Performance of Segment Type Switched Reluctance Motor using Grain-Oriented

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***Abstract* —Authors developed a segment type switched reluctance motor (SRM) as a rare earth less motor. The object is to reduce the acoustic noise and vibration as well as improve the torque characteristics. In this paper, we propose the performance improve method using grain-oriented electric steel as the segment core. The validity is confirmed experimentally.**

***Index Terms* – Grain oriented electric steel, Segment type, Switched reluctance motor**

I. INTRODUCTION

We previously proposed a novel segment type switched reluctance motor (SRM) in which the segment core was embedded in an aluminum rotor block to increase the torque and reduce the vibration and acoustic noise compared with the conventional VR type SRM [1]. The average torque was larger than the same-sized VR type SRM, and the vibration and acoustic noise were reduced well [1]-[3]. However, the efficiency is still lower than that of the permanent magnet type synchronous motor.

In this paper, we try to improve the torque and efficiency using the grain-oriented electric steel for the segment core that have low iron loss, high permeability and high saturation magnetic flux density performance.

II. NOVEL SEGMENT TYPE SRM

Fig. 1 shows the construction of a novel segment type SRM. This motor has 3-phase double layer full pitch stator windings. The segment core made of non-oriented electric steels is embedded in the aluminum rotor block. We call the rotor Type A. Fig. 2 shows the 2.2 kW and 1,800 rpm experimental machine of the novel segment type SRM with 6 stator poles and 4 rotor segment cores.

Fig. 3 illustrates the drive system. This system consists of the bipolar type driver using IGBT-based voltage source inverter and the controller using the floating point 32 bit DSP. The following events are processed in the DSP, such as rotor speed calculation using rotor position information from the rotary encoder, selection of the phase to apply current command from the table corresponding with position information, decision of current command to output through D/A converter. The sampling period of the all events is 200μs. The gate pattern for IGBT is generated by comparing the current command with a measured input current. The PWM inverter has 12 IGBT devices and is used not only for bipolar drive test but also for unipolar drive test.

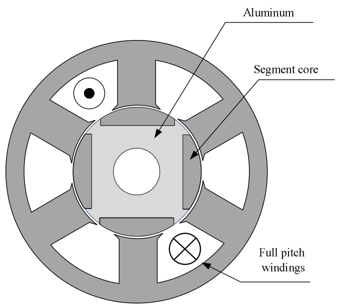
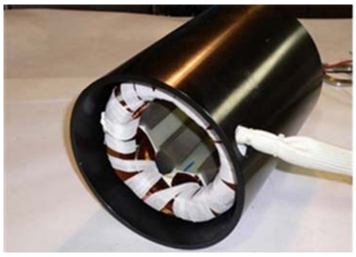


Fig.1. Construction of the segment type SRM (Type A)

(a) Stator



(b) Rotor

Fig. 2. Experimental machine of segment type SRM.

Fig. 4(a) shows the theoretical torque versus angle characteristics at 1,800 rpm. A line of circle shows the torque of the novel segment type SRM with aluminum block, a line of rectangular shows the conventional segment type SRM without aluminum block and a line of rhombus shows the VR type SRM under same constant current drive.

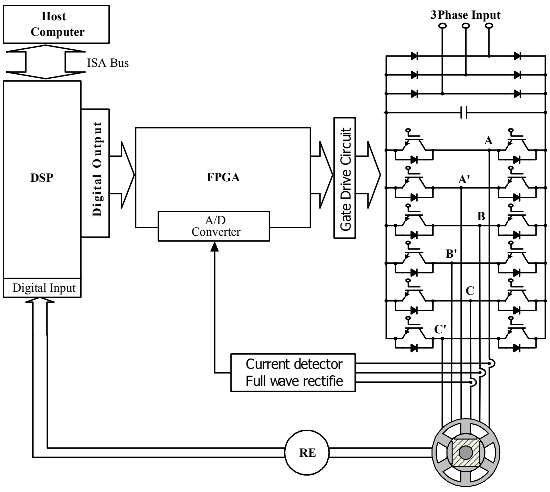


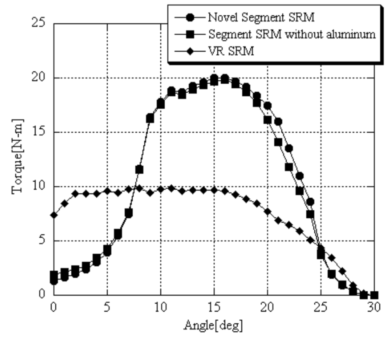
Fig. 3. Drive system.

