to 2.50-mm^2 wires that are also used as power lines are supported.

In addition, the same spring clamp terminal structure was applied to all terminals, making it possible to connect wires of the same size to all terminals regardless of main, auxiliary, or operation circuit, and regardless of magnetic contactor or magnetic relay.

In some cases, measures to prevent contact resistance of wires are required; for example, Company A in Table 2 instructs that only tinned wires should be used when stranded conductors are directly connected. As described in 2.1, the contact pressure per unit area of the spring clamp terminals used for these developed products is high. Therefore, even when non-plated bare copper wires are used, the contact resistance can be kept low.

As described above, the developed products support a wide variety of wire types and sizes without specific requirements or limitations on applicable size between circuits and between models, enabling flexible design of panels and equipment.

2.2.3 Electroscope slots and arrangement of coil terminals for improved usability

Regarding wiring to the developed products, two wires can be inserted per terminal and the products have

Table 2 Applicable wire sizes

Wire type	Comparison of applicable wire size between products made by Mitsubishi Electric and other companies (magnetic starters and relays)									
Solid conductor			ϕ0.8	ϕ1		ϕ1.6		ϕ2		
Stranded conductor (mm^2)			0.5 *	0.75 *	1 *	1.5	2	2.5	3.5	4
Ferrule with insulation collar (mm^2)	0.25	0.34	0.5	0.75	1	1.5	2	2.5		
Remarks	Mitsubishi Electric: All wire types in the cells enclosed by bold lines are applicable. Company A: Only the wire types in the dark- and light-gray cells are applicable. Stranded conductors require tinning. Wire sizes with asterisks* require an insulation stop. The connectable wire size varies between main circuits and auxiliary circuits. Company B: Only the wire types in the dark-gray cells are applicable.									

2 The Push-in CAGE CLAMP made by WAGO Kontakttechnik GmbH & Co. KG, Germany (“WAGO”) is used for the spring clamp terminals. “Push-in CAGE CLAMP” is a registered trademark of WAGO.

tool slots to enable each wire to be manipulated separately. Although other companies' products have the same function, our products with spring clamp terminals are easier to use than their products with screw terminals. When the screw of a product with screw terminals is loosened to remove one wire after two wires have been connected, both wires come off and so one wire needs to be tightened again. On the other hand, our products with spring clamp terminals allow individual wires to be separately manipulated, which is easier.

On our products, as shown in Fig. 1, an electroscope slot is provided for each terminal; the products of some other companies do not have such slots in which case tool slots are used instead for electrical checks. Because tool slots are intended for inserting and removing wires, when a tester pin is pushed into them for electrical checks, the wires may come off or become loose halfway, causing troubles. On the other hand, even when a tester pin is pushed into the electroscope slot of our product, there is no risk of the wire coming off. Even when electrical checks in awkward situations are needed, such as in a small space inside equipment or sequestered control panel, there is no issue of how strongly to push in the tester pin.

For products with screw terminals, the coil terminals are arranged deeper from the main terminals. On the other hand, for our products with spring clamp terminals, the coil terminals are arranged on almost the same surface as the main terminals as shown in Fig. 1. Wires are brought by hand close to the wire slots on our products with spring clamp terminals to connect them, unlike manipulating the wires on products with screw terminals. If there is a large step near a wire slot, it hinders wiring operations and makes it difficult to handle the wires. Therefore, on our products, the coil terminals are arranged on almost the same surface as the main terminals, which makes it easier to handle the wires.

2.2.4 Wire holders for smart wiring

In this development, a new wire holder was developed: wires can be routed along the magnetic contactors easily by tucking them into the wire holder. A patent for the wire holder was applied for in December 2019. The holder has the following three main functions.

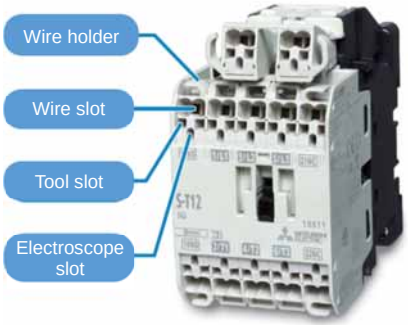


Fig. 1 S-T12SQ Magnetic contactor

(1) Gathering connected wires in one place

Because wires are connected to spring clamp terminals from the front, they are more visible compared to screw terminals, which does not look so good. Cable ties could be used to bind and gather connected wires neatly, but this involves complicated tasks such as preparing cable ties, binding wires with them, and cutting the extra cable ties. To solve this problem, new wire holders are provided to bring wires together without cable ties (Fig. 2); the holders can be used both before and after wiring.

