Electromagnetic Analysis and Design of Two-pole Line-start Permanent Magnet Synchronous Motor

Feng Yaojing, Yang Kai
College of Electrical and Electronic Engineering, Huazhong University of Science and Technology
1037 Luoyu Road, Wuhan, Hubei, 430074, China
E-mail: maryvon2003@126.com; yk@mail.hust.edu.cn

Abstract — This paper introduces a two-pole line-start permanent magnet synchronous motor (PMSM), and provides the magnetic circuit design and electromagnetic analysis of a 73.5kW line-start PMSM. First of all, the operating principle and structural features of the line-start PMSM are described briefly. The overall design scheme of the motor is introduced, and an interior rotor structure is presented, which adopts radial-set permanent magnets with multi-section for each pole. Then, a motor model is established, with the aid of the finite-element analysis software JMAG-Studio. The transient electromagnetic field is calculated and analyzed using the time-stepping finite-element method (FEM) coupled with field and circuits. The starting process and steady-state performance are simulated, and the results verify the model and the rationality of the motor parameter design.

I. INTRODUCTION

In term of the structure, line-start permanent magnet synchronous motor (PMSM) can be considered as squirrel-cage induction motor with permanent magnets embedded in the rotor. The permanent magnets provide magnetic flux and synchronous torque, so as to avoid exciting current loss. It has the same operating principle as that of an electric excited synchronous motor. During the transient start-up process, the rotor cage contributes to the production of an asynchronous torque that overcomes a PM transient braking torque and accelerates the rotor. In typical steady-state operation, the rotor moves in synchronism with the air-gap revolving magnetic field.

This paper presented the design of a 73.5kW two-pole three-phase line-start PMSM, and the rationality of the motor parameters is validated by electromagnetic analysis.

II. DESIGN OF TWO-POLE LINE-START PMSM

When the principle dimensions are constant, the higher power density is required, the more quantities of permanent magnets are needed, and apparently, they will occupy more space. However, the rotor slot cannot be too shallow, in order to obtain good starting performance. So, there is competition between the magnets and the rotor slots in line-start PMSM, especially in two-pole motors.

Previous researches have presented some typical rotor structures, as shown in Fig.1. These structures provide more space for permanent magnets at the cost of several rotor slots. The uneven distribution of rotor slots may affect the starting performance, and the rotor end rings make it difficult to place the magnets.

The ideal placement is in arc shape. However, although providing more space, permanent magnets in arc shape will bring high cost. Taking into account both performance and cost, the radial-set placement with multi-section of magnets is relatively reasonable.

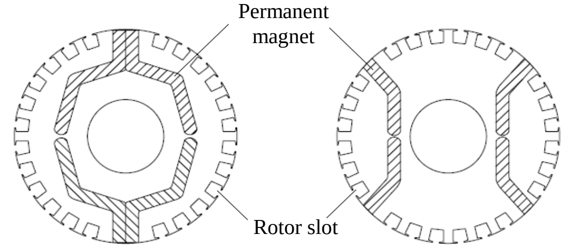


Fig. 1. Two types of rotor structure

In this paper, four-section of permanent magnets are adopted for each pole. The vent holes are oval-shaped instead of circle in order to avoid the saturation of magnetic flux density in the rotor. Fig.2 shows the rotor structure of the line-start PMSM.

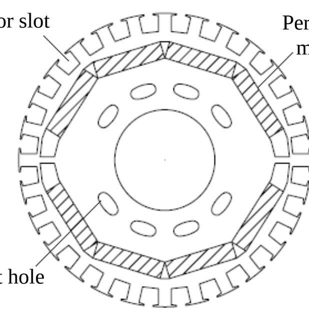


Fig. 2. Rotor structure with multi-section of magnets per pole

III. MODELING AND ANALYSIS

Computation of the transient electromagnetic field plays an important role in the motor design and operation. The finite element analysis software JMAG-Studio is used to create and analyze the model.

The two-pole line-start PMSM is running at 400V, 60Hz, and the rated power is 73.5kW. The parameters are set according to the design scheme, as is shown in Table I.

TABLE I
MOTOR MODEL PARAMETERS

Item	Value
Stator Inner Diameter	140.5 mm
Lamination Thickness	260 mm
Number of Poles	2
Number of Stator Slots	36
Rotate speed	3600 rpm
Resistance of Each Phase Coil	0.04 ohm
Number of Turns per phase	33

The magnets are magnetized in a radial direction, and the coils are Y-shaped connections with three-phase single-layer concentric windings.

The full physical model is shown in Fig. 3. Fig.4 shows a typical distribution of magnetic flux density, and Fig.5 shows the air gap flux density curve versus angle.

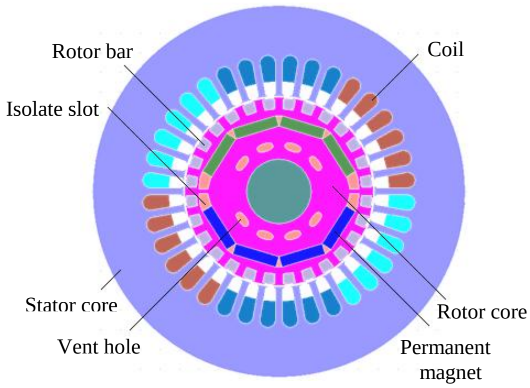
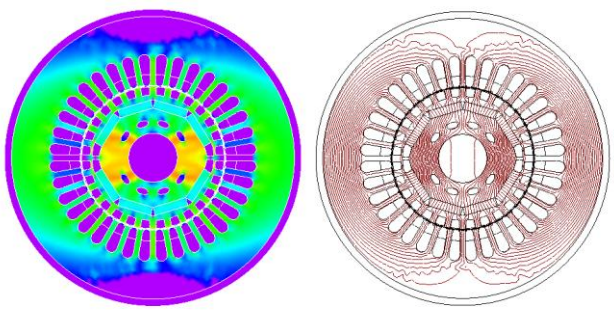


