A Comparative Study of the Line Start Permanent Magnet, Skeleton Type Brushless DC, and Snail-cam Type Switched Reluctance Motor for Fans

Ji-Young Lee †, Geun-Ho Lee*, Jung-Pyo Hong* and Jin Hur**

Abstract - The objective of this paper is to provide a comparison between the Line Start Permanent Magnet, Skeleton type Brushless DC, and the Snail-cam type Switched Reluctance Motor. These motors are compared under the same load characteristic as the cooling fan motor of a refrigerator. The comparison consists of speed, output power, efficiency, copper loss, and cost for three different motors. For the given application, the results provide an indication of the best machine suited with respect to performance and cost.

Keywords: Cooling fan, Line Start Permanent Magnet Motor, Skeleton type Brushless DC Motor, Snail-cam type Switched Reluctance Motor

1. Introduction

Facing the rising cost of electric energy, consumers and manufactures alike have paid a great deal of attention to energy saving in an attempt to reduce their operating costs. Improving the efficiency of the motors used in many types of household appliances can be one method of increasing the overall efficiency of the appliances. A detailed performance comparison would be helpful in selecting the best motor for a particular application considering efficiency.

In this paper, three different motors are introduced. These are the Line Start Permanent Magnet Motor (LSPM), Skeleton Type Brushless DC Motor (SBLDC) and Snail-cam Type Switched Reluctance Motor (SCSRM). These motors are compared with one another in terms of speed, output power, efficiency, copper loss, and cost under the same load characteristic as a refrigerator cooling fan motor. For an accurate comparison, the motor characteristics are calculated by 2-D FEM coupled with circuit equations, and the experimental results of three fabricated motors are presented. This study helps to examine the relative merits of LSPM, SBLDC and SCSRM. The basic characteristics of each motor are as follows:

1) Single-phase LSPM: LSPM has a number of features that make it attractive for this type of application [1]. Starting asynchronously by means of a rotor conduction can, it operates as a synchronous motor in steady state. This combination provides the steady state performance of a Permanent Magnet (PM) motor without the need for an expensive drive system [2].

2) Single-phase SBLDC: The shape of stator core resembles a skeleton and the inner rotor consists of a ring-shaped PM and a shaft core [3]. It requires the adoption of a detent groove and a transformation of the link parts of the stator in order to solve the various problems such as zero torque zones and the inflow of dust. It has a driver topology with only two power switches for this application.

3) Two-phase SCSRM: While only this motor has two phases in comparison with the above-mentioned motors, the driver system is identical to that of the SBLDC. A general 2-phase SRM has wide zero torque zones that can lead to starting problems, and rotates in a bi-direction, while the cooling fan requires only one-directional rotation [4-6]. Therefore, the snail-cam type rotor pole and the asymmetric stator pole are investigated to resolve the above-mentioned problems.

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2. Design and Analysis Results

The torque and speed characteristics of the cooling fan are shown in Fig. 1. The main consideration in designing the motors is as follows.

2.1 LSPM

This motor can start and operate at synchronous speed without using the drive system. To satisfy this characteristic considering the fan, this paper proposes the structure of LSPM as follows.

• Stator assembly: The main and auxiliary windings, which produce the 4-pole magnetomotive force wave (rotating or ellipse), are inserted into the 8-slot. The capacitor is attached directly to the auxiliary winding in order to improve the starting torque. The switching device such as a PTC resistor is connected to auxiliary winding parallel to the capacitor for disconnecting the auxiliary winding when the rotor speed is synchronized.

• PM: The 4-pole surface type PM is bonded on a rotor surface to produce the main magnetic flux.

• Rotor secondary conductor: To produce the starting torque, the cylinder type aluminum conductor surrounds the PM, and it consists of several slits needed to increase the second resistance.

