Comparison of 6-Phase Switched Reluctance Motors with 24 Stator Slots

Noboru NIGUCHI, Nozomu TAKEMURA, and Katsuhiro HIRATA

Division of Materials and Manufacturing Science, Graduate School of Eng., Osaka University, Suita, 565-0871, Osaka, Japan

Junka OKAMOTO and Hironori SUZUKI

COMPONENT PRODUCTION ENGINEERING CENTER, MITSUBISHI ELECTRIC CORP., Amagasaki, 661-8661, Hyogo, Japan

Abstract

This paper compares 6-phase switched reluctance motors (SRMs) with 24 stator slots. A 24-slot-20-pole (24/20) SRM has a small torque ripple compared with a conventional 24/16 3-phase SRM. However, the iron loss of a 24/20 SRM is larger than that of a 24/16 SRM because the number of rotor poles is large. In order to decrease the iron loss of a 6-phase SRM, 24/14 and 24/10 SRMs are firstly proposed in this paper. Next, the torque and iron loss characteristics of these 6-phase SRMs are compared. Finally, the effectiveness of the proposed 24/14 and 24/10 SRMs are discussed.

1 Introduction

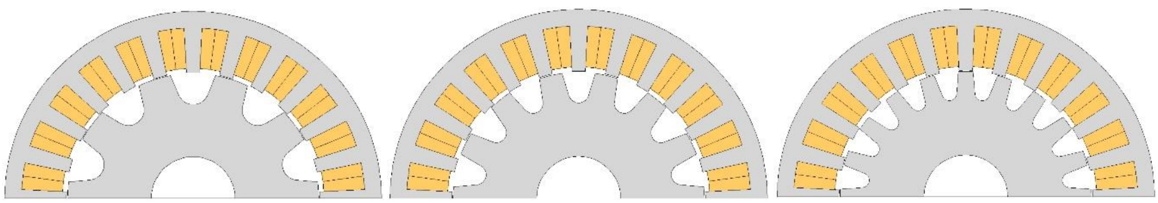
A traction motor of electric vehicles and hybrid electric vehicles usually utilize an interior permanent magnet synchronous motor (IPMSM). On the other hand, rare-earth-free motors such as an induction motor, electrically excited synchronous motor, and switched reluctance motor (SRM) have been developed for a traction motor. Among them, an SRM has not been used as a traction motor. One of the reasons why an SRM is not used is that the iron loss is large due to the large number of rotor poles [1].

In this paper, 3 6-phase SRMs with 24 slots are compared in terms of the iron loss and efficiency. When the number of slots is 24, 10-, 14-, or 20-salient-pole rotor is available. The operational principle of 3 SRMs are described in terms of modulated fluxes. 3 SRMs are designed, and the performance are compared at 3 rotation speeds: low, middle, and high rotation speeds.

2 Configuration of 3 Switched Reluctance Motors

3 SRMs with 24 slots shown in Figure 1 are compared. 3 SRMs have the same stator. The outer diameter and stack length of the stator is ϕ180 and 55 mm, respectively. The number of coil turns per slot is 10, and connected in parallel in a phase. In addition, the 6-phase coils form a star connection. The width of the salient pole of the rotor is optimized that the phase current would be small when the maximum torque is generated. The coil arrangement of 3 SRMs is shown in Table 1, where the current is applied in the order of the A, F, E, D, C, and B phases.

The 24/20 SRM has a conventional winding, and 12-pole-pair magnetic flux is created due to the DC component of the coil current. The 12-pole-pair magnetic flux creates an 8-pole-pair modulated flux due to the 20 salient poles. Therefore, the 8-pole-pair modulated flux synchronizes with the 8-pole-pair rotating magnetic field, and the rotor rotates as a 16-pole-24-slot 3-phase motor. Similarly, the coil arrangement of the 24/14 SRM creates a 6-pole-pair magnetic flux due to the DC component of the coil current. The 6-pole-pair magnetic flux creates a 8-pole-pair modulated flux due to the 14 salient poles, and the rotor rotates as a 16-



(a) 24/10 (b) 24/14 (c) 24/20

Figure 1: Switched reluctance motor with 24 slots

Table 1: Coil arrangement

Slot No.	1	2	3	4	5	6	7	8	9	10	11	12
24/10	A	D	B	E	C	F	D	A	E	B	F	C
24/14	A	D	F	C	E	B	D	A	C	F	B	E
24/20	A	B	C	D	E	F	A	B	C	D	E	F

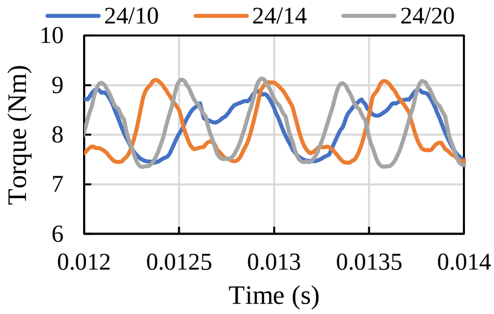


Figure 3: Torque waveforms

Table 2: Performance at 1182 rpm

	24/10	24/14	24/20
Torque	8.2 Nm	8.1 Nm	8.2 Nm
Efficiency	96.1%	96.3%	96.3%
Phase current	39.8 A	38.5 A	38.5 A
Copper loss	136 W	127 W	127 W
Iron loss in rotor	6.2 W	7.7 W	8.6 W
Iron loss in stator	19.3 W	17.5 W	16.3 W

pole-24-slot 3-phase motor. On the other hand, the coil arrangement of the 24/10 SRM creates a 6-pole-pair magnetic flux due to the DC component of the coil current. The 6-pole-pair magnetic flux creates a 4-pole-pair modulated flux due to the 10 salient poles, and the rotor rotates as a 8-pole-24-slot 3-phase motor.

3 Comparison under Pulse Drive

In order to compare 3 SRMs, the performance at 1182 rpm is computed under pulse drive. The target torque at 1182 rpm is 8 Nm, and the hysteresis control is applied, where the maximum current is adjusted so that the torque is about 8 Nm. The torque waveforms are shown in Figure 3, and the performance is shown in Table 2. From these, the torque ripple and efficiency are almost the same with each other. However, the difference can be found in the iron loss. The iron loss in the rotor and stator increases and decreases, respectively, as the number of rotor salient poles increases. This mechanism will be described in the full paper.

4 Conclusion

In this paper, 3 6-phase SRMs with 24 stator slots were compared by finite element analysis. A difference was found in the iron loss of the rotor and stator. This will be investigated in the full paper, and the performance under middle and high rotation speeds will be investigated.

References

[1] N. Takemura, K. Hirata, N. Niguchi, and H. Suzuki, *Development of a 12/10 Hex Connection SRM for Electric Vehicle Traction Motors*, Proceedings of the 25th International conference on Electrical Machines (ICEM2022), pp.239-245, 2022.