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

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Abstract- **The objective of this paper is to provide a comparison between the Line Start Permanent Magnet, Skeleton type Brushless DC and Snail-cam type Switched Reluctance Motor. These motors are compared under the same load characteristic as a 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.**

I. INTRODUCTION

Facing the cost rise of electric energy, consumers and manufactures have paid much attention to energy saving in an attempt to reduce their operating costs. Improving the efficiency of motors as parts of many household appliances can be one method of improving the overall efficiency of the appliances. The detailed performance comparison would be helpful to select the best motor for a particular application considering the efficiency.

In this paper, three different motors are introduced. There are Line Start Permanent Magnet (LSPM), Skeleton type Brushless DC (SBLDC) and Snail-cam type Switched Reluctance Motors (SCSRM). These motors are compared with each others in speed, output power, efficiency, copper loss and cost under the same load characteristic as a cooling fan motor of a refrigerator. For the 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 as this application. The basic characteristics of each motor are as follows:

1) Single-phase Line Start Permanent Magnet Motor (LSPM) : LSPM has a number of features which make it attractive for this type of application. 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 [1].

2) Single-phase Skeleton type Brushless DC Motor (SBLDC): The shape of stator core resembles a skeleton and the inner rotor consists of a ring-shaped PM and a shaft core [2]. It needs an adoption of a detent groove and a transformation of the link parts of stator to solve the various problems such as zero torque zone and the inflow of dust. It has a driver topology with only two power switches for this application.

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

II. DESIGN AND ANALYSIS RESULTS

The torque and speed characteristics of three motors are demanded to meet those of the cooling fan shown on Fig. 1. The main consideration to design the motors is as follows:

A. LSPM

This motor can start and operate at synchronous speed without using 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 in 8-slot. The capacitor is attached directly to 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 rotor speed is synchronized.
- PM: The 4-pole surface type PM is bonded on rotor surface to produce the main magnetic flux.

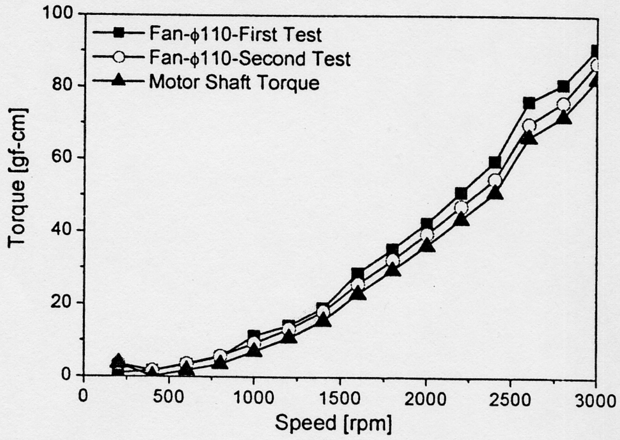

Fig. 1. Torque and Speed characteristics of fan

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

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

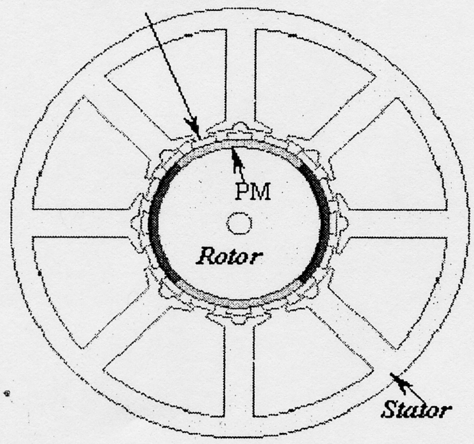

Fig. 2. Single-phase Line Start Permanent Magnet Motor

B. SBLDC

The detent groove and the link part of stator core in SBLDC have influence on its performance such as efficiency, the torque ripple and the zero torque zones. Therefore it needs to investigate the effect of these parameters.

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

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

• Lower link part: The open part in 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 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

C. 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 zero torque zones. It needs one directional rotation due to the fan shape. Reducing zero torque zones is to avoid the starting problem.

