A Comparative Analysis of Two Kinds of Poles for Washing Machine's IPMSM with the Same Torque and Output Power

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***Abstract*-Structure of motor can be designed variously according to necessary condition with the same torque and output power. Specially, characteristic of motors are varies according to selection of the number of poles and slots on the assumption that constraints of motor are the same. It goes without saying that is identity of pole and slot ratio.**

In this paper, it is comparative that are characteristics of two kinds of Interior Permanent Magnet Synchronous Motor (IPMSM) which have 8poles/12slots (8p/12s) and 16poles/24solts (16p/24s) through analysis simulation by using finite element method and experiment.

I. INTRODUCTION

Recently, it does actively research on energy saving of the home appliance due to exhaust resources.

The motor which is one of the home appliance parts has been researched continuously to have high efficiency by creating new motor or optimizing design of motor [1]-[3]. It is significantly important that is selection of the number of poles and slots in motor design due to reduction of design time and efforts to come true good characteristics. Generally, the design of motor is various according to designers and purposes. But characteristics of motor are not same.

Interior permanent magnet synchronous motor (IPMSM) is representative of the high efficiency motor as well as high power density, high torque density, and wide range speed control [1]-[3]. But design of IPMSM is not easy though IPMSM has many merits. Characteristics of IPMSM are greatly affected by the motor shape, for instance, which are barrier shape, permanent magnet shape, and so on [4]-[5].

This paper deals with two types of IPMSM for washing machine. One is 8 poles / 12 slots (8p/12s) with concentrated winding and the other is 16 poles 24 slots (16p/24s) with concentrated winding. The ratio of pole and slot of two types is the same as the ratio is 2:3. It is consider the all comparison condition of two types of motor as one and the same thing except the number of poles and slots. The reason of selection the ratio of pole and slot as 2:3 and concentrated winding is that the design of IPMSM is very easy and widely used [4].

This paper process is as follows: The first, two types of motor are optimized by using finite element method (FEM). The seconds, characteristics of motors are compared. The third, the validity of simulation is identified through the experiment.

II. DESIGN OF TWO TYPES OF IPMSM

IPMSM operation is divided into two parts. One is constant torque region and the other is constant power region. In washing machine, laundry mode belongs to the constant torque region and spin-drying mode belongs to the constant power region. Fig. 1 shows torque versus speed curve for washing machine IPMSM. In this paper, design details of the IPMSM is as follows: Constant torque is 20Nm at 45rpm (speed)/12V (back-emf) and constant power is 800Watt from 400rpm to 1300rpm. The kind of PM which applies to the IPMSM is NdFeB with 1.27T. The specification of the IPMSM for washing machine in the paper is indicated in Table I.

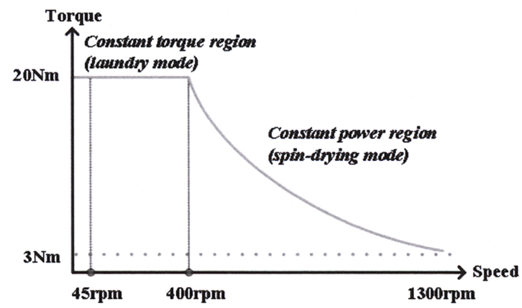
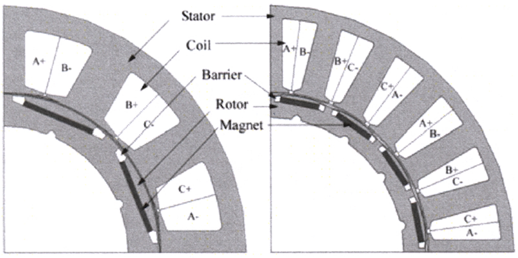


Fig. 1. Torque versus speed curve for washing machine IPMSM

TABLE I
SPECIFICATIONS OF IPMSM

Parameters	Unit	Specifications
Rated Torque (constant torque region)	Watt	840
Rated Power (constant power region)	Nm	20 @ 45rpm
Base RPM	rpm	400
Maximum speed	rpm	1300 @ 3Nm
Number of Poles / Slots / Phases		8/12/3, 16/24/3
Size of Diameter / Stack	mm	250 / 24
Residual flux density of PM (NdFeB)	T	1.27
Air-gap	mm	0.8



