New Servo Motors "HK Series"

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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

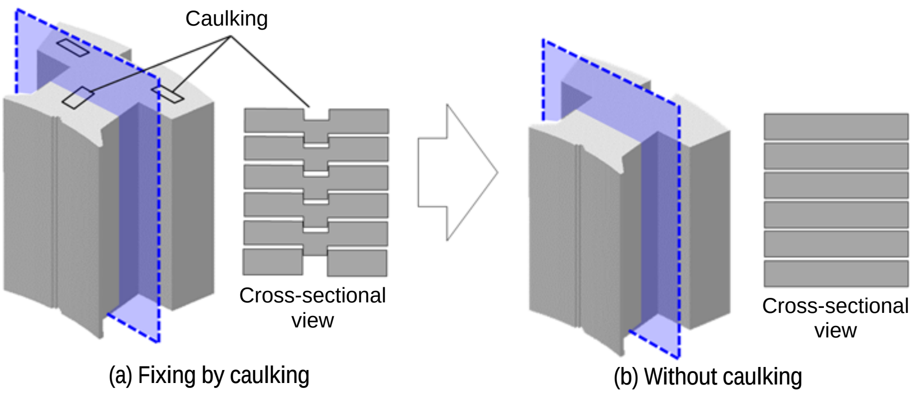

Fig. 1 Comparison of method of fixing magnetic steel sheets

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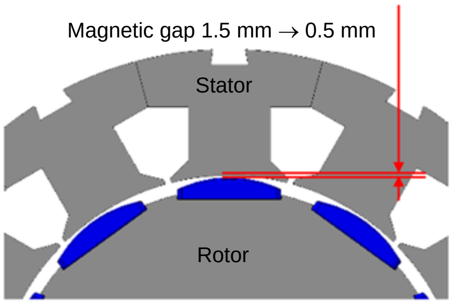