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

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

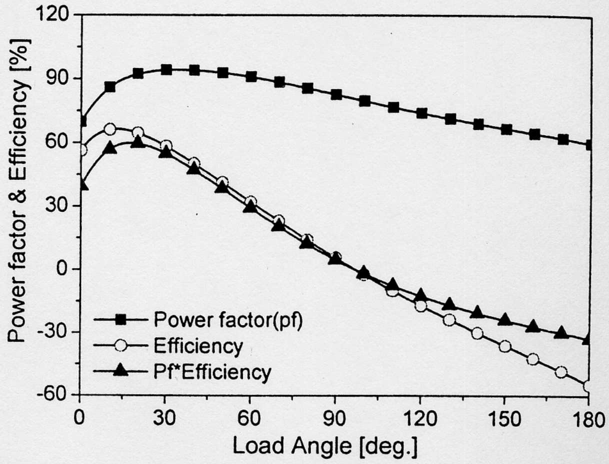

Fig. 3. Variation of power factor and efficiency with load angle (LSPM)

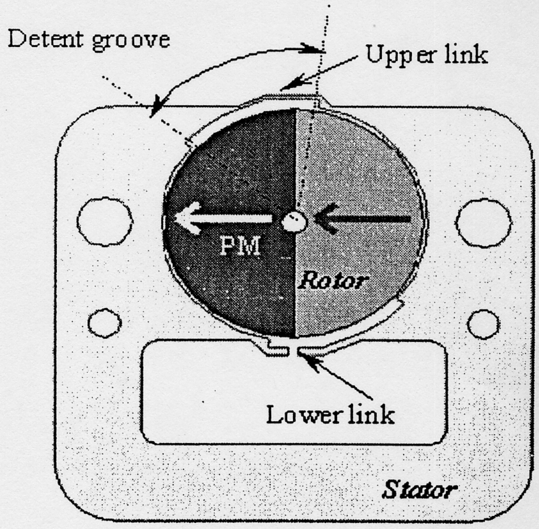

Fig. 4. Single-phase Skeleton type Brushless DC Motor

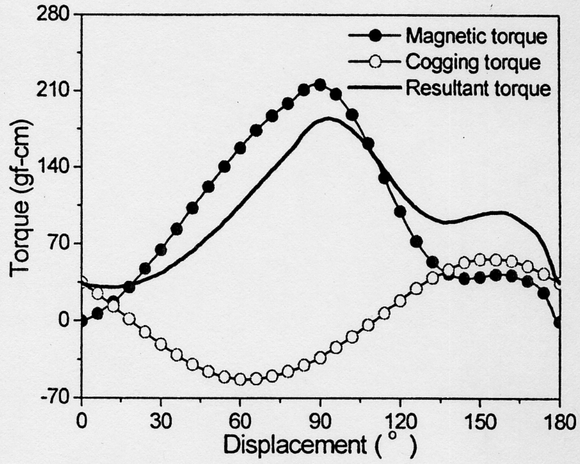

Fig. 5. Variation of torque with displacement of rotor (SBLDC)