(a) 8 poles / 12 slots (b) 16 poles / 24 slots

Fig. 2. Two types of IPMSM

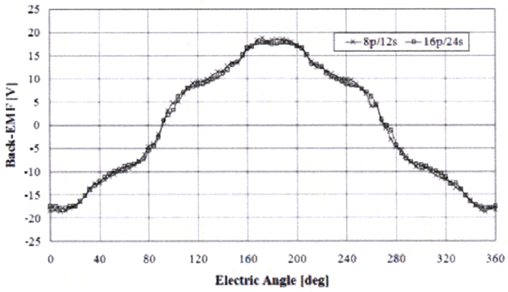


Fig. 3. Back-emf of two types of IPMSM

Fig. 2 shows the basic analysis models which are 8p/12s and 16p/24s with concentrated winding. The specifications of two types of motor are almost similar except the number of poles and slots. These models are optimized.

Fig. 3 shows the back-emf. Back-emf of two types of motor is nearly similar because two types of motor have been designed same torque and power.

III. Comparison of Simulation Result

Torque of IPMSM is composed two parts. One is magnetic torque and the other is reluctance torque. The torque equation is expressed as follows:

$$T = P_n\{\Psi_a I_a \cos\beta + \frac{1}{2}(L_q - L_d)I_a^2 \sin 2\beta\} \quad (1)$$
$$= T_m + T_r$$

where, P_n is pole pair, Ψ_a is magnet linkage flux, I_a is peak value of input current, β is current phase angle, and L_d and L_q are respectively d-axis and q-axis inductance. The first term, T_m is the magnetic torque and the second term, T_r is reluctance torque.

A. Torque versus Current Phase Angle Curve

The two types of IPMSM for washing machine have the target 20Nm at 45rpm in the constant torque region. Fig. 4 shows the torque versus current phase angle curve about simulation and experiment. Current phase angle, β must be decided in order to produce the maximum torque, 20Nm at 45rpm. If the current phase angle is changed, the magnetic torque and reluctance torque are changed as equation (1) shows.

The magnetic torque of IPMSM is only produced at $\beta = 0^o$. The reason of pure magnetic torque of 16p/24s ($\beta = 0^o$) is higher than 8p/12s's is that total torque of motors is the same and reluctance torque of 16p/24s is lower than 8p/12s's owing to small difference between L_q and L_d (salient difference) of 16p/24s. The maximum torque of 8p/12s simulation and experiment is produced at $\beta = 20^o$, but the maximum torque of 16p/24s simulation is produced at $\beta = 10^o$ and the maximum torque of 16p/24s experiment is produced at $\beta = 20^o$. The reason of current phase angle difference between simulation and experiment result is a little error of barrier size and position when the IPMSM was manufactured. It will be expected that 16p/24s is more profitable than 8p/12s in the flux weaken control. Fig. 5 shows inductance according to current phase angle. It is expected to have merit that 8p/12s is more profitable than 16p/24s in the flux weakening control, because simultaneously with the increasing of β the difference of L_q and L_d of 8p/12s is higher than 16p/24s.

B. Torque versus Current Curve

Generally, washing machine is required high starting torque about 40Nm owing to high inertia. IPMSM must be instantaneously supplied high current in order to produce starting torque.

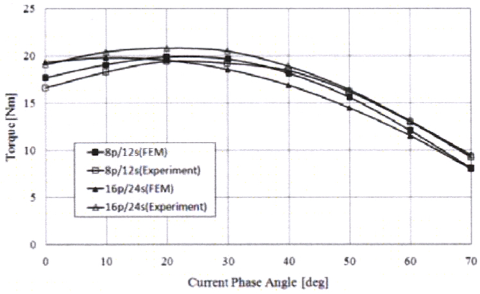
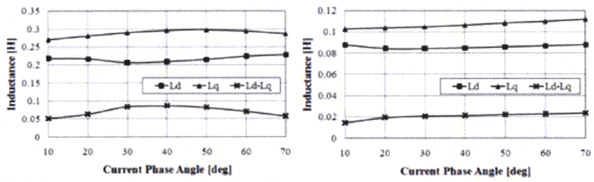