Since four stator poles are excited, as shown in Fig. 5(a), the maximum torque of both segment type SRM is twice as that of the VR type SRM. Their average torques are as follows; the novel segment type SRM 10.34 N-m, the segment type SRM without aluminum block 10.07 N-m, the VR type SRM 7.40 N-m. Fig. 4(b) shows the radial force versus angle characteristics per one pole at 1,800 rpm. In the region of about 22 degrees, two stator poles of the VR type SRM are attracted to the rotor with large radial forces with 4,000 N, respectively. When the current is switched to another phase at 30 degrees, the poles released from the large attractive force and causes vibration and acoustic noise. In comparatively, four stators of the segment type SRM are, respectively, attracted with 1,400 N at 24 degrees, about one-third of that of the VR type SRM. Therefore, the vibration and acoustic noise are reduced rather than the VR type SRM.

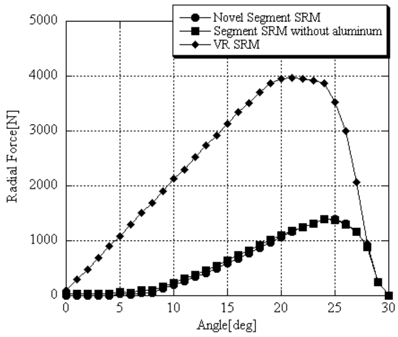
The experimental output characteristics are compared with the conventional VR type SRM. Fig. 6(a) shows efficiency-output characteristics at 1,800 rpm. The efficiency of the novel segment type SRM decreases with increasing output. It mainly depends on copper loss in the large coil end and eddy current loss in the aluminum rotor block. However the rated efficiency at 2kW and 1,800 rpm is about 80% and that of low output region is better than the VR type SRM.

Fig. 6(b) shows input current-output characteristics. When comparing at the same speed and current, the output of the novel segment type SRM increases by about 50% rather than the VR type SRM.

Furthermore, the vibration and acoustic noise are reduced rather than the VR type SRM. The vibration of the novel segment type SRM is 21 m/s^2 at 1,800 rpm and torque of 3 N-m, while that of the VR type SRM is 48 m/s^2.

