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Design a Line Start synchronous Motor and Analysis Effect of the Rotor Structure on the Efficiency

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***Abstract*—**The line start permanent magnet motor (LSPMM) combines a permanent magnet rotor for a better motor efficiency during synchronous running with an induction motor squirrel cage rotor to permit the motor starting by direct coupling to power source. In this paper effect of the rotor structure on a line start synchronous permanent magnet motor (LSPMM) is analyzed. LSPMM motor with three different structures for rotor is designed by using RMxprt software; efficiency and line current of LSPMM motor for different structures in full-load condition have been presented. The results indicate that with correct choosing of rotor structure, maximum efficiency can be found.

***Keywords*—**Permanent magnets, LSPMM motor, rotor.

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 directly from a three-phase or single-phase voltage system [1]. Such a construction generates important technical advantages like reduced manufacturing costs and/or better performances, as well as reduced running costs, if the volume ratio between permanent magnets and squirrel cage is properly chosen [2]. As the main field is generated by permanent magnets, no magnetizing current is needed. That leads to an important increase of power factor at full load operation, as well as to reduced losses in stator windings [3]. So, LSPMM could replace common induction motors in many applications with better results. Centrifugal applications (fans and pumps driving) could be one of those, as their torque-speed characteristic suits the LSPMM. The various papers and patents regarding LSPMM in single or three-phase applications are another proof of motor's advantages. Miller [4] was probably the first who explained the synchronization process in such a motor based on the different types of torques applied at start. Remarkable technical solutions were patented by Boyd [5], Kliman [6, 7] and Stephens [8]. These three authors also wrote a joint paper [9] regarding the design of the starting armature and the automatic synchronization process. Important results have been also reported by the Swedish research team from the Royal Institute of Technology Stockholm of Nee, Lefevre, Thelin and Soulard [10-11], about designing and testing LSPMM. An interesting "spoke-rotor" LSPMM was introduced by Kurihara and Rahman [12]. Last, but not least, it must be mentioned the single phase LSPMM analyzed and tested by Popescu Mircea et al [13] from SPEED Laboratory, Glasgow, and the recent patent of Chu [14] of a variable, special shaped periphery of the rotor for improving the starting and running performance of the LSPMM via d-q axis inductances.

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In contrast with the abovementioned solutions, the current LSPMM construction presents few differences and obvious advantages. In this paper presents an improved version of the LSPMM with enhanced rotor structure.

II. Design of LSPMM Motor

The LSPMM considered for analysis, in this paper is a three-phase as shown in Fig. 1.

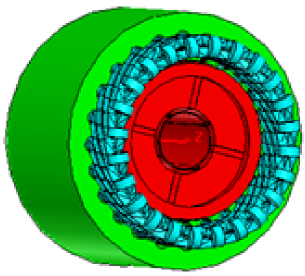

Fig. 1 LSPMM motor

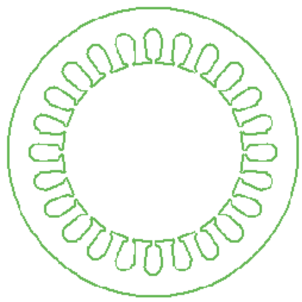

Fig. 2 The Stator of LSPMM designed with RMxprt

Structure of the rotor is one of effective parameters on performance of LSPMM. For analyzing effects of rotor structure on motor performance, Stator of LSPMM motor (Fig. 2) with RMxprt software is designed. Moreover three phase 2-layer winding structure of LSPMM is shown in (Fig. 3)

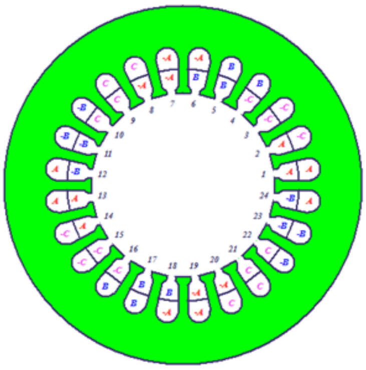

Fig. 3 Winding structure of LSPMM

Then rotor with three different structures is designed simulated. The efficiency of LSPMM is calculated as follows:

$$eff = Pin / Pout \quad (1)$$

$$Pout = Pin - (Pfw - Pcu - Pt - Pfe) \quad (2)$$

III. Analysis of LSPMM Motor

The motor main parameter is shown in table I.