(2) Preventing wire markers from shifting

Wires are sometimes bound together near the terminals to prevent the wire markers from shifting along the wires connected to the ducts of the mounting surfaces of control panels. Using cable ties increases the number of parts as described above, makes operations complicated, and requires treating the remnants. Wire holders are a new means of preventing wire markers from shifting simply by tucking wires into the holders.

(3) Preventing wires from breaking

Magnetic contactors themselves vibrate, and wires are connected from their wiring sections to the mounting surfaces of control panels that do not vibrate much. This causes vibrational stress to be unavoidably applied to the sections of the spring clamp terminals that hold the electric wire conductors (Fig. 3(a)). If this state continues, the conductors may break due to metal fatigue. Instead, by passing wires from the mounting surface of a control panel through the wire holders once and then connecting them to the spring clamp terminals, the sections enclosed by the dotted lines in Fig. 3(b) are united with the magnetic contactor. This greatly reduces the stress

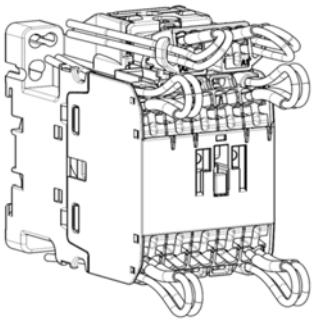
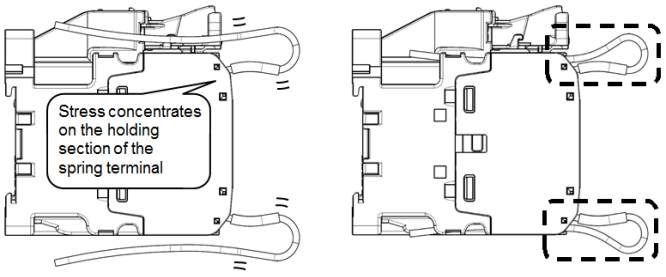
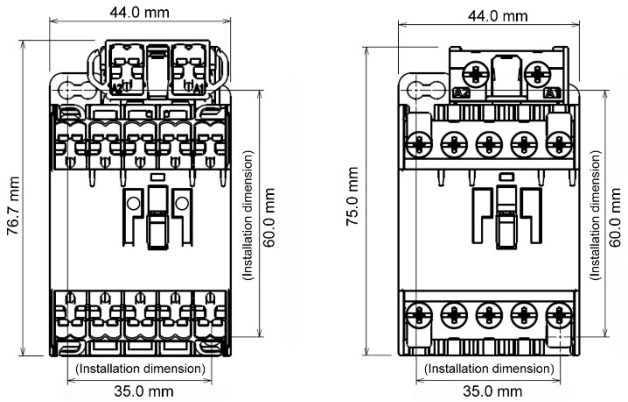


Fig. 2 Example of using the wire holder



(a) Without using wire holders (b) Using wire holders

Fig. 3 Preventing wire breakage



(a) Our product with spring clamp terminals (b) Product with screw terminals

Fig. 4 External shape

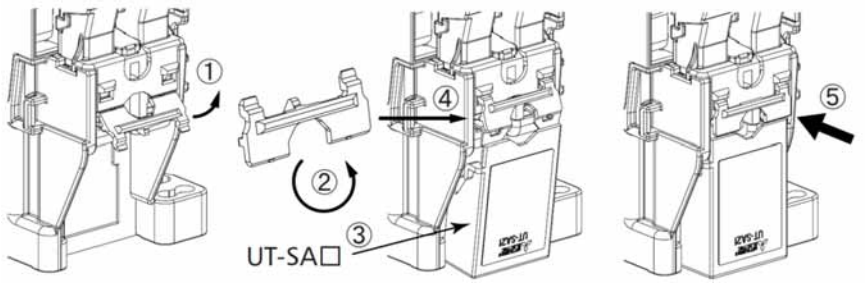


Fig. 5 Installation of surge absorber

on the holding sections of the spring clamp terminals, reducing the risk of wire breakage.

