Development of SANMOTION R Series, a Small Diameter 20 sq. AC Servo Motor

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1. Introduction

Industrial products are evolving at an ever-increasing pace, making the development of manufacturing equipment which support this essential. Servo motors are a core component of manufacturing equipment and their performance and quality have a significant impact on equipment. Amidst this, semiconductor manufacturing equipment, in particular implementation processes, are developing rapidly with a focus on the Asian market, and in addition to small-scale implementation applied to high performance mobile devices, there is also an increase in the medium/large-scale implementation markets such as high performance home electrical appliances and on-board devices. This means there are many demands on the implementation equipment such as increased implementation speed and multi-functional implementation, therefore servo motors are also required to have higher performance.

Due to this situation, Sanyo Denki newly developed the “SANMOTION R” series featuring a motor with a flange size of 20 sq. (see Figure 1) as a next-generation product. In the conventional P series, we had offered 20 and 28 sq. versions, however the new model is capable of covering the 28 sq. motor torque range with a flange size of 20 sq., not to mention achieve high-speed, multi-functional implementation. This paper discusses the below three topics.

(1) Development concept
(2) Overview of performance enhancement technology
(3) Motor performance comparison

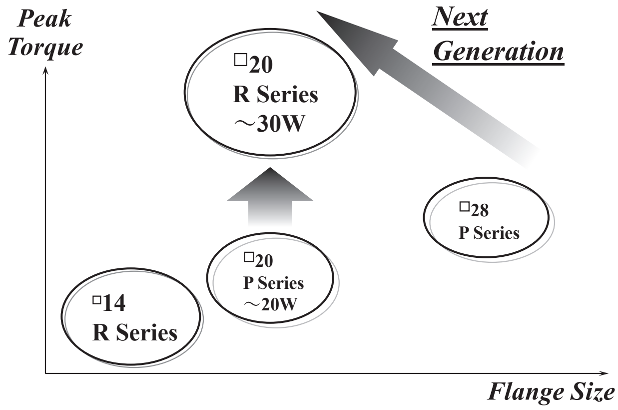

Fig. 1: Positioning of the new model SANMOTION R 20

2. Development concept

The concept of the new model is explained using Figure 2, which shows the new model installed on equipment. On the implementation equipment, several dozen small-diameter motors are located on the head, and Z direction movement is made via linear mechanisms such as ball screws. Moreover, the head is mounted on an XY stage such as a linear motor in order to move it at high speed [(1)]. In this case, the requirement of servo motor functions is to move the equipment fast. Here, fast is categorized into three functions.

(1) Motor shaft operation is fast

In order to shorten the Z axis acceleration/deceleration time and return operation time as well as shorten workpiece positioning time, naturally it is necessary to increase the acceleration rate by raising motor torque, but for axes which have a long stroke, it is feasible that a pattern where the axis fully accelerates and then moves at a constant speed may be adopted, therefore there is a preference for motors which possess a wide output range and can maintain high torque until high rotation speeds are reached.

(2) Head operation is fast

The head itself must be made lighter in order to alleviate the load on the XY axes which operate the head and enhance acceleration performance. As such, the lightening of the motors, which have a combined mass of several dozen, is desirable as components of the head.

(3) Repetitive operation is fast

The Z axis is often operated based on a repetitive acceleration pattern therefore there is a need to minimize the heat generation caused by motor loss. Moreover, if the motor loss is great, a large amount of power is consumed, which is problematic from an environmental perspective. As such, a low loss motor able to reduce the heat generation of the equipment and contribute to energy conservation is desirable.

In other words, the concept of this new model was creating a lightweight, low loss and wide output range motor which offers the above explained three fast operations.

