Development of Small Capacity, High Precision AC Servo Motor

"SANMOTION R" Without the Rare Earth Metal Dysprosium

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1. Introduction

Due to the soaring cost and uncertain supply of rare earth in recent years, the profitability of high performance servo motors which use neodymium rare earth magnets (hereinafter "magnets") is worsening. Dysprosium, which is classified as a heavy rare earth element, is particularly important to improve the temperature property of magnets and as such, is used in the magnets of servo motors. The raw material price of dysprosium (FOB/China) was $147.5 / kg at the beginning of 2010 but soared to $3,410 / kg by July 2011, more than a 20-fold increase in just a year and a half as part of a "rare earth shock" . In preparation for the reduction in rare earth availability likely to occur in the future, moves are being made to significantly reduce magnet usage, with achieving dysprosium-free magnets being the urgent challenge as the development of products unaffected by raw material cost and resource procurement is favorable.

Meanwhile, cost competition is growing in the servo motor market due to the demand for motor performance suitable for users' equipment and the emergence of motors made in developing countries. There is a particular demand for higher precision in order to improve machining performance in application on machine tool feed shafts.

The "SANMOTION R" Series R5 servo motor is a product developed with the concepts of dysprosium-free, less magnet usage and higher precision. This document discusses the study of an optimized design for high torque and reduced magnet usage, which are in a trade-off relationship with each other, as well as the shift to low cogging torque, low speed fluctuation and the benefits towards higher precision by improving current loop gain.

2. Optimized Design and Performance Improvement

2.1 Study of an optimized design for high torque and reduced magnet usage

By combining an optimized design support tool, [modeFRONTIER], a magnetic field simulation CAE, [JMAG-Designer] and 3D CAD, [SolidWorks], optimized design was examined (See Fig. 1). There are 4 objective functions (target specifications) of optimized design. Namely, higher torque, minimal magnet usage, low cogging torque and low torque ripple; in other words, multi-objective optimization. By taking magnet demagnetization bearing force into consideration when setting restraint conditions (minimum standard value), we executed an automatic search for the optimal solution with dysprosium-free as a presumption.

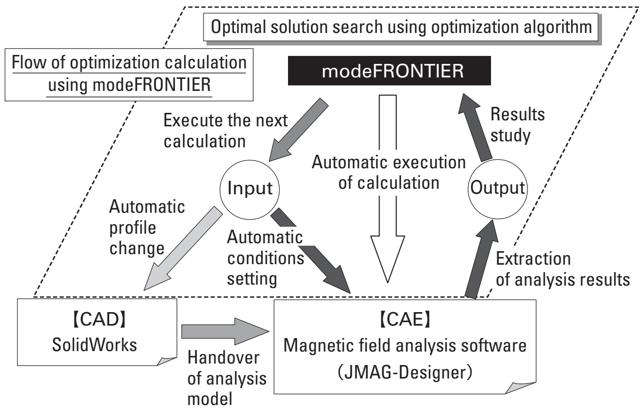

Fig. 1: Automatic optimal solution search using an optimized design support tool

Fig. 2 shows the results of an automatic optimal solution search only extracting the torque and magnet usage (Motor with 750 W rated output) Around 300 models are automatically calculated. As can be seen from the figure, torque improvement and magnet usage reduction are at a trade-off with one another, and the threshold indicated by the curved line is the optimal solution aggregate, referred to as Pareto solutions.

From amongst the Pareto solutions, the model which achieved the target torque of 8 N·m was adopted as the optimal solution. Through this optimization study, it was possible to reduce magnet usage by around 60% compared with the conventional model.

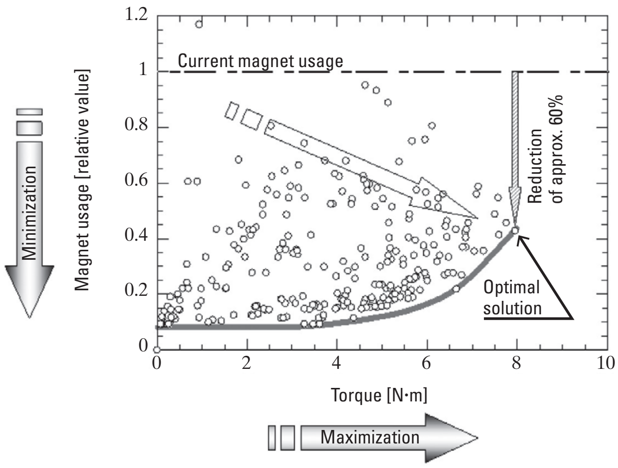

Fig. 2: Results of an optimization study for high torque and magnet reduction (Flange square size 80 mm, rated output 750 W)

2.2 High precision

There is a demand for servo motors with stable speed control on machine tool feed shafts which are required to perform high precision machining. The new model achieves the below as a high precision design.