2.2.5 External shape similar to products with screw terminals

The external shape of our new products with spring clamp terminals is similar to that of magnetic contactors and magnetic relays with screw terminals which are widely used (Fig. 4), making it easy to replace existing models with the new models. In addition, when installing the developed products onto the mounting surfaces of control panels with screws, the installation dimensions are the same as those of products with screw terminals, which reduces the time for wiring of existing models and improves the quality.

In addition, because crimp terminals and other parts protrude from the top and bottom of magnetic contactors with screw terminals, devices installed above and below them need to be separated to some extent. On the other hand, wires are connected from the front of magnetic contactors with spring clamp terminals, making it more flexible to install devices above and below them, and contributing to downsizing control panels and equipment.

2.2.6 Compatibility with existing coil surge absorbers

Magnetic contactors with spring clamp terminals do not require special coil surge absorbers and the UT-SA□ series available for existing magnetic contactors with screw terminals can be used. Using the same options for the screw terminal specifications reduces the time for arrangements and stocking.

When installing a surge absorber, it is only necessary to open the cover, insert the absorber, and close the cover as shown in Fig. 5. The internal spring contact eliminates the risk of lost screws and improper installation.

3. Conclusion

This paper described magnetic starters and magnetic relays with spring clamp terminals that reduce time and effort, and improve quality. We will continue developing peripheral equipment and rating frames based on customer needs.

Reference

(1) Y. Kohi.: Circuit Breakers and Circuit Protectors with Spring Clamp Terminal Contributing to Labor Saving and Stable Quality, Mitsubishi Denki Giho, 94, No. 4, 252-255 (2020)

Circuit Breakers and Circuit Protectors with Spring Clamp Terminals Contributing to Labor-Saving and Stable Quality

Author: *Yuta Kohi**

1. Introduction

Currently, the labor shortage is worsening due to the decreasing labor population and the number of skilled workers is falling. Therefore, there is growing demand for product types that can be connected by simple wiring with stable quality even when performed by young workers. Previously, the main connection method in Japan was tightening with screws. However, as the frictional force acting between the male and female threads provides the fastening power, the screws may become loose when used in environments subject to vibration or impact and while the panels are transported. Therefore, the screws need to be periodically tightened and tightened again at installation sites. To solve these problems, Mitsubishi Electric Corporation has added new small circuit breakers and circuit protectors with spring clamp terminals to the lineup.

This paper describes the small circuit breakers and circuit protectors with spring clamp terminals along with other labor-saving types of circuit breakers.

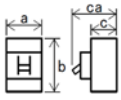
2. Product Types and Advantages of New Types

Mitsubishi Electric Corporation developed new small circuit breakers and circuit protectors with spring clamp terminals as 32-A or lower product types that are often used for branching for control panels and distribution boards. They have advantages of both labor-saving and downsizing.

2.1 Product types

Table 1 lists the product specifications. Advantages of the NF32-CVF/NV32-CVF small circuit breaker listed in the table include narrower width compared to products in the same price range with similar performance, which contributes to downsizing panels. In addition, they have openable small terminal covers as standard, securing safety and saving labor. They can be installed onto IEC 35 mm rails as standard and can be removed with one touch without tools, providing high workability. Therefore, the new products with spring clamp terminals are