Fig. 3. Physical model of the line-start PMSM



(a) Contour display (b) Flux line display

Fig. 4. The distribution of magnetic flux density

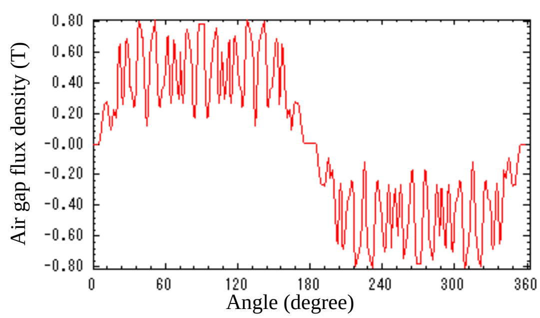


Fig. 5. The air gap flux density

The no-load electromotive force (EMF) and cogging torque can be obtained by running an analysis on the model as a generator with no load. The EMF curve and cogging torque curve versus time are shown in Fig. 6 and Fig. 7.

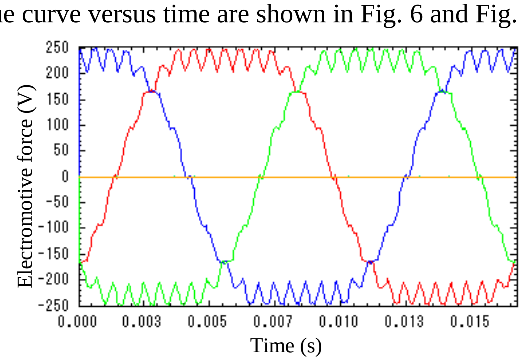


Fig. 6. The no-load electromotive force (EMF)

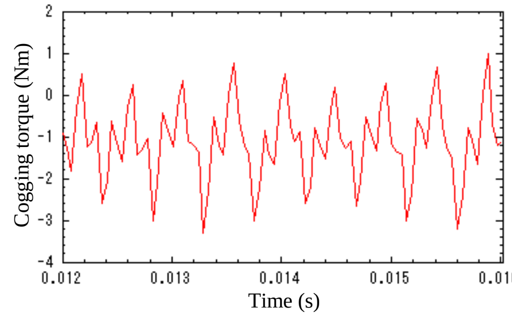


Fig. 7. The cogging torque

The no load and load staring performance can be simulated by using the time-stepping FEM coupled with field and circuits. Fig. 8 and Fig. 9 show the starting torque curve versus time at no-load and full-load, respectively.

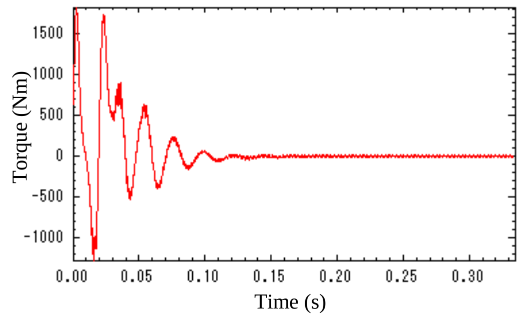


Fig. 8. The starting torque under no load

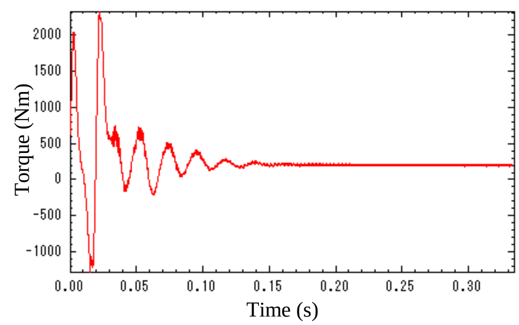


Fig. 9. The starting torque under full load

IV. REFERENCES

[1] C. A. da Silva, J. R. Cardoso, R. Carlson, “Analysis of a Three-Phase LSPMM by Numerical Method,” *IEEE Trans. on Magn.*, vol.45, no.3, pp. 1792-1795, 2009.

[2] W. Fei, P. C. K. Luk, J. Ma, J. X. Chen and G. Wang, “A High-Performance Line-Start Permanent Magnet Synchronous Motor Amended From a Small Industrial Three-Phase Induction Motor,” *IEEE Trans. on Magn.*, vol.45, no.10, pp. 4724-4727, 2009.

[3] T. T. Ding, N. Takorabet, F. M.Sargos, and X. H. Wang, “Design and Analysis of Different Line-Start PM Synchronous Motors for Oil-Pump Applications,” *IEEE Trans. on Magn.*, vol.45, no.3, pp. 1816-1819, 2009.

[4] Q. F. Lu and Y. Y. Ye, “Design and Analysis of Large Capacity Line-Start Permanent-Magnet Motor,” *IEEE Trans. on Magn.*, vol.44, no.11, pp. 4417-4420, 2008.

[5] C. K. Lee and B. I. Kwon, “Design of post-assembly magnetization system of line start permanent-magnet motors using FEM,” *IEEE Trans. on Magn.*, vol.41, no.5, pp. 1928-1931, 2005.

[6] A. M. Knight and C. I. McClay, “The design of high-efficiency line-start motors,” *IEEE Trans. on Ind. Applicat.*, vol.36, no.6, pp. 1555-1562, 2000.

[7] R. Y. Tang, *Modern Permanent Magnet Machines-Theory and Design* (in Chinese). Beijing, China. Machine Industry Press, 1997.