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

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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

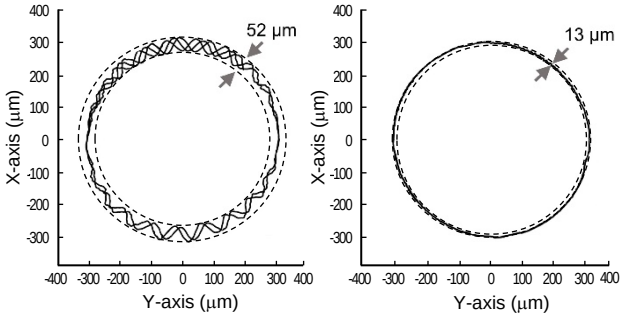
The MR-J5 series offer ultrahigh speed, high response, and high accuracy that are among the best in the industry. For this series, the dead time in various types of arithmetic processing was reduced by approximately 50% by adopting a special LSI featuring our proprietary high-speed servo architecture, 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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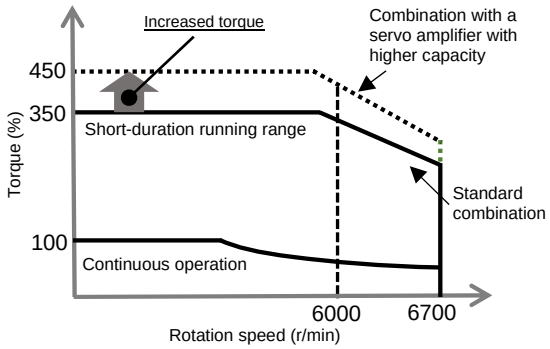


Fig. 2 Freedom of combination with servo motor

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

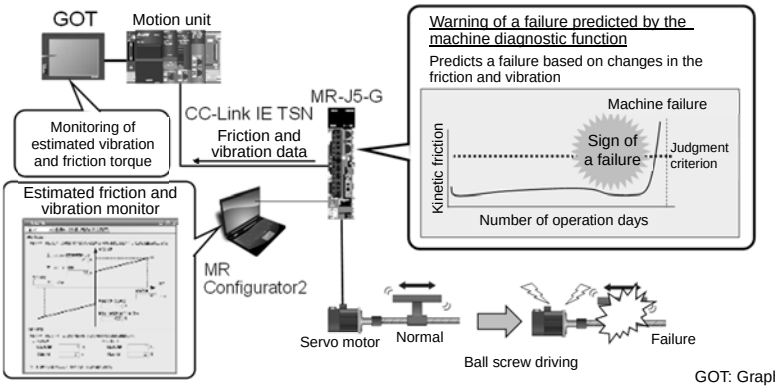
The gear diagnostic function predicts a failure in the gear mechanisms (e.g., reduction gears) connected to servo motors. In gear diagnosis, the backlash amounts of the gears are estimated based on the internal data (current and position) of the servo amplifiers in to-and-fro positioning operation and 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