Table 1 Specifications

Products		Small circuit breaker WS-V F Style								Circuit protector		
Models		NF32-CVF/ NV32-CVF		NF32-SVF/ NV32-SVF		NF63-CVF/ NV63-CVF; NF63-SVF/ NV63-SVF		NF50-SVFU/ NV50-SVFU		CP30-BA		
Appearance												
Number of poles		2	3	2	3	2	3	2	3	1	2	3
Rated current (A)		NF: 3 – 32 NV JIS: 5 – 32 NV CE·CCC: 5 – 30		NF: 3 – 32 NV: 5– 32		NF: 3 – 30 NV: 5 – 30		NF: 3 – 30 NV: 5 – 30		0.1 – 20		
Applicable wire size	Solid conductor	ϕ1.6, ϕ2.0		ϕ1.6, ϕ2.0				ϕ1.6, ϕ2.0 (14 – 12AWG)		ϕ1.6, ϕ2.0		
	Stranded conductor	1.0 – 10 mm^2		1.0 – 10 mm^2				2.0 – 10 mm^2 (14 – 8AWG)		0.75 – 4 mm^2		
	Ferrule	1.0 – 6 mm^2		1.0 – 6mm^2				2.0 – 6 mm^2 (14 – 10AWG)		0.75 – 2.5 mm^2		
External dimensions (mm) 	a	36	54	36	54	36	54	36	54	17.5	35	52.5
	b	140		140				140		99		
	c	52		68				68		65		
	ca	65		90				90		65		
Wire insertion port		2 ports/pole										

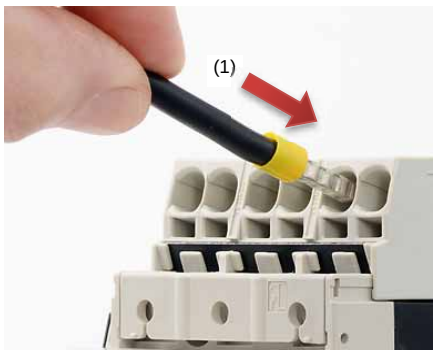
**Fukuyama Works*

expected to save labor. While the length and width of small circuit breakers other than the NF32-CVF/NV32-CVF listed in the table are the same as those of the NF32-CVF/NV32-CVF, their interrupting capacity is higher and they can be applied to more types of circuits. The NF50-SVFU/NV50-SVFU comply with UL489 Listing and so can be shipped to North America. In addition, the CP30-BA circuit protector in the table is suitable for protecting equipment and its operation characteristics can be selected depending on the equipment to be connected or protected. Regarding the external shape of the products, the width is 17.5 mm for the 1-pole product and 52.5 mm for the 3-pole product, which is remarkably small.

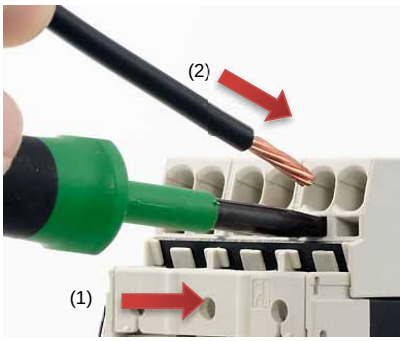
2.2 Advantages of the new products

2.2.1 Saving time

Regarding applicable wire types, in addition to ferrules (European type rod terminals), stranded conductors and elemental solid conductors can be connected, which is the first in Japan for circuit breakers with spring clamp terminals.*1 Solid conductors and ferrules can be connected in one action by pushing them in. Connection of a stranded conductor is completed simply by opening the spring with a tool, inserting the wire, and pulling out the tool (Fig. 1). When connecting elemental wires, crimping is unnecessary and so the total working time is shorter than when connecting ferrules. For reference, Fig. 2 compares the time required for wiring by unskilled workers according to the Japan Switchboard & control system Industries Association (JSIA).(1)



(a) One action (ferrules and solid conductors)



(b) Two actions (stranded conductors)

Fig. 1 Two types of wiring method

2.2.2 Easy wiring

Regarding ferrules, when the insulation sleeve sections have been inserted deeper from the surface of wire insertion ports, connection is completed. This wiring indicator (Fig. 3) makes it easier to visually check the connection. When wires are inserted from the front, bulges in the wires become larger compared to the screw terminal specification. With the newly developed products, the wire insertion ports are tilted at an angle of 15° to the front of the main body, thus reducing bulges in the wires (Fig. 4).