TABLE I
SPECIFICATIONS ADOPTED FOR THE SIMULATED LSPMM

NAME	RATING VALUES	UNIT
Rated Power	0.55	kW
Rated Voltage	220	V
Number of Poles	4	-
Rated Speed	1500	rpm
Number of Stator Slots	24	-
Winding connection	Delta	-
Air gap	5	mm
Outer Diameter of stator	120	mm
Inner Diameter of stator	75	mm
Length of Rotor	65	mm
Inner Diameter of rotor	26	mm

Design1: In this case, rotor and pole structure are shown in (Fig.4), (Fig.5) respectively.

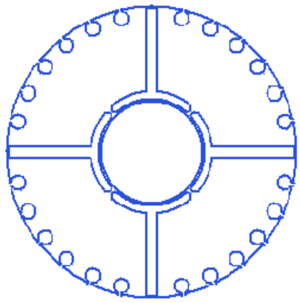

Fig. 4 Rotor structure of LSPMM at first state

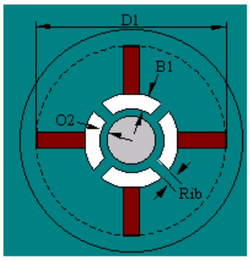

Fig. 5 Pole structure of LSPMM at first state

After designing motor with this type of rotor structure (Fig. 6) and simulating motor in full-load condition flowing results is obtained.

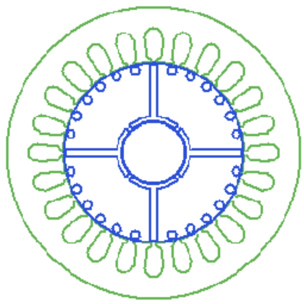

Fig. 6a LSPMM at first state

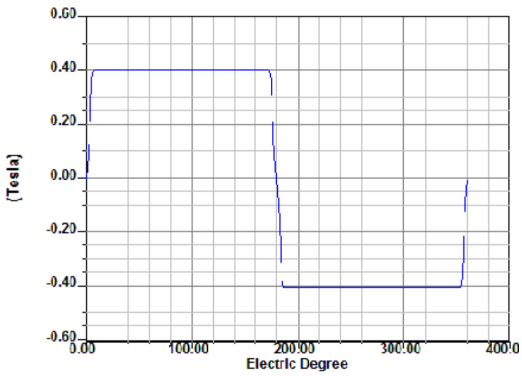

Fig. 6b Air gap flux versus electrical degree

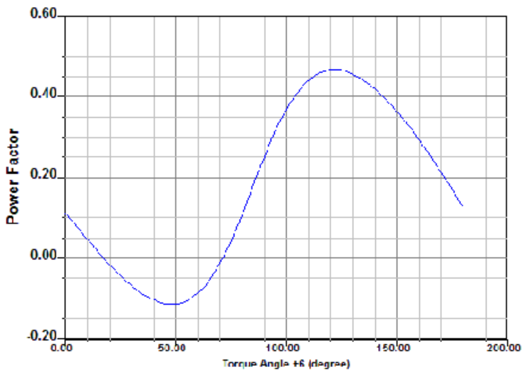

Fig. 7 Power factor versus torque angle

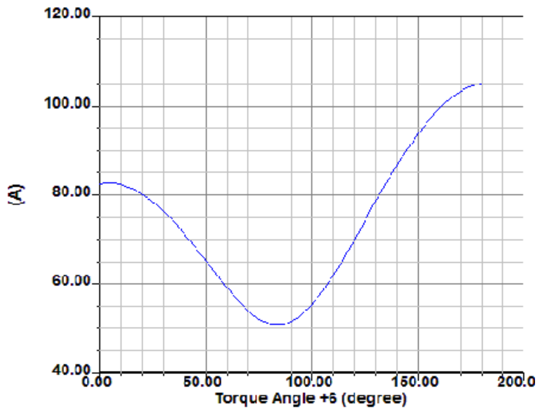

Fig. 8 Line current versus torque angle

It is seen that in this design flux of air gap reaches to 0.4 Tesla, and power factor reaches to 0.45 which is very small for LSPM. Fig.8 shows the line current. As we can see line current reach to the highest value of 105 Amper that is not suitable for LSPMM.

Design2: In this state, LSPMM motor is designed by changing structure of rotor and pole according to (Fig.9), (Fig.10) respectively.

