Development of High-Speed Switched Reluctance Motor for Electric Power Tools

Kenji Nakamura¹, Yuya Kumasaka¹, Osamu Ichinokura¹
¹Graduate School of Engineering, Tohoku University, 6-6-05 Aoba Aramaki Aoba-ku, Sendai 980-8579, Japan
E-mail: nakaken@ecei.tohoku.ac.jp

Abstract. This paper presents design and experimental evaluation of a switched reluctance (SR) motor used for electric power tools. First, characteristics of a previous designed 6/4-pole SR motor is shown and compared to a permanent magnet (PM) motor used in present electric power tools. Next, to further improve characteristics, a 12/8-pole SR motor is designed and evaluated in experiment. It is proved that the performance of the prototype 12/8-pole SR motor is almost comparable or superior to the present PM motor.

1. Introduction

Electric power tools including an electric screw driver and an electric impact driver etc. have generally employed less expensive universal motors. But recently, permanent magnet (PM) motors are being employed instead of the universal motors due to high-power, high-efficiency, and maintenance-free operation. However, the cost of rare-earth magnets used in the PM motors is high and its supply is unstable because of few producing countries. Therefore, it is expected to develop the rare-earth-free, high-power, high-efficiency, and maintenance-free motor for electric power tools.

A switched reluctance (SR) motor is simple and robust, less expensive due to no PMs, and maintenance-free. Thus, it is expected to be put into various fields [1]-[4], especially into high-speed applications like electric power tools. However, torque and efficiency of the SR motor are generally inferior to those of the PM motor.

In a previous paper [5], to overcome the above problem, we designed a 6/4-pole SR motor for electric power tools using a three-dimensional finite element method (3D-FEM), and indicated the possibility that the designed SR motor has almost the same performance as a PM motor used in present electric power tools. This paper describes further improvement of the SR motor and indicates experimental results of the prototype SR motor to demonstrate the performance of the prototype motor is almost comparable or superior to the present PM motor.

2. Characteristics of a previous 6/4-pole SR motor [5]

Figure 1(a) shows specifications of the PM motor used in present electric power tools. It is a three-phase, six-slots, and four-pole motor. The core material is non-oriented Si steel with a thickness of 0.35 mm, and the magnet material is Nd-Fe-B.

Figure 1(b) indicates the previous designed SR motor. The motor diameter and the axial length, and the core material are the same as those of the PM motor. On the other hand, the gap length is 0.2 mm, while the PM motor has 0.5 mm since the gap length greatly influences on the performance of the SR motor. In addition, the winding space factor is higher because the SR motor has an open slot structure.
It was investigated from a geometrical viewpoint how many windings can be placed in the stator slot of the SR motor as shown in Figure 1(c). Thereby, the winding space factor of the designed SR motor was estimated about 47%, while the PM motor has about 24%.

Figure 1(d) indicates current density versus torque characteristics calculated by the 3D-FEM. It is understood that the torque of the designed SR motor is almost the same as that of the PM motor, however that the torque increasing becomes gentle under heavy load since magnetic saturation occurs in the stator salient pole.

3. Design and experimental evaluation of a 12/8-pole SR motor

To improve the magnetic saturation, the number of the poles is increased twice, namely, a 12/8-pole SR motor is designed as follows: let the winding diameter and the number of windings per phase of the 12/8-pole SR motor be the same as those of the 6/4-pole one. Accordingly, the number of windings per pole of the 12/8-pole SR motor is half the 6/4-pole one. Under the above conditions, the slot shape and dimensions are optimized from a geometrical viewpoint in the same manner shown in Figure 1(c). As a result, the widths of the stator pole and yoke of the 12/8-pole SR motor are about 60% of the 6/4-pole one, namely, it is expected to improve the magnetic saturation because the relative widths of the stator pole and yoke of the 12/8-pole SR motor are wider than those of the 6/4-pole one. Figure 2 indicates a comparison of contour diagrams of flux density of the 6/4-pole and 12/8-pole SR motors. The figure reveals that the magnetic saturation is relieved in the 12/8-pole SR motor.

In addition, the length of the coil-end can be shortened since the number of windings per pole becomes half. Thereby, the stack length of the stator core of the 12/8-pole SR motor can be increased to improve the torque. Figure 3(a) shows shape and dimensions of the prototype 12/8-pole SR motor which is designed based on the above conditions. As shown in the figure, the stack length of the stator core is increased from 10.85 mm to 13.45 mm. Figure 3(b) indicates an appearance of the prototype SR motor, and (c) illustrates an experimental system.
Figure 3. (a) Shape and dimensions of the prototype 12/8-pole SR motor, (b) Appearance of the prototype SR motor, and (c) Experimental system.

Figure 4(a) shows comparison of the current density versus torque characteristics. It is understood that the maximum torque of the prototype SR motor is larger than that of the present PM motor, and the measured values are agree well with the calculated ones. Figure 4(b) indicates the torque versus speed characteristics. The prototype SR motor exhibits the good performance as designed. Figure 4(c) shows the efficiency characteristics. From the figure, it is understood that the maximum efficiency of the prototype 12/8-pole SR motor is about 80%.

4. Conclusion
This paper presented the design and experimental evaluation of the SR motor used for electric power tools. First, characteristics of the previous designed 6/4-pole SR motor was indicated and compared to the PM motor used in present electric power tools. Next, to further improve characteristics, the 12/8-pole SR motor was designed. As a result, the relative cross sections of the stator pole and yoke of the 12/8-pole SR motor were larger than those of the 6/4-pole one, and thereby the magnetic saturation was relieved. Finally, the prototype 12/8-pole SR motor was evaluated experimentally. It was proved that the prototype SR motor has good performance as designed, and that the maximum torque of the prototype SR motor is larger than that of the present PM motor.

References
[1] Becerra R C, Ehsani M, and Miller T J E 1993 IEEE Trans. Power Electron. 8 257-263
[2] Ferreira C A, Jones S R, Drager B T and Heglund W S 1995 IEEE Trans. Power Electron., 10 55-61
[3] Rahman K M, Fahimi B, Suresh G, Rajarathnam A V and Ehsani M 2000 IEEE Trans. Ind. Applicat. 36 111-121
[4] Nakamura K, Suzuki Y, Goto H and Ichinokura O 2005 Journal of Magnetism and Magnetic Materials 290-291 1334-1337
[5] Isobe K, Nakamura K and Ichinokura O 2014 Journal of the Magnetics Society of Japan 38 194-198