Fig. 4. Torque versus current phase angle curve



(a) 8 poles / 12 slots (b) 16 poles / 24 slots

Fig. 5. Inductance according to current phase angle

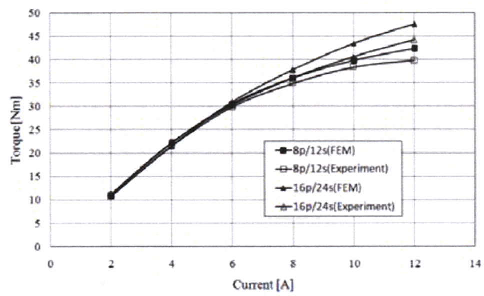
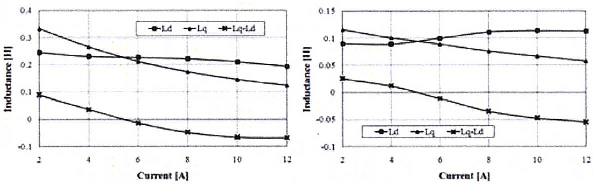
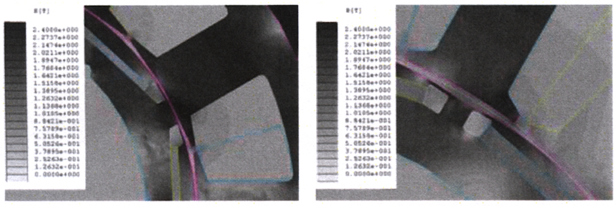


Fig. 6. Torque versus current curve



(a) 8 poles / 12 slots (b) 16 poles / 24 slots

Fig. 7. Inductance according to current magnitude



(a) 8 poles / 12 slots (b) 16 poles / 24 slots

Fig. 8. Torque versus current curve

But a controller, which supplies current to the motor, has current limit about 12A. So, torque of two types must be analyzed respectively according to current magnitude.

Fig. 6 shows the torque versus current curve about simulation and experiment.

In the torque versus current curve, it is known that the rate of increase torque has decreased since the current magnitude is about 5~6A. The reason of the rate of increase torque decreasing is saturation. Specially, 8p/12s is decreased quickly compare with 16p/24s, so it is known that saturation of 8p12s is faster than 16p/24s. In the Fig. 5, it is known that the torque increases linearly until the current is from 0A to 5~6A, but the torque increases nonlinearly if the current is inputted more than 6A. Fig. 7 shows the change of inductances such as L_q, L_d, L_q-L_d according to current magnitude. The saturation point is difference of L_q and L_d is zero. Fig.8 shows the saturation of IPMSM respectively at the 10A. It is known that Saturation of 8p/12s is higher than 16p/24s at the 10A in the Fig. 8. Consequently, it is ensured that 16p/24s is more reliable than 8p/12s in the starting machine mode.

C. Comparison of Torque ripple

Torque ripple produce acoustic noise and mechanical vibration of the motor. So, torque ripple must be reduced, fair means or foul [5]-[10].

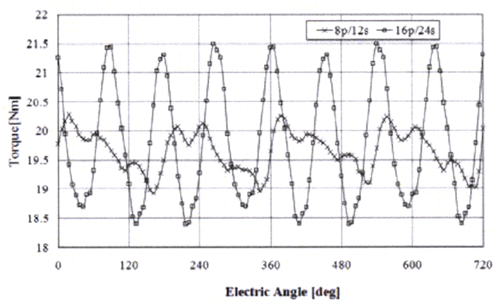


Fig. 9. Torque ripple of two types of IPMSM

The major cause of torque ripple in the IPMSM is cogging torque, harmonics of back-emf, adding of the reluctance torque, and so on. Fig. 9 shows the torque ripple of two types of motor. This torque is simulated at the 45rpm and maximum torque control. Torque ripple of 16p/24s is higher than 8p/12s because reluctance torque of 16p/24s is higher than 8p/12s. It is known that the reluctance torque becomes source of torque ripple.

IV. CONCLUSION

This paper deals with two types of IPMSM for washing machine as the ratio of pole and slot is 2:3. 8p/12s IPMSM has good merit which is low torque ripple. But the motor has been saturated easily in the constant torque region when the washing machine starts. So, this machine is inputted high current in the constant torque region to produce torque overcome the load.

Consequently, in this paper, though it is not easy to decide what the proper motor for washing machine is, but 16p/24s is a little more profitable than 8p/12s for washing machine.

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