Design Algorithm of Barriers and Magnets in the Rotor for LSPM Motor

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Abstract — The capacitor-run single-phase line-start permanent-magnet motor (LSPM) is a synchronous hybrid PM/reluctance motor that is being developed for applications including compressors and others that require a high-efficiency alternative to the induction motor. The analytical design method of LSPM has been researched, but it cannot consider the leakage flux and the saturation effect in the rotor core exactly. And the numerical method for design is almost correct, but it takes long time to calculate. In this paper, both analytical method and numerical method are used to suggest the rotor design process of the single-phase LSPM motor. The cage-bar is designed to generate the maximum starting torque by analytical method. The torque generated from the synchronous speed is divided into reluctance torque and magnetic torque to design barriers and permanent-magnets. In this process, optimal design method and current phase angle estimation method is suggested. In final design process, tapering of the stator teeth is conducted for reducing cogging torque. Finally, the appropriate electrical steel is selected through the comparison of the analysis results in LSPM.

I. INTRODUCTION

Permanent-magnet motors, equipped with a cage rotor, may represent a higher efficiency alternative to induction motors. Generally defined as line-start permanent-magnet (LSPM) motors, they may be supplied from a three-phase or single-phase voltage system. [1]

The single-phase LSPM motor has received less attention than the integral-horsepower three-phase motor, probably because of the significantly greater degree of difficulty in its design and performance analysis. Capacitors are required for starting and may be desirable for steady-state running also. The generally unbalanced operation of the single-phase motor makes analysis and design difficult. [2] In this study, both analytical method and numerical method are used to suggest the rotor design process of the single-phase LSPM motor.

II. DESIGN PROCESS

The main reason why the single phrase inductor is being replaced with the LSPM motor is due to the high efficiency and high torque in the rating section. Also in order to replace an inductor, enough starting torque and enough pullout torque also need to be considered. The suggested design process considers the above 3 factors. The entire design process is shown in Fig. 1 and TABLE I shows the specifications of the target LSPM Motor.

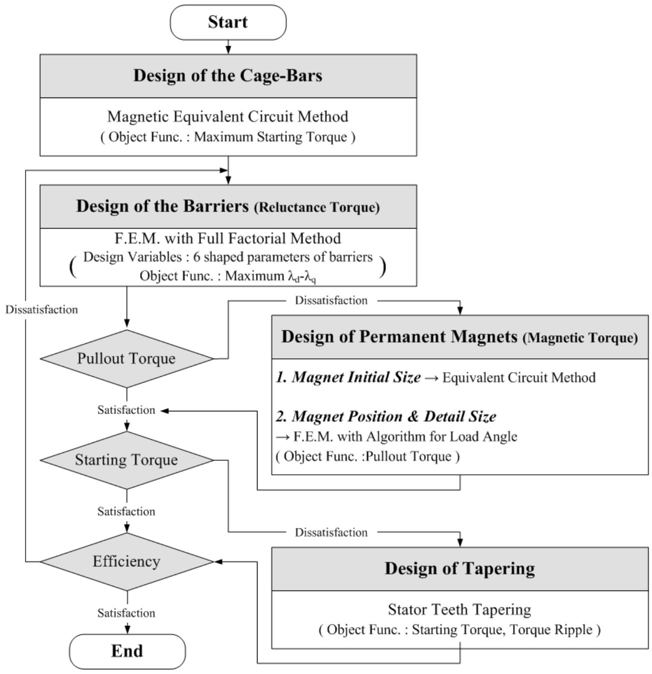


Fig. 1. Design Algorithm of the rotor of LSPM

TABLE I
SPECIFICATIONS FOR THE TARGET LSPM

Item	Specification
Rated Power	94.3[W]
Input Voltage	220[V]
Rated Torque / Pullout Torque	0.5[Nm] / Above 0.75Nm
Speed	1800[rpm]
Stack Length	45[mm]
Transient Time	Under 0.2[sec]
Efficiency	Above 65[%]

III. DESIGN OF THE BARRIERS

The conventional LSPM design process mainly used magnetic torque from permanent magnets, just like the IPM design. However, this type of design decreases the starting torque because the magnet force also works as breaking torque. [3] Also, high-quantity permanent magnets are one of the main reasons for increased motor costs. In this study, in order to solve these problems, the barrier was designed to have the most reluctance torque in the positive-sequence system and adding a permanent magnet for the maximum torque and efficiency is suggested.

In order to increase the reluctance torque to the highest point, the optimal design for barrier was performed. If the reluctance torque is calculated with the analytical method, the magnetic saturation and leakage flux between ribs and cage-bars can't be calculated, which decreases the accuracy. Also, if the reluctance torque is calculated with FEM, it will consume much time because the voltage transient analysis needs to be performed. In order to solve such problems, the gap between the d-axis and q-axis flux-linkage which receive the most effect from the changes of rotor shapes in the reluctance torque formula, was decided as an object function to perform the optimal design. At this time, the eddy-current of the cage-bar was disregarded. The result of conducting FEM analysis on the sum of the linkage flux of the main winding is shown in Fig. 2. At this time, the maximum value can be decided as d-axis linkage flux and minimum value as q-axis linkage flux. There were a total of 6 design variables, as presented in Fig. 3.