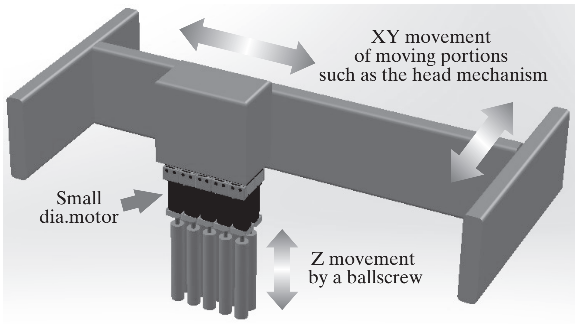

Fig. 2: New model installed on equipment

3. Overview of Performance Enhancement Technology

3.1 Technology for expanding output range and reducing loss

Figure 3 is a phasor diagram. It assumes a situation where the coil specification is standardized so that the motor induction voltage of the conventional model and new model will be the same. The figure demonstrates that the voltage drop on the conventional model due to resistance is extremely large. On semiconductor manufacturing equipment and implementation equipment, there are many cases of driving at low voltage such as bus voltages of 48 or 24 V DC for inverter drive circuits [2]. In order to drive the motor at high torque and high speed even with low voltage, it is necessary to reduce voltage drops caused by resistance as much as possible. Moreover, by reducing resistance, copper loss can be reduced and heat generation can be suppressed.

Therefore, in order to expand output range and achieve low loss, it is necessary to reduce coil resistance by securing sufficient space for coil insertion and increasing the slot occupancy rate as much as possible. To achieve this, we applied the following two technologies.

(1) Magnetic circuit dual-purpose frame structure

The majority of motors have some sort of structure around their stator core to serve as a cage. Techniques include placing a core inside an aluminum frame or molding the core in using insert molding. Such frames must be thick enough to account for aluminum strength and resin flow, which in turn results in decreased torque and reduced coil space.

Hence, by making the frame from magnetic material and thus a part of the magnetic circuit it was possible to sufficiently secure a space of ϕ20 to configure the magnetic circuit. This means it is possible to design so that space for coil insertion is sufficiently secured.

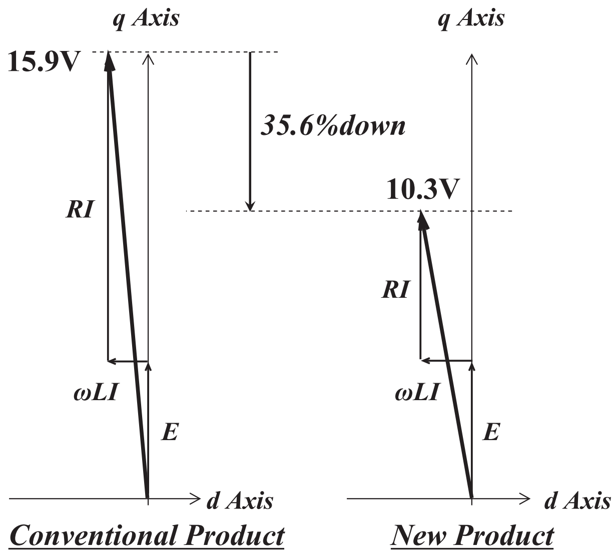

Fig. 3: Phasor diagram
(N = 3000 min^{-1})

(2) Application of high occupancy rate coils

On the conventional model, winding wire was wound using the inner nozzle method. This method is widely adopted and has good productivity, however has demerits such as winding wire alignment deterioration, and reduced occupancy rate due to securing the nozzle path therefore not a suitable method if the aim is to raise the occupancy rate as much as possible and pack the conductor.

As such, on the new model, winding wire is first wound with an air core. This is then mechanically bent into an arc and then inserted into a core, thus achieving a high occupancy rate. High density is achieved by winding with an air core and coil space is utilized to the fullest by forming the coil into an arc.

By using the above two technologies, we succeeded in significantly reducing coil resistance. As shown in Figure 3, the voltage drop of the new model was only 10.3 V compared with 15.9 V on the conventional model, achieving a significant reduction of 35.6%. This means it is possible to reduce voltage drop and achieve a wide output range even when excitation current is high and at high rotation.

3.2 Technology for lightening

Figure 4 is a pallet diagram of the mass for each motor component. In the case of the conventional model, the stator and rotor account for 62.5% of overall mass. Moreover, approximately 78% of the stator weight is accounted for by the stator core.

Therefore, in order to reduce weight, waste of the magnetic material, which makes up the magnetic circuit in the portion which generates an electro-magnetic force, must be kept to a minimum and the core mass must be reduced as much as possible.