Fig. 2 shows the designed LSPM, and Fig. 3 represents the analysis results according to load angle. Parameters such as inductance and back-EMF are calculated by using the 2-D Finite Element Method (FEM), and the load angle characteristics are computed from equivalent circuits considering symmetric coordinate components.

2.2 SBLDC

The detent groove and the link part of the stator core in the SBLDC influence its performance in areas such as efficiency, torque ripple and zero torque zones. Therefore, investigation is needed to determine the effect of these parameters.

• Detent groove: It leads to an increase in the starting torque and a decrease in the torque ripple.

• Upper link part: The link is closed to protect dust and its thickness is very minimal to minimize the flux leakage that prevents back-EMF distortion.

• Lower link part: The open part in the lower link is filled with the coil bobbin to prevent the inflow of dust and it reduces the flux leakage driven by PM.

Fig. 4 shows the designed SBLDC. The upper link part is closed and the lower one is open. Fig. 5 shows the variation of torque with displacement of rotor.

2.3 SCSRM

The proposed rotor and stator pole shapes are adopted for the improvement of the motor characteristics as follows:

• Snail-cam type rotor pole: This shape makes the motor rotate in one-direction only and reduces the zero torque zones. It requires one directional rotation due to the fan shape. Reducing zero torque zones is required to avoid the problems that can occur during startup.

• Asymmetric stator pole: The inductance ratio and the average torque increase by decreasing unaligned inductance and increasing aligned inductance.

The designed model is shown in Fig. 6. Fig. 7 depicts the characteristic graph of inductance, flux and torque according to the displacement of the rotor [7]. The characteristic profiles are computed by 2-D time-stepping FEM coupled with circuit equation.

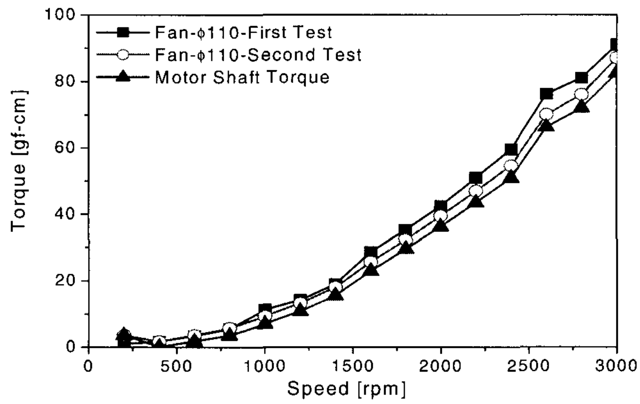

Fig. 1 Torque and speed characteristics of the cooling fan

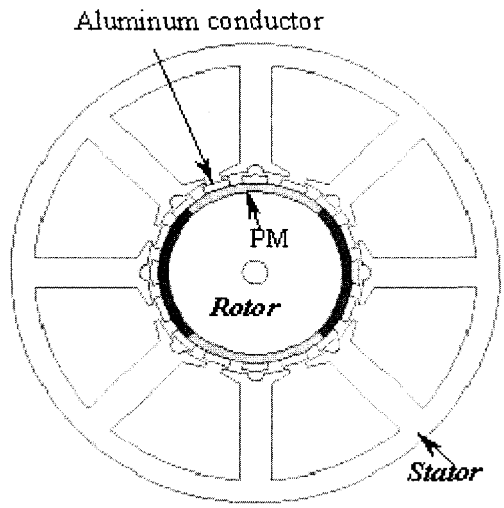

Fig. 2 The designed single-phase line-start permanent magnet motor (LSPM) for the cooling fan