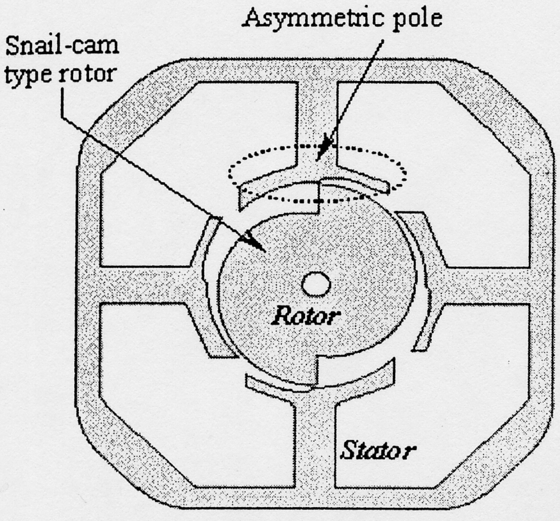

Fig. 6. Two-phase Snail-cam type Switched Reluctance Motor

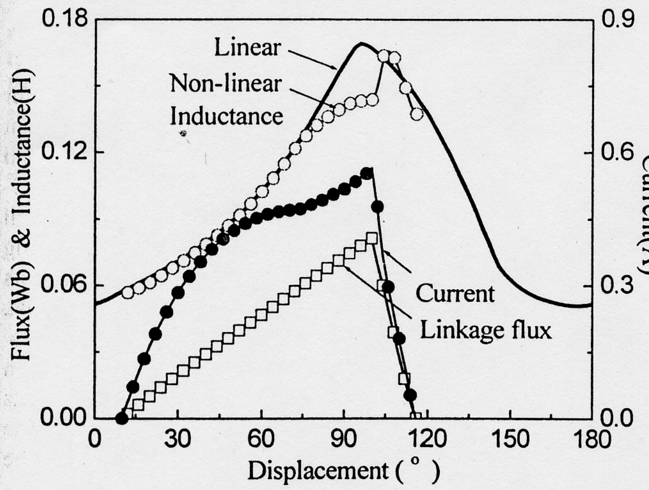

Fig. 7. Variation of flux and inductance with displacement (SCSRM)

III. Comparison Of Performance

Fig. 8 is the system consisting of SCSRM, the cooling fan and it's driver. That of SBLDC has the same composition. Before comparing the characteristics of each motor, the experiment results are shown on from fig. 9 to fig. 13. These results verify the accuracy of 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 back-emf of SBLDC respectively. The analysis and measured current of SCSRM are compared on Fig. 13.

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

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, in a 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 the large copper loss per unit output power compared with the others using the PM as magnetic flux source. Therefore, SCSRM has the lowest efficiency in three motors. To be precise, SCSRM is similar in production cost to SBLDC because it has not only the controller but also a ring-shaped PM for a sensor.

TABLE I. 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.