However, if the portion which generates an electro-magnetic force is simply reduced, torque will decrease. In an attempt to solve this problem of multiple output parameters contradicting each other, we performed analysis coupling optimization support tools to electro-magnetic simulations [3]. The below technologies were applied to the new model using these techniques.

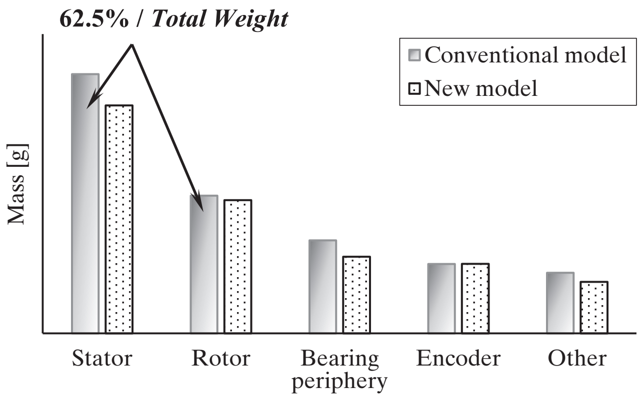

Fig. 4: Mass pallet analysis per component

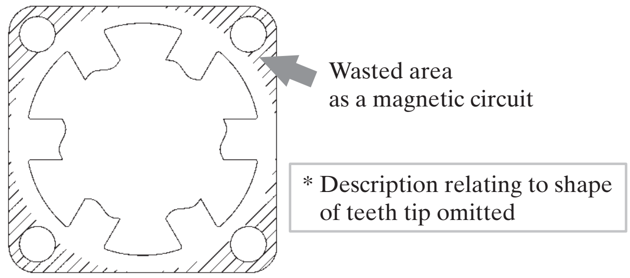

Fig. 5: Shape of the conventional model stator core

Figure 5 shows the shape of the conventional model stator core. The core is square-shaped and makes up a part of the magnetic circuit, however squares are wasted area in this case. This wasted portion accounts for approximately 30% of the stator core cross-section area and also contributes to higher mass. In consideration of this, we removed the wasted portion of the magnetic circuit (indicated by the diagonal lines in Figure 5, and made the outer circumference of the stator round. This made it possible to reduce the wasted space of the magnetic circuit. Figure 4 shows that the new model weighs less than the conventional model, with the mass of the stator in particular being notably reduced. This made it possible to achieve lightening.

4. Motor Performance Comparison

Figure 6 shows the torque vs. speed characteristics The characteristics of the new model are shown with a solid line, while those of the conventional model are shown with a broken line. Compared with the conventional model, the new model is high torque, high speed, and offers a wide output range.

Figure 7 shows the developed motor. The outer circumference of the frame is round, making it possible to reduce mass to 128 grams, which is approximately 8.5% less than the conventional model, which was 140 grams.

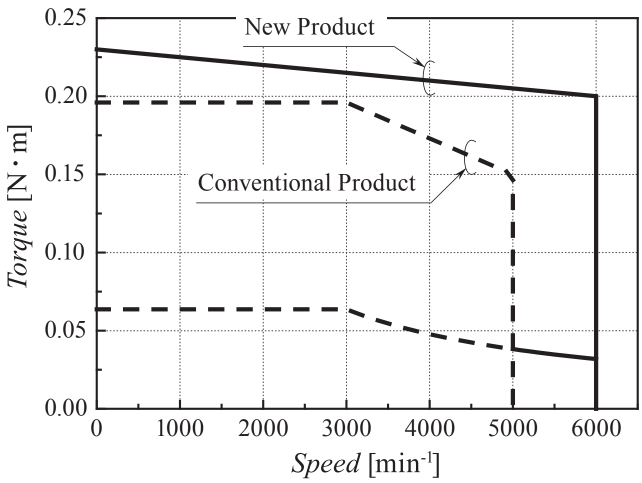

Fig. 6: Torque vs. speed characteristics
(Combined with a Sanyo Denki amplifier, 48 V DC)