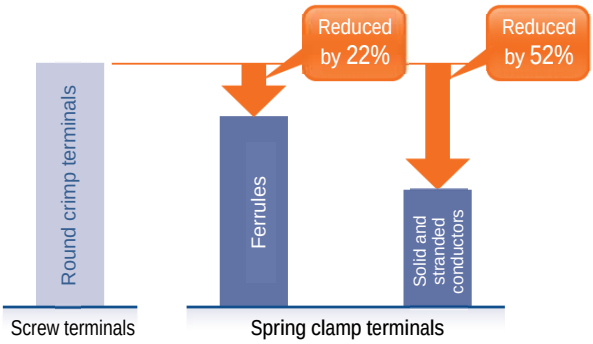


Fig. 2 Comparison of wiring time by unskilled workers (2 years of work experience)

(a) Connection completion

(b) Improper connection

Fig. 3 Wiring indicator

1 As of April 23, 2019, researched by Mitsubishi Electric

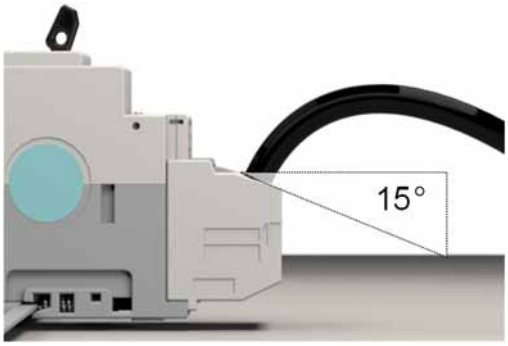


Fig. 4 Reduction of wiring bulges by tilting of wire insertion port

For the screw terminal specification, when multiple wires are connected to one pole by crossover wiring, the wires with crimp terminals need to be stacked and tightened, which increases the workload. On the other hand, our products with spring clamp terminals have two wire insertion ports for each pole terminal, making crossover wiring easy.

2.2.3 Stable quality

Our products with spring clamp terminals eliminate the need for skilled screwing as well as variations between workers and between tools, thus ensuring consistent connection quality. In addition, because the springs continuously apply pressure at a certain level, the terminals do not become loose due to vibration, impact, or use for a long time unlike screw terminals, making additional tightening and torque management unnecessary (maintenance-free). We have obtained third-party certification conforming to IEC60947-7-1 for the terminal sections as terminal blocks for copper conductors (screwless-type clamping units) and so our products can be used safely and securely.

2.2.4 Flexible specifications

In addition to the standard specification for which both line and load terminals are spring clamp terminals, we provide other specifications: only one side (line side or load side) has spring clamp terminals and the other side has screw terminals. These specifications are useful when large-diameter wires with a cross section of more than 10 mm^2 need to be connected to the line side and screwing is to be performed for wiring sections at the customer's site. Lead wire terminal blocks with spring clamp terminals have also been added to the lineup along with the main bodies. These terminal blocks can be installed into main bodies with screw terminals, and are ideal for various needs, for example, customers who want to try using lead wire terminal blocks because they are concerned about applying them to main circuits due to large current-carrying capacity (Fig. 5).

(a) Screws on the line side + spring clamp terminals on the load side

(b) Screws on the main body + terminal block with spring clamp terminals

Fig. 5 Examples of specification variations

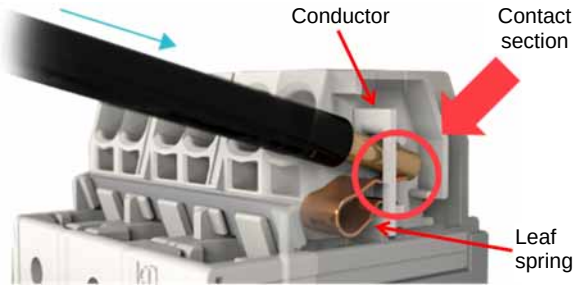


Fig. 6 Terminal structure of NF32-CVF

3. Technical Characteristics of Spring Clamp Terminals

Spring clamp terminals are screwless-type terminals and have long been used overseas (particularly in Europe). A terminal mainly consists of two parts (conductor and leaf spring). The leaf spring presses the wire strongly against the conductor for conducting electricity. Figure 6 shows an example of the terminal structure of the NF32-CVF circuit breaker with spring clamp terminals. An inserted wire is surrounded by a leaf spring on one side and by a conductor on the other three sides. The leaf spring applies pressure to the wire in the direction of the section that is in contact with the conductor. The contact area of the contact section

was designed to be smaller, which increases the force applied to the small area, achieving the required contact pressure and low contact resistance.