- Improved speed fluctuation for the motor itself (low cogging torque, low torque ripple)
- Current frequency was improved in order to improve speed frequency responsiveness and disturbance suppression responsiveness.

Fig. 3 shows the cogging torque compared with the conventional model (comparison with Sanyo Denki's R2 servo motor) The cogging torque of the new model is approximately 30% less than that of the conventional model. Fig. 4 shows a comparison of speed fluctuation. Speed fluctuation is between 18 and 30% less on the new model compared to the conventional model. By making the cogging torque and speed fluctuation smaller in this way, the new model motor improves the root causes effecting speed controllability.

Fig. 5 shows a comparison of the current frequency responsiveness with the conventional model. The current loop gain in the vicinity of 500 Hz which effects speed controllability in machine too feed shafts is improved by 2.4 to 4.1 dB in the new model compared with the conventional model. Improving current frequency responsiveness improves the control of the precision feed in machine tools and contributes to the improvement of machining performance. Current frequency responsiveness is improved by optimizing motor impedance and control parameters.

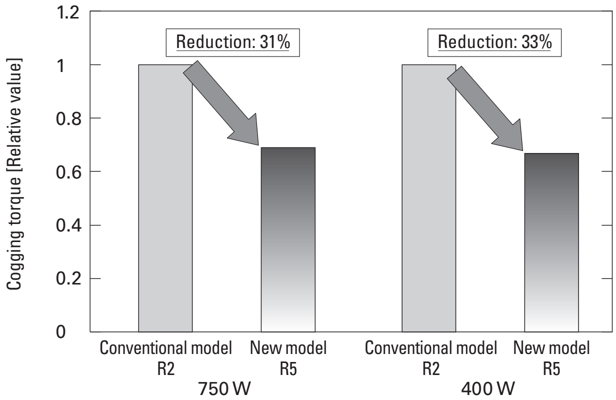

Fig. 3: Comparison of cogging torque (Comparison between the conventional model and the new model)

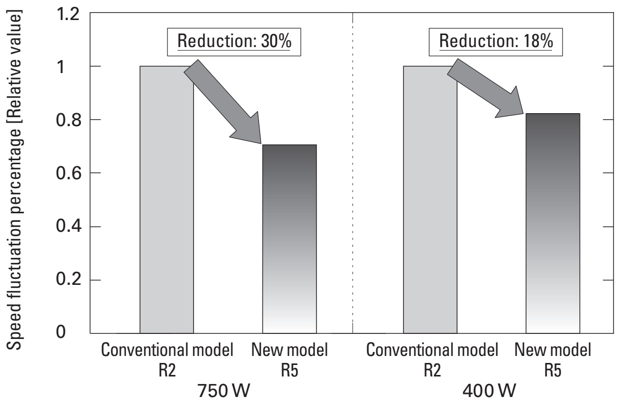

Fig. 4: Comparison of speed fluctuation (Comparison between the conventional model and the new model)

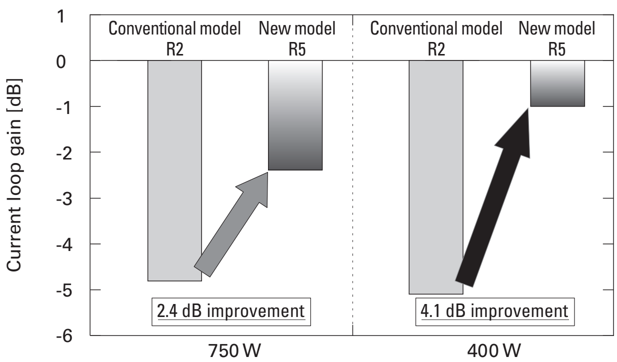

Fig. 5: Comparison of current frequency responsiveness (Comparison between the conventional model and the new model, 500 Hz)

3. Product Lineup

Fig. 6 shows the new model, while Table 1 outlines the major specifications. On the type with a flange square size of 60 mm, there are two types of rated outputs; 200 W and 400 W. For each of these, low speed and high speed specifications have been prepared with maximum speed of 3000 and 6000 min^{-1}. The flange square size of 80 mm has only one type of rated output; 750 W, for which there is a low speed specification with a maximum speed of 5000 min^{-1}, and high speed of 6000 min^{-1}. As the standard specification, a serial communication absolute encoder is used with a 17-bit resolution (maximum resolution of 20 bits)

Figures 7 through to 9 show torque vs. speed. The output also achieves a wide range. The low speed servo motor has particularly good high precision, making it suitable for precision feed equipment such as machine tool feed shafts. The high speed servo motor is suitable for applications which seek high speed such as industrial robots.