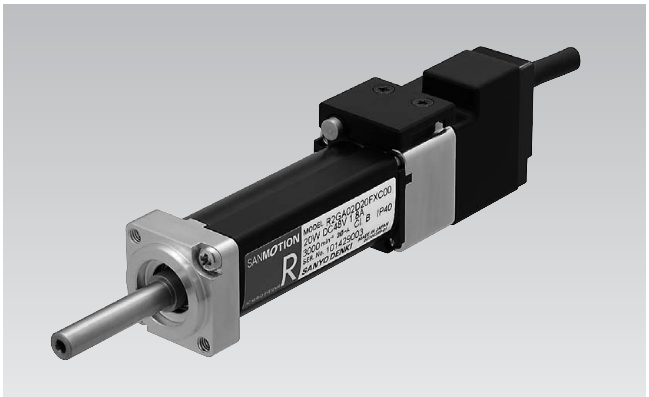

Fig. 7: The developed motor

Motor performance is compared with Sanyo Denki's lineup. The below formula is applied to motor constant density(4).

$$\frac{K_m}{Wt} = \frac{T_R}{\sqrt{W_c}} \cdot \frac{1}{Wt} = \frac{T_R}{\sqrt{3RI_R^{\ 2}} \cdot Wt} \qquad [(\mathrm{Nm/W}^{0.5})/\mathrm{kg}] \qquad (1)$$

Where,	K_m	:	Motor constant	$[\mathrm{Nm/W}^{0.5}]$
	Wt	:	Motor mass	[kg]
	T_R	:	Rated torque	[N·m]
	W_c	:	Copper loss	[W]
	R	:	Phase resistance	[Ω]
	I_R	:	Rated current	$[A_{rms}]$

However, the mass of the motor is the sum of the components which generate torque, namely the stator core, coils, magnets and shaft.

Using Formula (1), Figure 8 compares the characteristics of Sanyo Denki's motors (2) which are driven by the same low-voltage amplifier.

Compared with the conventional 20 sq. motor, there is an improvement of 73.5%. The smaller the motor flange size is made, the more restrictions there are on components such as machining accuracy and assembly accuracy, therefore it becomes difficult to increase torque. In addition, the heat dissipation area decreases, therefore increasing temperature elevation due to loss. The new model reduces loss significantly compared with the conventional model.

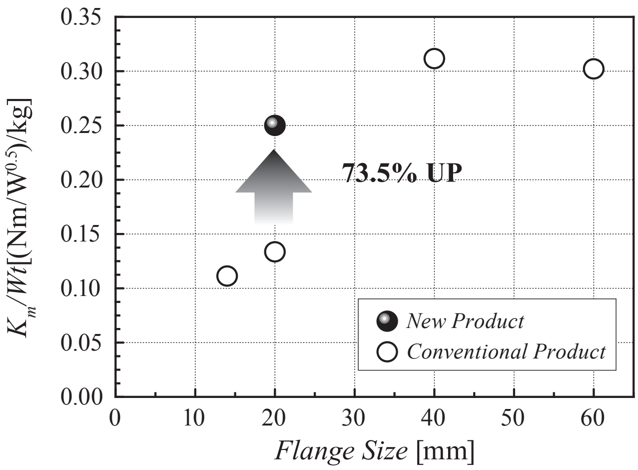

Fig. 8: Comparison of motor constant density

5. Conclusion

This paper has presented the technical achievements of the new model, "SANMOTION R" Series, a Small Diameter 20 sq. AC Servo Motor.

Based on the concepts of a motor with wide output range, lightweight and low loss, we developed a next-generation small diameter motor. By applying a magnetic circuit dual-purpose frame structure with high occupancy rate coils, we achieved both expansion of the output range and lightening. Moreover, by reducing copper loss, motor heat generation was suppressed which also contributed to energy conservation.

Sanyo Denki would be delighted if we could make even a small contribution to the creation of new value in our customers' development of next-generation products.

Reference

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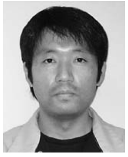

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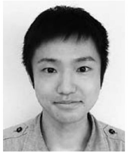

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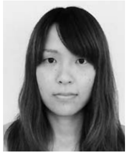

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