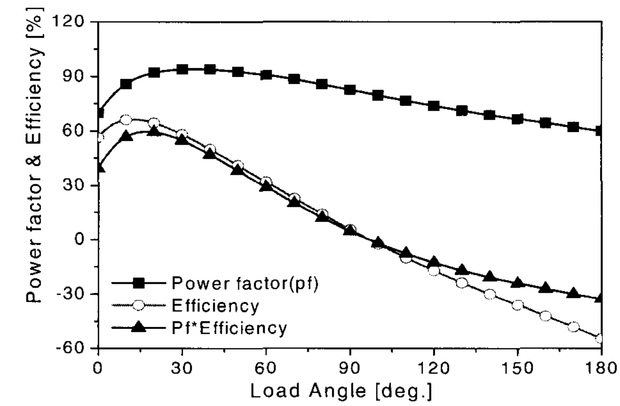

Fig. 3 Variation of power factor and efficiency with load angle (LSPM)

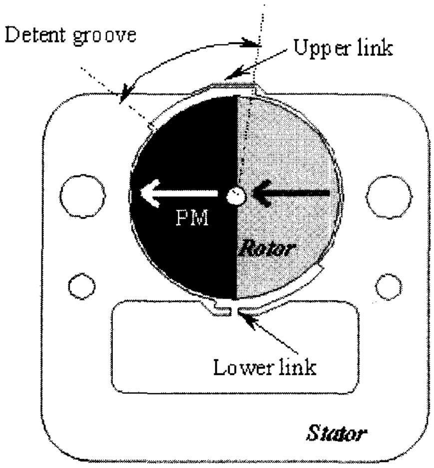

Fig. 4 Designed single-phase skeleton type brushless DC motor (SBLDC) for the cooling fan

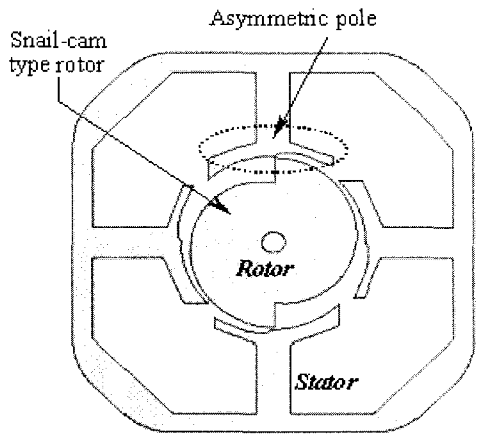

Fig. 6 The designed two-phase snail-cam type switched reluctance motor (SCSRM) for the cooling fan

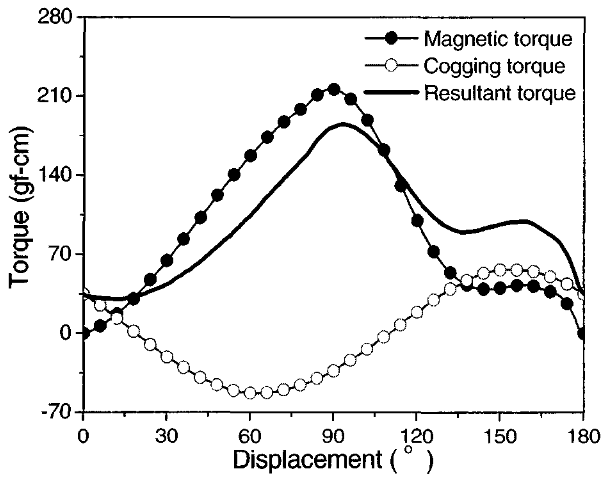

Fig. 5 The Variation of torque with displacement of rotor (SBLDC)

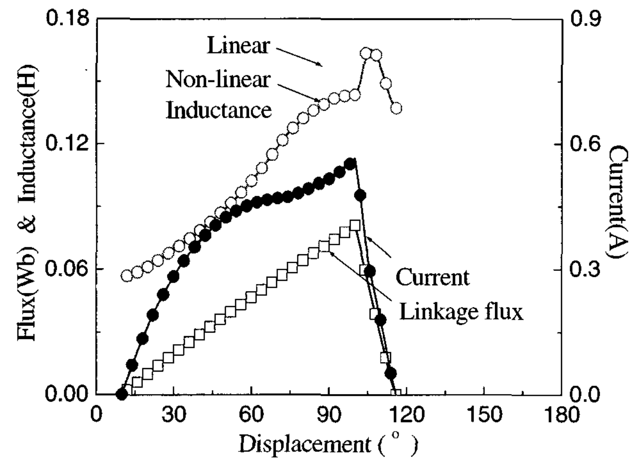

Fig. 7 The variation of flux and inductance with displacement (SCSRM)