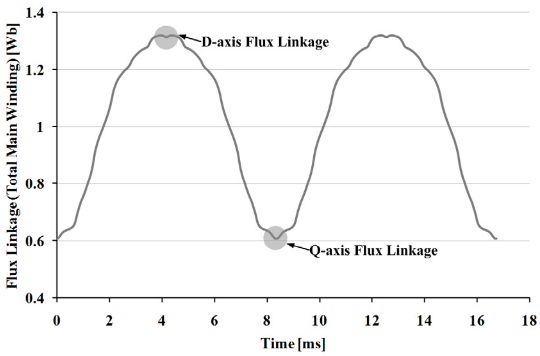
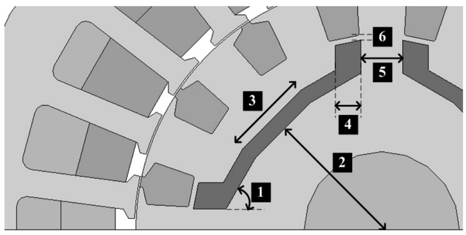


Fig. 2. Sum of the flux-linkage of the main winding



1	55	60	65	[deg]	4	1.5	2	2.5	[mm]
2	15	15.5	16	[mm]	5	1	1.5	2	[mm]
3	4	5	6	[mm]	6	0.5	1	1.5	[mm]

Fig. 3. Design variables of barrier in the rotor

IV. Design of the Magnets

When the magnet rotates on open-circuit it generates the electromotive force (EMF) $E_m = j\omega N_m \Phi$ in the main winding and $E_a = -\omega N_a \Phi$ in the auxiliary winding, where Φ is the fundamental magnet flux/pole. Since the number of turns had already been decided, the flux linkage of the air gap was calculated by using EMF to determine the approximate width of the permanent magnet.

When the cross section of the permanent magnet is decided, the insertion location of the permanent magnet needs to be decided. As shown in Fig. 4, three ways of inserting the permanent magnet were considered. At this time, a model that has the same sum of the permanent magnets can lower torque ripple from the rated load but maximize the efficiency needed to be selected. This can be changed depending on the barrier shape. The analysis result on each model is shown in TABLE II. In this study, the permanent-magnet location was decided as Model 1.

TABLE II
Analysis Result of Three Models

Item	Efficiency	Torque Ripple	Pullout Torque	Starting time
Model 1	69.3 %	0.21 Nm	0.79 Nm	0.22 Sec
Model 2	67.8 %	0.26 Nm	0.75 Nm	0.2 Sec
Model 3	68.5 %	0.25 Nm	0.75 Nm	0.19 Sec

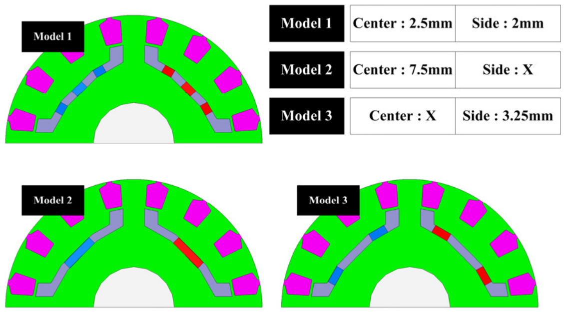


Fig. 4. Insertion location of the permanent-magnet

V. Conclusion

In this study, both the analytical method and numerical method are used for the rotor design process of LSPM and divided into magnetic torque and reluctant torque. And method for current phase angle estimation is suggested. Finally, the appropriate electrical steel is selected for the LSPM design.

VI. Acknowledgment

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VII. References

[1] Mircea Popescu, T. J. E. Miller, Malcolm I. McGilp, Giovanni Strappazzon, Nicola Trivillin, and Roberto Santarossa, "Line-Start Permanent-Magnet Motor: Single-Phase Starting Performance Analysis," IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 39, NO. 4, pp. 1021-1030, JULY/AUGUST 2003.

[2] T. J. E. Miller, "Single-Phase Permanent-Magnet Motor Analysis, " IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. IA-2 1, NO. 4, pp. 651-658, MAY/IJUNE 1985.

[3] T. J. E. Miller, Mircea Popescu, Calum Cossar, Malcolm McGilp, Giovanni Strappazzon, Nicola Trivillin, and Roberto Santarossa, "Line-Start Permanent-Magnet Motor Single-Phase Steady-State Performance Analysis, " IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 40, NO. 2, pp. 516-525, MARCH/APRIL 2004.