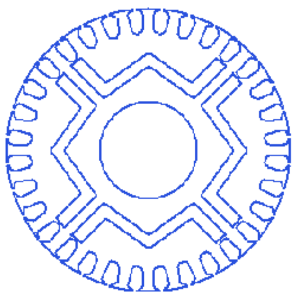

Fig. 9 Rotor structure of LSPMM at second state

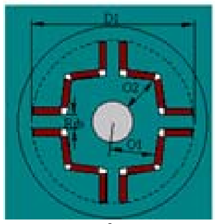

Fig. 10 Rotor structure of LSPMM at second state

After designing motor with this type of rotor structure (Fig. 11) and simulating motor in full-load condition flowing results is obtained.

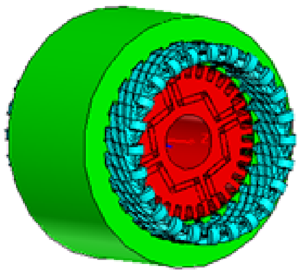

Fig. 11 three dimensional design of LSPMM at second state

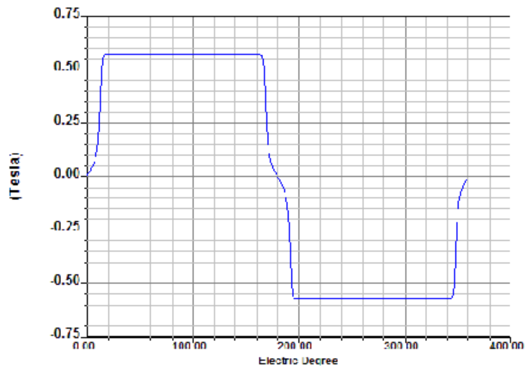

Fig. 12 Air gap flux versus electrical degree

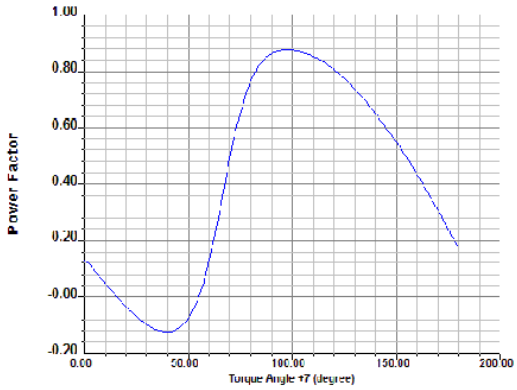

Fig. 13 Power factor versus torque angle

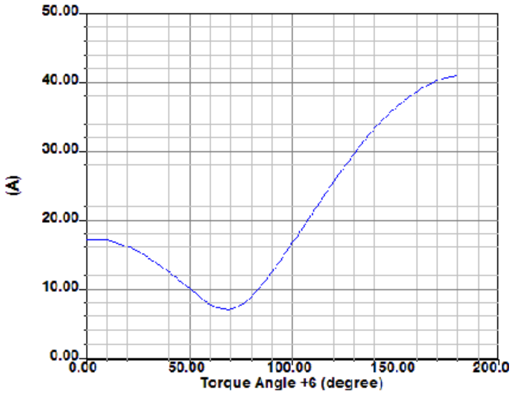

Fig. 14 Line current versus torque angle

It is seen that in this design flux of air gap reaches to 0.55 Tesla, and power factor reaches to 0.85, which is doubled in contrast to previous design for LSPM. Also line current can reach to the highest value of 40 Amper which is decreased significantly.

Design3: In the third state, LSPMM motor is designed by changing structure of rotor and pole according to (Fig.15), (Fig.16) respectively.

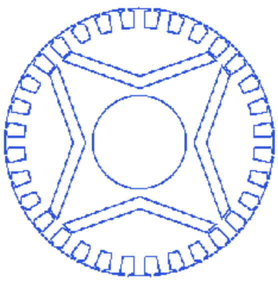

Fig. 15 Rotor structure of LSPMM at third state

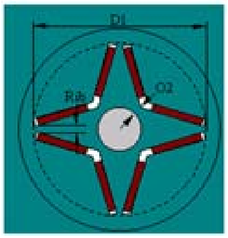

Fig. 16 Rotor structure of LSPMM at third state

After designing motor with this type of rotor structure (Fig. 17) and simulating motor in full-load condition flowing results is obtained.