3. Comparison of Performance

Fig. 8 is the system consisting of SCSRM, the cooling fan and its driver. The system for the SBLDC has the same composition. The experiment results are shown from Fig. 9 to Fig. 13. These results verify the accuracy of the analysis results of each motor. Fig. 9 and Fig. 10 are the experimental results of LSPM, and Fig. 11 and Fig. 12 are analysis and experimental results of the back-EMF of SBLDC respectively. The analysis and measured current of SCSRM are compared in Fig. 13.

Table 1 presents the comparison of the experimental data of three fabricated motors. Although the motors are designed for the identical fan, the speed and the output power of each motor vary because the characteristics of the motors are very dissimilar.

The frequency of input voltage, 60(Hz), has influence on the speed of the LSPM only. The speed of the other motors changes according to variation of the input voltage value. However, since three motors have the identical volume and use the same fan as load, this experimental comparison can provide an indication of the proper choice.

Table 1. The comparison of experimental results for each motor

Motor	Speed (rpm)	Output Power (W)	Efficiency (%)	Copper loss (W)	Cost
LSPM	1800*	3.77	50.26	2.50	Low
SBLDC	2705	1.8	56.2**	0.63	High
SCSRM	2483	1.76	25.5**	1.32	Middle

* The frequency of input voltage is 60 (Hz).

** The efficiency is calculated for both the motor and its controller.

The efficiency is calculated for both the motor and its controller in SBLDC and SCSRM. In spite of considering both the motor and its drive, SBLDC takes the highest efficiency. However, from the viewpoint of the efficiency per unit cost, LSPM is excellent. It is inferred that LSPM is superior in cost to the others because of not having the controller. SCSRM has a large copper loss per unit output power compared with the others using the PM as a magnetic flux source. Therefore, SCSRM has the lowest efficiency of the three motors. To be precise, SCSRM is similar in production cost to SBLDC because it not only has the controller but also has a ring-shaped PM for a sensor.

4. Conclusion

In this paper, LSPM, SBLDC and SCSRM are studied for the cooling fan motor of a refrigerator. Three different motors are designed and compared for their performance and cost. For design, the motor characteristics are calculated by 2-D FEM coupled with circuit equations. The experimental results of three fabricated motors are presented for providing an indication of the proper choice. The comparison consists of speed, output power, efficiency, copper loss and cost. From the data presented in the previous sections, SBLDC has the highest efficiency and the cost of LSPM is the lowest of the three motors. This study helps to examine the relative merits of LSPM, SBLDC and SCSRM as this application.