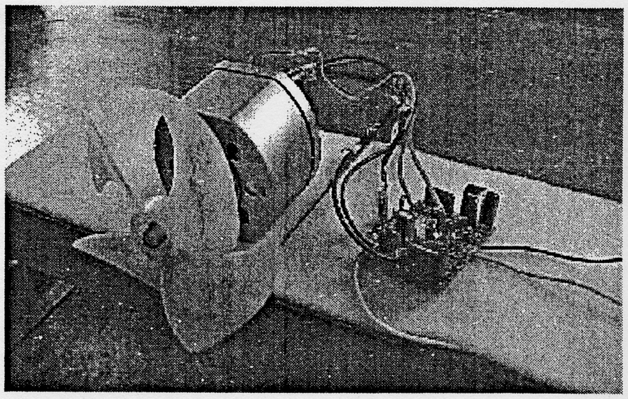

Fig. 8. Cooling fan motor with the fan and driver

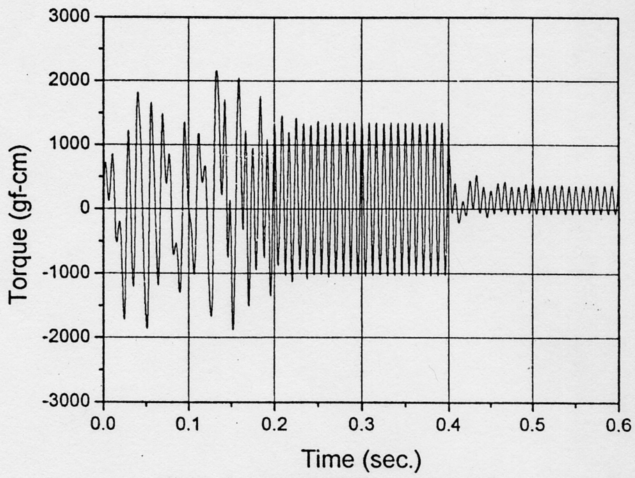

Fig. 9. Torque of LSPM at starting point

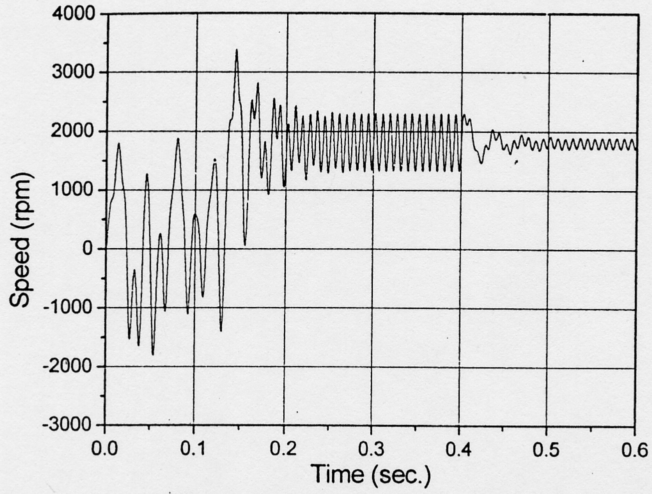

Fig. 10. Speed of LSPM at starting point

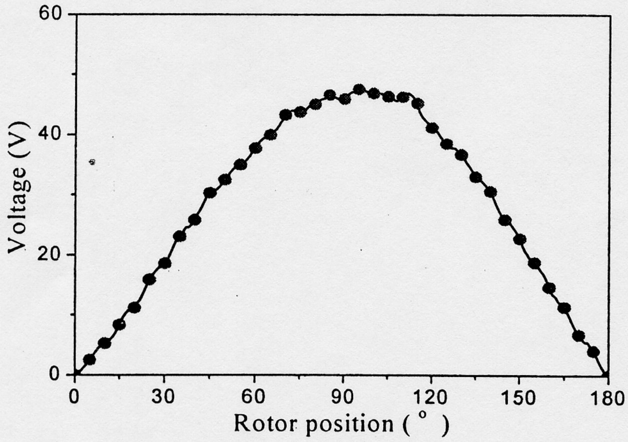

Fig. 11. Back-emf of SBLDC (Analysis value)

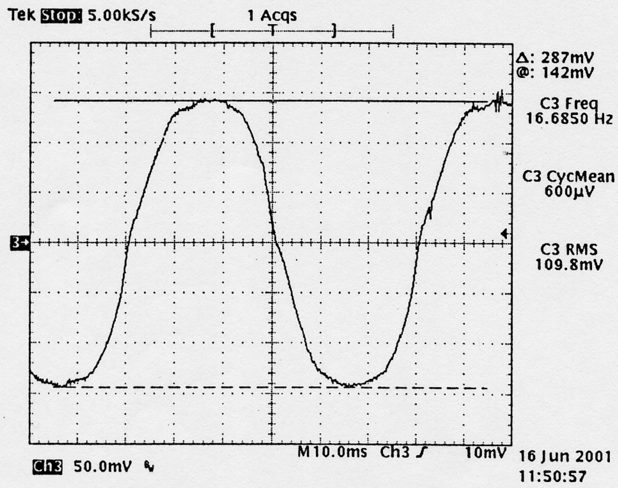

Fig. 12. Back-emf of SBLDC (Experimental value)

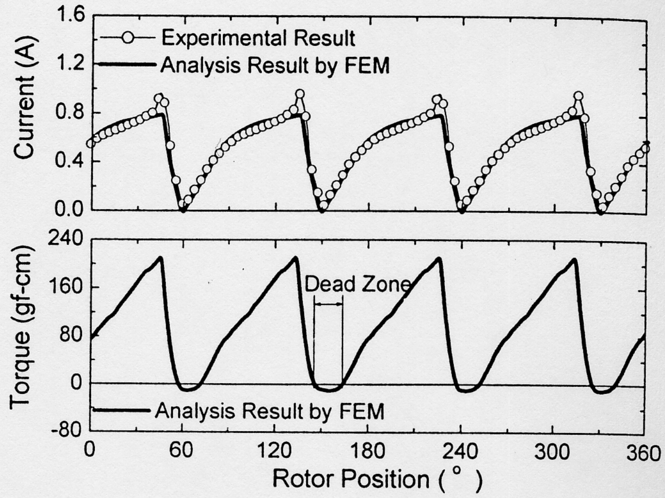

Fig. 13. Current (upper) and torque (lower) of SCSRM

IV. Conclusion

In this paper, LSPM, SBLDC and SCSRM are studied for the cooling fan motor in the refrigerator. Three different motors are designed and compared for the 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 in three motors. This study helps to examine the relative merits of LSPM, SBLDC and SCSRM as this application. The analysis and measured results of each motor will be explained continuously in an extended paper.

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