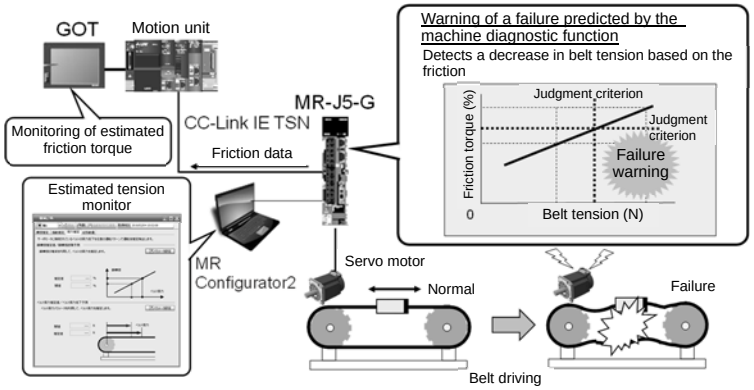


Fig. 4 Belt diagnosis

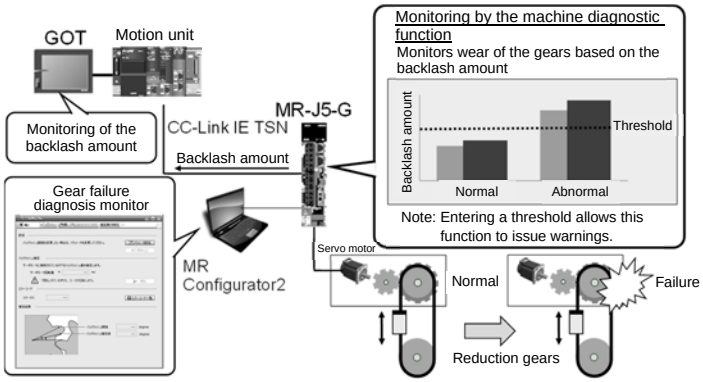


Fig. 5 Gear diagnosis

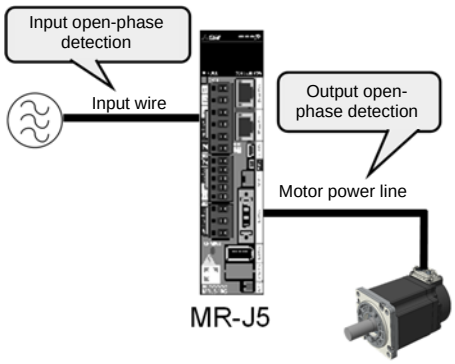


Fig. 6 Open-phase detection

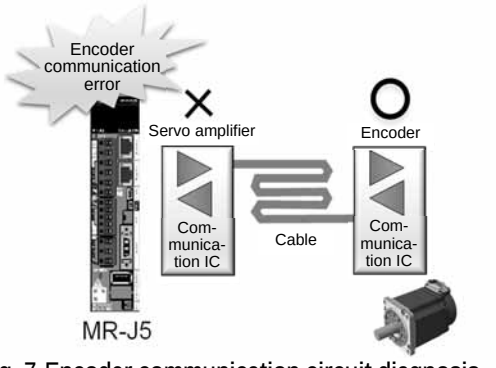


Fig. 7 Encoder communication circuit diagnosis

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.

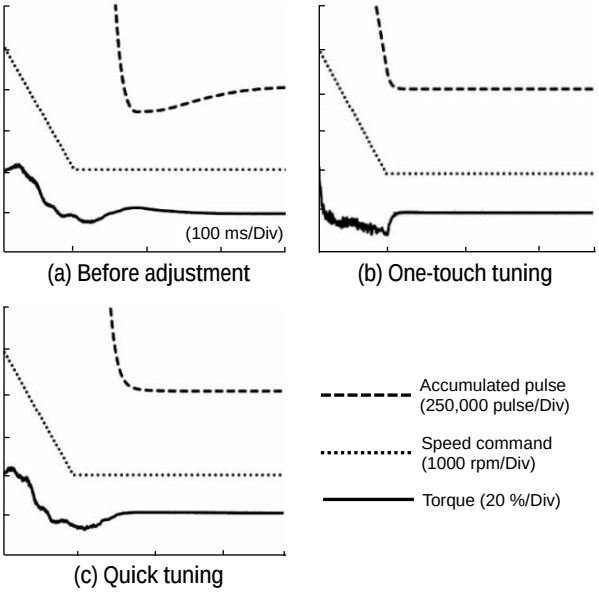


Fig. 8 Adjustment results by various tuning functions

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

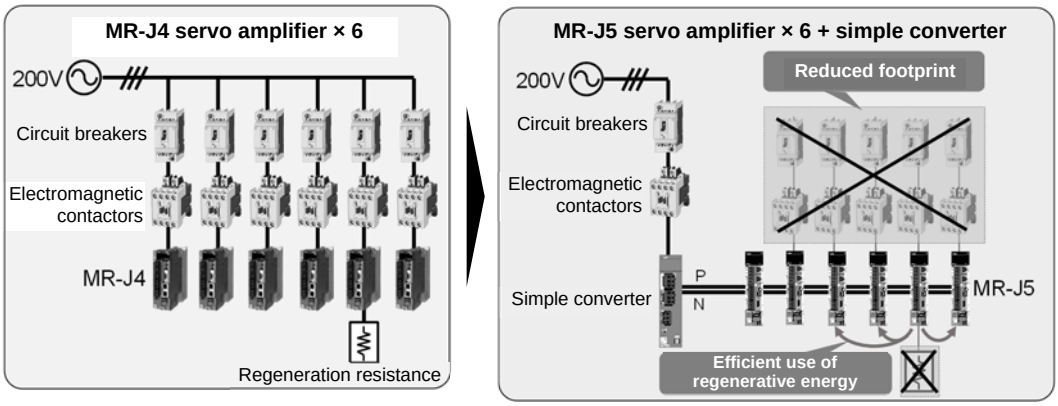
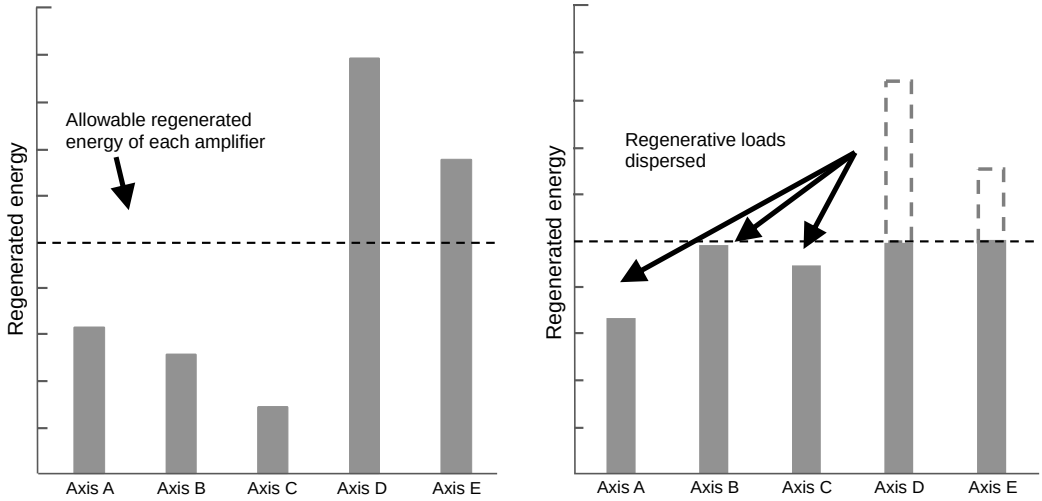


Fig. 9 Configuration example of common bus system by utilizing MR-CM



(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.