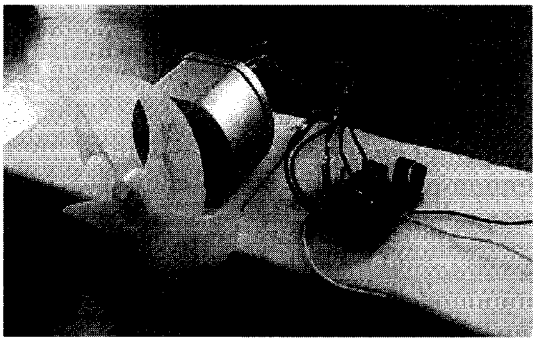

Fig. 8 The cooling fan motor with the fan and driver

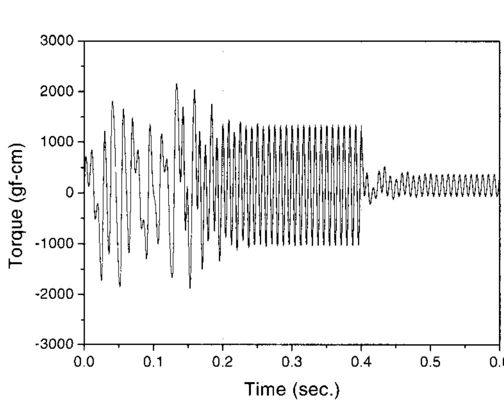

Fig. 9 The torque of LSPM at starting point

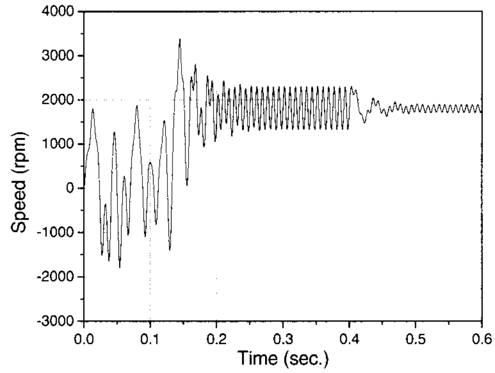

Fig. 10 Speed of LSPM at starting point

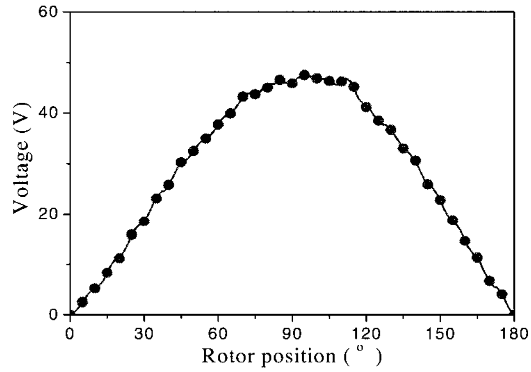

Fig. 11 Back-emf of SBLDC (Analysis value)

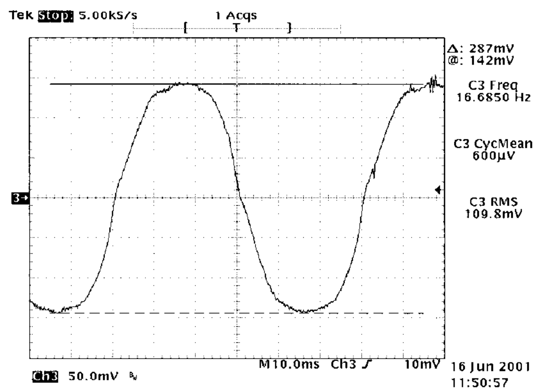

Fig. 12 Back-emf of SBLDC (Experimental value)

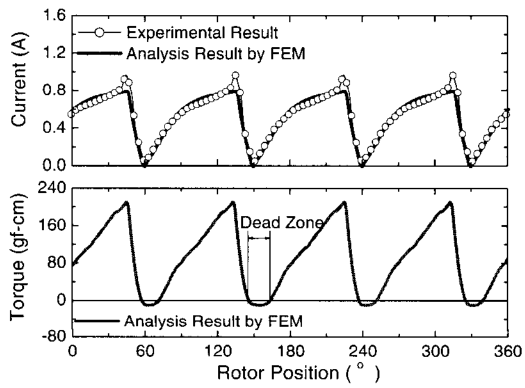

Fig. 13 Current (upper) and torque (lower) of SCSRM

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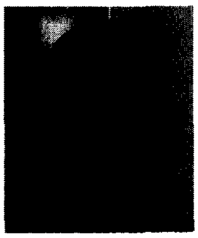

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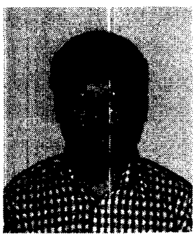

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