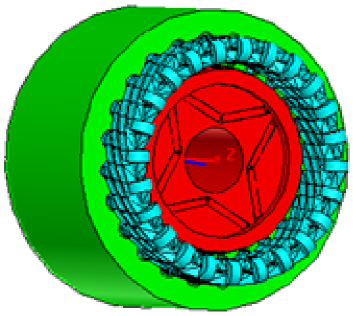

Fig. 17 Three dimensional design of LSPMM at third state

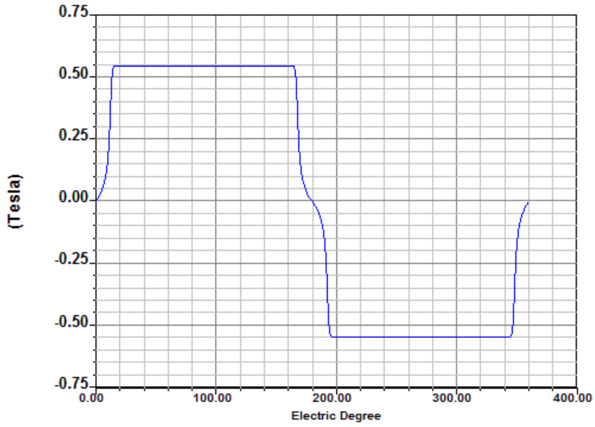

Fig. 18 Air gap flux versus electrical degree

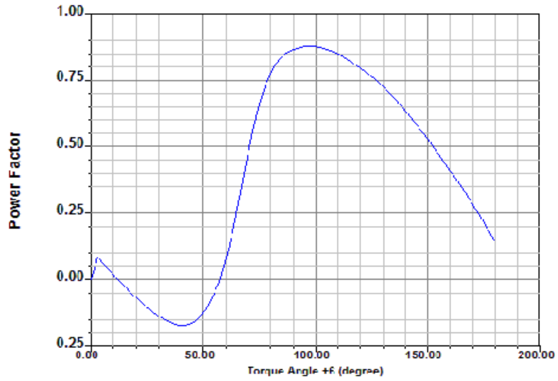

Fig. 19 Power factor versus torque angle

It is seen that in this design flux of air gap reaches to 0.6 Tesla, and power factor reaches to 0.9, which is increased significantly in contrast to the first design for LSPM. Line current reaches to the same value of the second design.

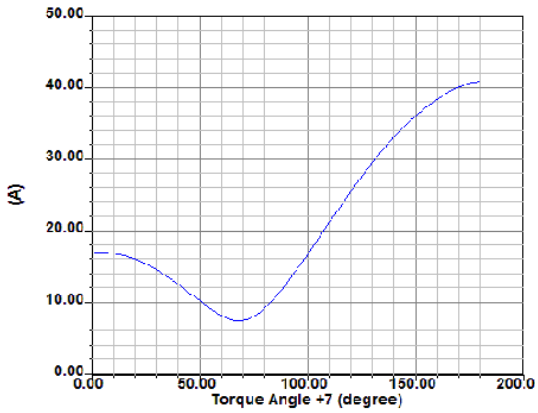

Fig. 20 Line current versus torque angle

IV. Simulation and Results

For the first design values of the total loss, speed, and efficiency of the motor are shown in table II. It is seen that total loss is extremely large in this design as a result efficiency of motor is not acceptable.

TABLE II
THE RESULTS OF MOTOR ANALYSIS

NAME	VALUE	UNIT
Total Loss	1366.65	W
Speed	1500	rpm
efficiency	31.919	%

For the second design values of the total loss, speed, and efficiency of the motor are shown in table III. It is seen that total loss is decreased in this design as result efficiency is higher in contrast to previous design, but still it is not suitable for LSPMM.

TABLEIII
THE RUSULTS OF MOTOR ANALYSIS

NAME	VALUE	UNIT
Total Loss	211.35	W
Speed	1500	rpm
efficiency	72.162	%

In the third design values of the total loss, speed, and efficiency of the motor are shown in table IV. It is seen that total loss is decreased considerably in contrast to first design as result efficiency is reached to the highest value, which is acceptable for LSPMM.

TABLE IV
THE RESULTS OF MOTOR ANALYSIS

NAME	VALUE	UNIT
Total Loss	102.801	W
Speed	1500	rpm
efficiency	92.075	%

The results shows that rotor structure plays an important role in improving efficiency LSPMM motor and by changing the structure of rotor line current, total loss, and efficiency will be changed. Of course for more improvement of motor performance other parameters should be determined.

V. Conclusion

A complete model was developed with the objective of examining the behavior of the LSPMM motor. It can be concluded that rotor play an important role in improving the efficiency of LSPMM motor. By changing the structure of rotor efficiency is changed. Hence, care should be taken in choosing the best structure for permanent magnets which yields maximum efficiency. It concluded from simulations that the largest flux density in the air gap and the smallest loss is the result of the third case.

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