Another important point is flexibility for various types of wire. Although pushing in ferrules often saves labor, it has negative aspects, such as purchasing and managing ferrules and crimp tools and crimping operations, which take time. In addition to ferrules, elemental solid conductors and stranded conductors can be used for the new products thanks to their sufficient spring force, thus further saving labor (Fig. 7).

4. Other Labor-Saving Types of Circuit Breakers

4.1 Plug-in type circuit breakers for distribution boards

Plug-in type circuit breakers for distribution boards can be directly connected to bus bars (Fig. 8). They can be connected with one touch (insertion only) and no additional tightening is required. Multiple poles can be inserted at once, greatly reducing the working time. Branching conductors are not required, which saves space. The dimension from the circuit breaker installation surface to the front panel cut face has been standardized as 124 mm for the 125-A to 630-A frames, which enables standardization of the panel design. All the types come with connection indicators as standard.

Fig. 7 Applicable wire types

4.2 Molded case circuit breakers and earth leakage circuit breakers for distribution boards

4.2.1 Line side plug-in type circuit breakers

As small circuit breakers for distribution boards, line side plug-in type circuit breakers that can be directly connected to bus bars have been added to our product lineup (Fig. 9). Like the plug-in type circuit breakers for distribution boards, they can be installed with one touch, reducing the working time. Because additional tightening on the line side is also unnecessary, distribution boards can be produced more quickly and the maintenance process can be omitted.

4.2.2 Load side quick terminal type circuit breakers

Load side quick terminal type circuit breakers can be connected to terminals in one action by inserting wires to the terminals, as is the case with circuit breakers with spring clamp terminals (Fig. 10). Solid conductors can be used as wires and the applicable wire size is ϕ1.6 to ϕ2.6. This type comes with the connection indicator as standard.

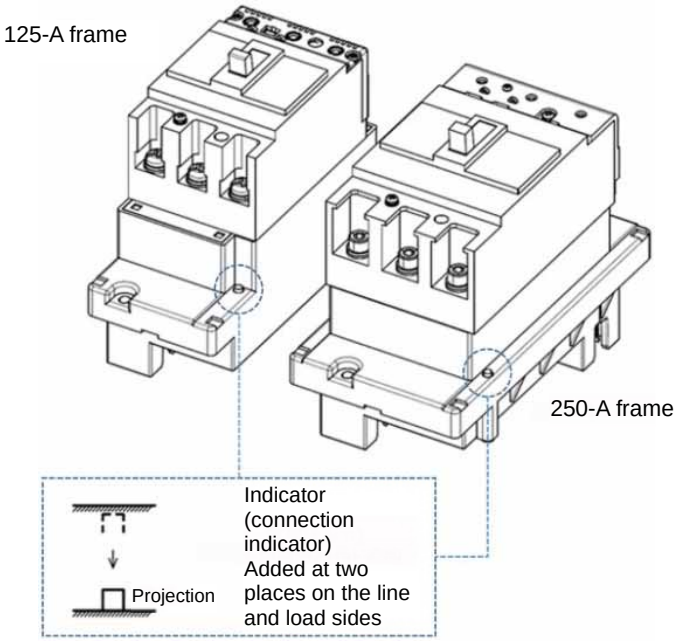


Fig. 8 Plug-in type circuit breaker for distribution board

Line side plug-in types	
Molded case circuit breakers for distribution boards	Earth leakage circuit breakers for distribution boards
 BH-CP1	 BV-CP1

Fig. 9 Line side plug-in type circuit breaker

Load side quick terminal type (QT)	
Molded case circuit breakers for distribution boards	Earth leakage circuit breakers for distribution boards
 BH-C1 QT	 BV-CP2 QT

Fig. 10 Load side quick terminal type circuit breaker

5. Conclusion

This paper described our circuit breakers with spring clamp terminals that help save labor and stabilize quality, along with other labor-saving types of circuit breakers. We will continue developing products that match customer needs, including expanding the number of models with spring clamp terminals and considering circuit breakers that further save labor.

Reference

(1) Control and Information System Committee under JSIA: Research Study on Cost Reduction of Control Panel Production, 1. Research Study on Rationalization of Wiring (2014)

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