Fig. 6: The new model

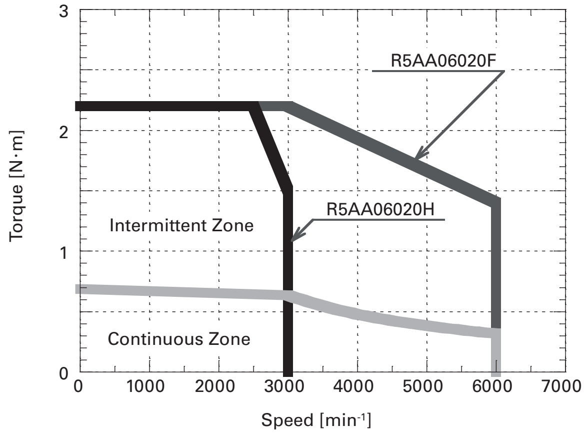

Fig. 7: Torque vs. speed characteristics
(Flange square size □60 mm, 200 W)

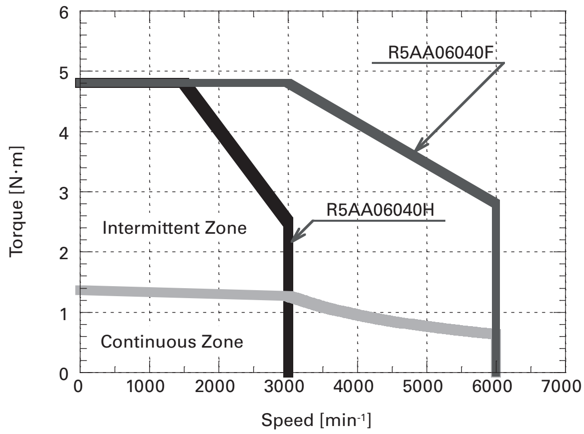

Fig. 8: Torque vs. speed characteristics
(Flange square size □60 mm, 400 W)

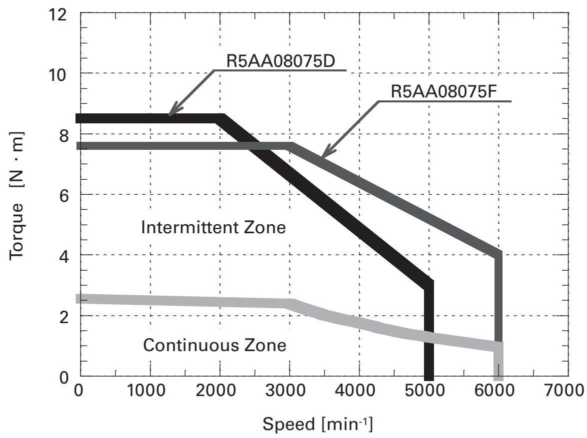

Fig. 9: Torque vs. speed characteristics
(Flange square size □80 mm, 750 W)

Motor model No. / 〈 〉 Flange squared dimensions			R5AA06020H	R5AA06020F	R5AA06040H	R5AA06040F	R5AA08075D	R5AA08075F
Item	**Symbol**	**Units**	〈□60mm〉				〈□80mm〉	
Rated output	P_R	W	200		400		750	
Rated speed	N_R	min^{-1}	3000					
Max. speed	N_{max}	min^{-1}	3000	6000	3000	6000	5000	6000
Rated torque	T_R	N·m	0.637		1.27		2.39	
Continuous stall torque	T_S	N·m	0.686		1.37		2.55	
Instantaneous max. stall torque	T_P	N·m	2.2		4.8		8.5	7.6
Rotor inertia	$J_M \times 10^{-4}$	$kg \cdot m^2(GD^2/4)$	0.198		0.414		1.65	
200 V AC compatible amplifier model No.			RS2A01			RS2A03		

4. Conclusion

This document has introduced the technical advantages of the new model, “SANMOTION R” series R5 servo motor.

By reducing magnet usage significantly and achieving dysprosium-free magnets as a way to alleviate rare earth issues of recent years, we have created a product which is not easily effected by raw material cost and alleviates the problem of uncertain supply due to export amount limitations of rare earth producing countries.

Moreover, the new model has significantly reduced cogging torque and speed fluctuation, therefore achieving excellent current frequency responsiveness. It is a motor suitable for high precision locating and smooth precision feed, ideal for applications such as machine tool feed shafts which are required to have high precision and high quality machining ability. As an alternative to the high inertia motor conventionally adopted, this is an AC servo motor which can greatly contribute to machine downsizing and cost reduction.

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