Fig. 2 Cross-sectional drawing of a servo motor

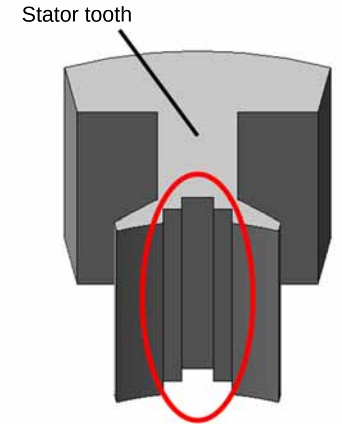


Fig. 3 Two-stage dummy slot

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

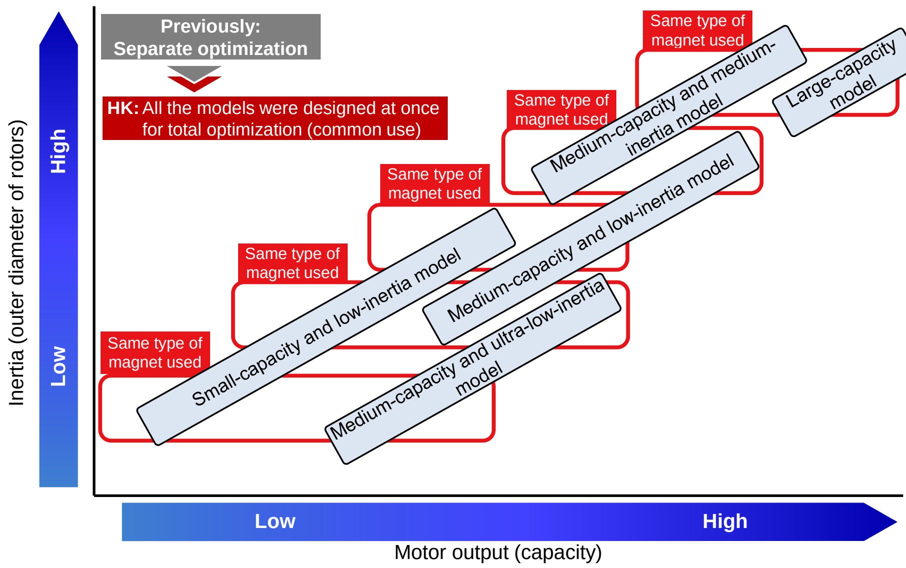


Fig. 4 Common magnet designing

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

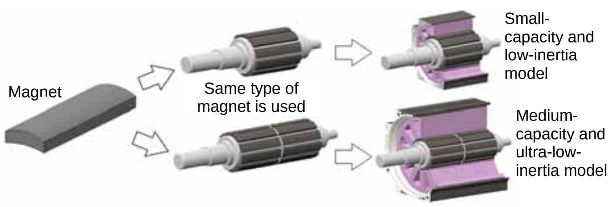
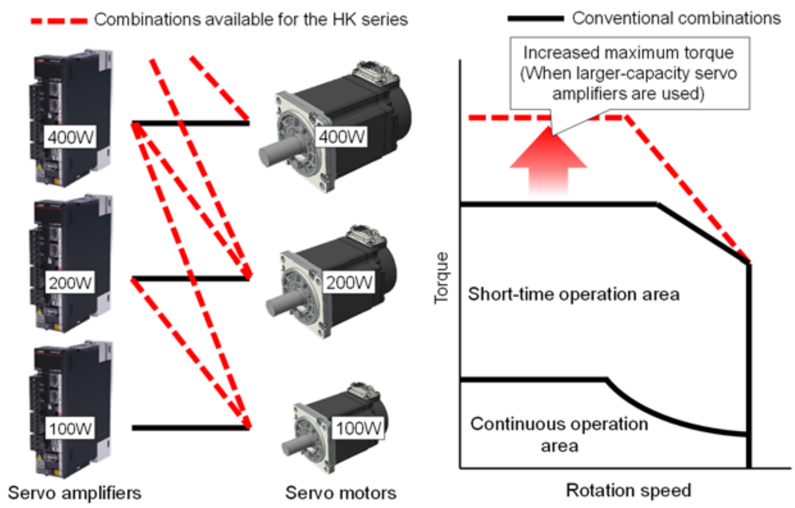


Fig. 5 Use of common magnet for several models

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).

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

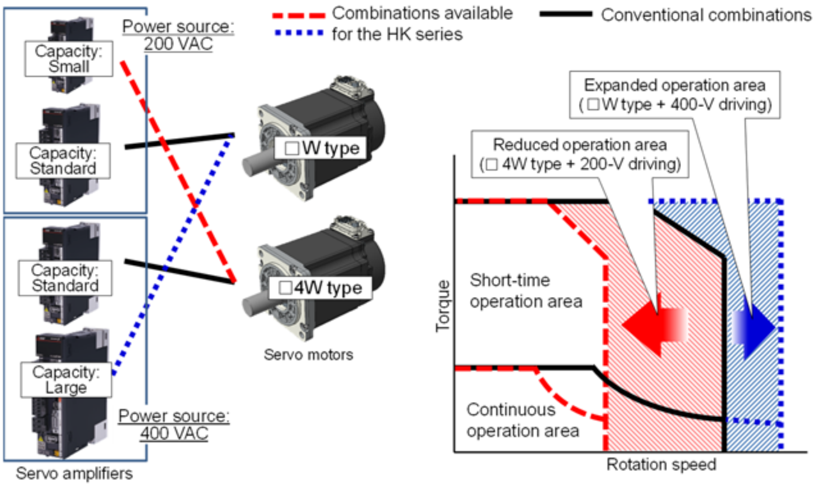


Fig.7 Driving of 200 V/400 V class servo motors

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.

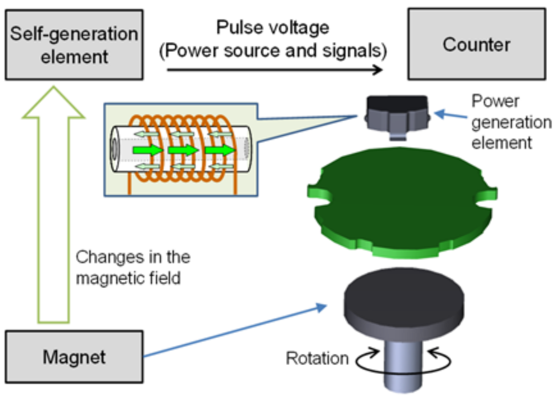


Fig. 8 Principle of batteryless absolute position encoder

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.

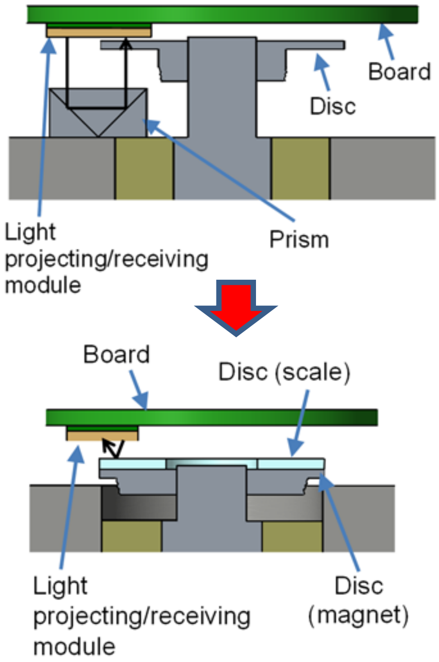


Fig. 9 Optimization of optical detection

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.