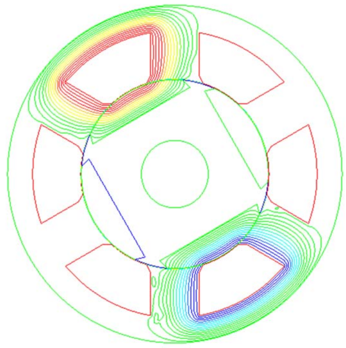


(a) Torque - angle characteristics

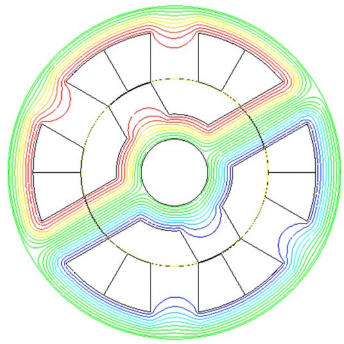


(b) Radial force per pole - angle characteristics

Fig. 4. Performance characteristics

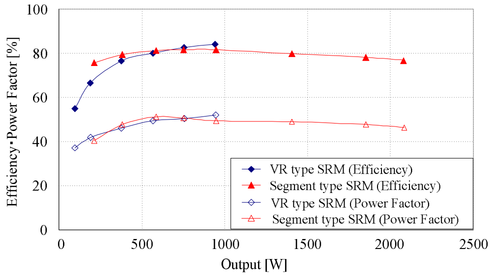


(a) Novel segment type SRM

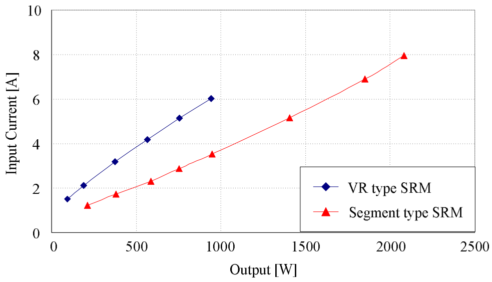


(b) VR type SRM

Fig. 5. Flux distributions



(a) Efficiency, Power factor



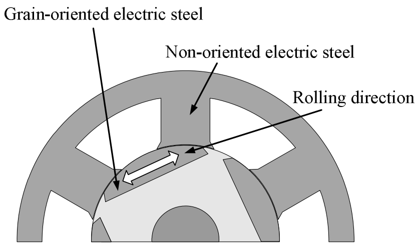
(b) Current

Fig. 6. Output characteristics at 1,800 rpm.

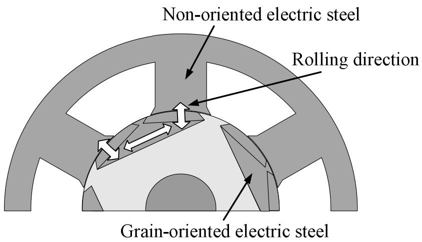
III. Performance of Grain-Oriented Electric Steel Type SRM

A. Rotor construction

We made two type rotors having grain-oriented electric steel segment core and investigate the performance characteristics analytically experimentally. The rotors are shown in Fig. 7. In Fig. 7(a), the grain-oriented electric steel is stacked with same rolling direction. We call it Type B. In Fig. 7(b), the grain-oriented electric steel is divided tree parts. We call it Type C. The B-H curve is shown in Fig. 8.

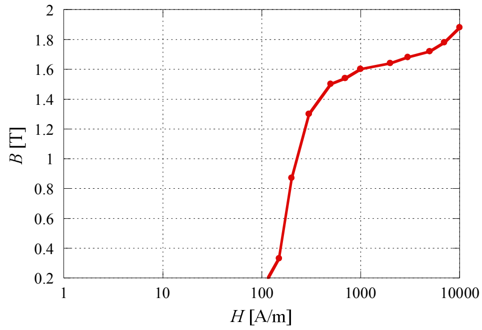


(a) Type B

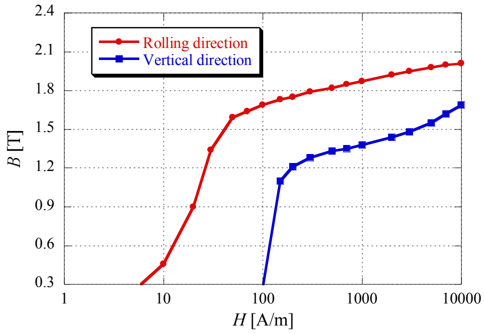


(b) Type C

Fig. 7. Rotor construction



(a) Non-oriented electric steel



(b) Grain-oriented electric steel

Fig. 8. B-H curve of iron steels.

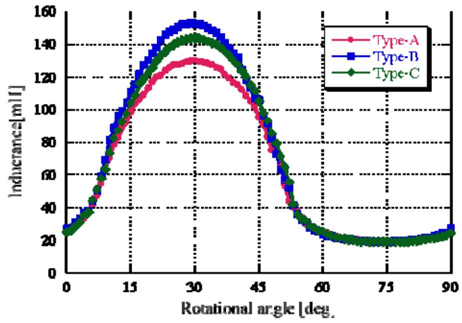


Fig. 9. Inductance characteristics.

B. Performance Characteristics

Fig. 9 shows the experimental inductance characteristics of the tree type rotors. Inductance of Type B and Type C is larger than that of Type A. The inductance of Type B is larger than Type C, because it has no split.

Fig. 10 shows the experimental characteristics of average torque, iron loss + eddy current loss, efficiency at 600 rpm. The analytical results show that the torque of Type C is greater than that of the other rotors, the losses of Type B and C smaller than Type A, and the efficiency of Type C is highest. In experiment, however, there are no differences in the torque, losses and efficiency among the three type rotors.

Fig. 11 shows the experimental characteristics at 1800 rpm. In this case the iron loss + eddy current loss of Type B and C is smaller than that of Type A. Consequently the efficiency of Type B and C is better than Type A

Table I compares the efficiency at 600rpm, 1200rpm, 1800rpm. It is shown that the grain-oriented steel segment core increases the efficiency about 1.5% rather than usual non-oriented steel segment core.

. CONCLUSIONS

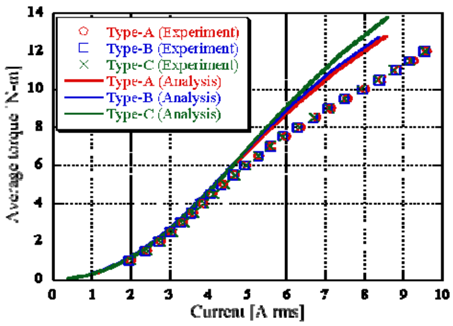
In this paper we show the experimental result about the segment type SRM that uses grain-oriented electric steel for the rotor segment core. The efficiency is increased by 1.5% compared with using non-oriented electric steel.

In this paper, the firing angle is fixed. The efficiency will be improved by optimizing the firing angle.

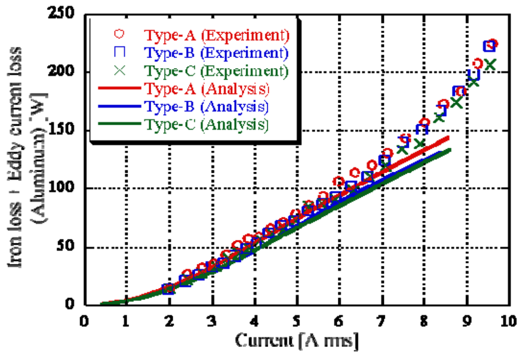
TABLE I

MAXIMUM VALUE OF EFFICIENCY

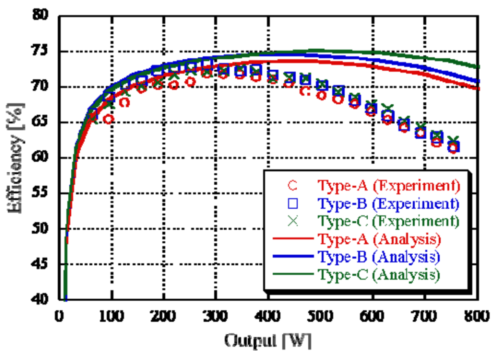
	600rpm	1200rpm	1800rpm
Non-oriented steel	71.9%	73.3%	73.2%
Grain-oriented steel	73.2%	75.0%	74.6%



(a) Average torque

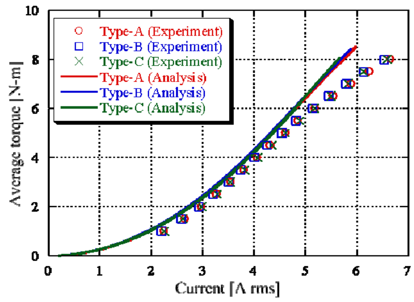


(b) Iron loss and Eddy current loss

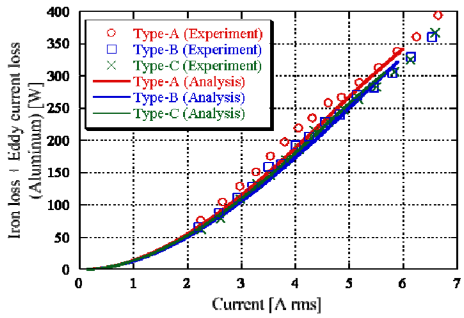


(c) Efficiency

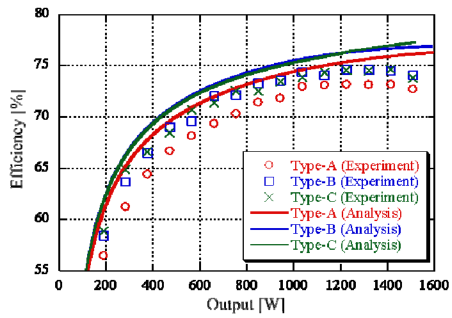
Fig. 10. Performance characteristics at 600 rpm.



(a) Average torque



(b) Iron loss and Eddy current loss



(c) Efficiency

Fig. 11. Performance characteristics at 1800 rpm.

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