Segmented Magnets in Line-start Permanent Magnet Synchronous Motor for Reducing Magnet Demagnetization

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Abstract — The large demagnetization field during the starting process of line-start permanent magnet synchronous motor (LSPMSM) will cause the irreversible demagnetization of permanent magnet. In this paper, for reducing magnet demagnetization, the magnets in LSPMSM were segmented to optimize the magnetic circuit. And the performances of motor before- and after- magnets segmented were compared by the two-dimensional time-stepping finite element method(FEA). Finally, the results show that the motor after its magnets segmented has better ability of anti-demagnetization.

I. Introduction

Due to the armature reaction magnetic field, the magnets in LSPMSM are easily demagnetized, especially during the start process. When the composite magnetic field(produced by the currents of rotor bar and stator winding)is in the opposite direction of the permanent magnetic field(produced by the permanent magnet), the magnet's average working point is slow, and the irreversible demagnetization are most probably occurred [1]-[2], which will seriously influences the performances of LSPMSM.

In the paper [3], the magnet's position is varied to minimize the demagnetizing effect. In the paper [4], the optimized rotor pole shape is proposed to reduce the partial demagnetization. In this paper, the permanent magnet is segmented into two, and a small iron bridge is placed between two segments, when the stator current is applied, more of the armature-reaction demagnetization field cross through the gap other than magnets [5]-[6], the magnet's average working point will be high.

A 22 kW 8 poles 'V-type' magnetic structure of LSPMSM has been taken as an example in this paper, and the performances of LSPMSM before- and after- its magnets segmented were compared based on the two-dimensional time-stepping finite element method(FEA). The results of comparison show that the segmented magnets have better ability of anti-demagnetization.

II. Model Design and Analysis Method

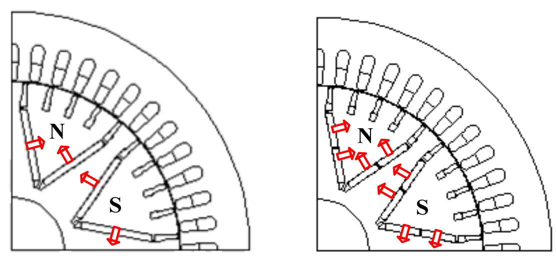
A. Design parameters and models

The main data of the LSPMSM design are given in Table I.

The FEA models of LSPMSM are shown in Fig.1, the arrows on magnet present the magnetization direction. The two models are the same except for the permanent magnet. Fig.1(a) is conventional model whose magnet is not segmented, while Fig.1(b) is the model whose magnet is segmented into two sections.

TABLE I
22kW LSPMSM DESIGN PARAMETERS

Design Parameters	Value
Number of stator/rotor slots	48/40
Rate speed(r/min)	750
Outer diameter of stator(mm)	368
Inner diameter of stator(mm)	260
Air gap length	0.65
Axial length of stator core(mm)	215
Thickness of magnet(mm)	5.3
Magnet material	NdFeB



(a)Before magnet segmented (b)After magnet segmented
Fig. 1. FEA models of LSPMSM before- and after- its magnets segmented

B. Analysis method

2-D time-stepping finite element method is usually used to analyze the transient performance of the motor, which can consider the saturation, eddy current and skin effect. And the starting performance just as speed, winding current and electromagnetic torque can be gained by this method. The element flux density of the permanent can also be gained, then the average working point of the magnet is calculated.

The equation of the electromagnetic field can be presented in(1)

$$\begin{cases} \frac{\partial}{\partial x}(\frac{1}{\mu}\frac{\partial \boldsymbol{A}}{\partial x})+\frac{\partial}{\partial y}(\frac{1}{\mu}\frac{\partial \boldsymbol{A}}{\partial y})=-\boldsymbol{J}_s+\sigma\frac{\partial \boldsymbol{A}}{\partial t} & (G) \\ \boldsymbol{A}=0 & (\Gamma 1) \\ \nu_1\frac{\partial \boldsymbol{A}}{\partial \boldsymbol{n}}-\nu_2\frac{\partial \boldsymbol{A}}{\partial \boldsymbol{n}}=\boldsymbol{\delta}_c & (\Gamma 2) \end{cases} \quad (1)$$

where $\boldsymbol{A}$ is magnetic vector potential, $\boldsymbol{J}$s is current density, and μ is permeability, σ is conductivity, $\boldsymbol{\delta}_c$ is equivalent surface current density of permanent magnet, $\boldsymbol{\nu}_1$ and $\boldsymbol{\nu}_2$ are reluctivities of different mediums.

The discrete equation of the electromagnetic boundary value problem, coupling with the circuit equation and motion equation can be presented by matrix as in (2).

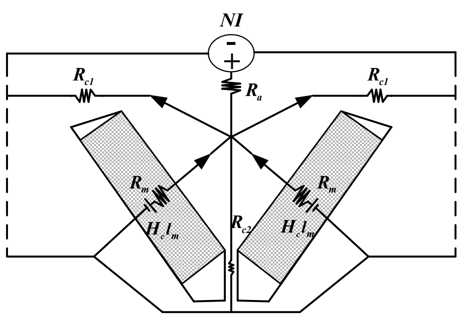
$$
\begin{bmatrix} \boldsymbol{K} & \boldsymbol{S} & \boldsymbol{B} & 0 & 0 \\ 0 & \boldsymbol{R}_{\mathrm{s}} & 0 & 0 & 0 \\ 0 & 0 & \boldsymbol{R}_{\mathrm{r}} & 0 & 0 \\ \boldsymbol{A}^{\mathrm{T}}\boldsymbol{H} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \boldsymbol{A} \\ \boldsymbol{I}_{\mathrm{s}} \\ \boldsymbol{I}_{\mathrm{r}} \\ \Omega \\ \theta \end{bmatrix} + \begin{bmatrix} \boldsymbol{P} & 0 & 0 & 0 & 0 \\ \boldsymbol{M} & \boldsymbol{L}_{\sigma\mathrm{s}} & 0 & 0 & 0 \\ \boldsymbol{N} & 0 & \boldsymbol{L}_{\sigma\mathrm{r}} & 0 & 0 \\ 0 & 0 & 0 & -J_{\mathrm{m}} & 0 \\ 0 & 0 & 0 & 0 & -1 \end{bmatrix} \frac{\partial}{\partial t} \begin{bmatrix} \boldsymbol{A} \\ \boldsymbol{I}_{\mathrm{s}} \\ \boldsymbol{I}_{\mathrm{r}} \\ \Omega \\ \theta \end{bmatrix} = \begin{bmatrix} \boldsymbol{F}_{\mathrm{A}} \\ \boldsymbol{U}_{\mathrm{s}} \\ \boldsymbol{0} \\ T_{\mathrm{m}} \\ 0 \end{bmatrix} \quad (2)
$$

where $\boldsymbol{I}_{\mathrm{s}}$ and $\boldsymbol{I}_{\mathrm{r}}$ are separately rotor end ring current and stator winding current, $\boldsymbol{U}_{\mathrm{s}}$ is voltage source, $\boldsymbol{\Omega}$ is rotor mechanical angular velocity, and θ is angle of rotor position.

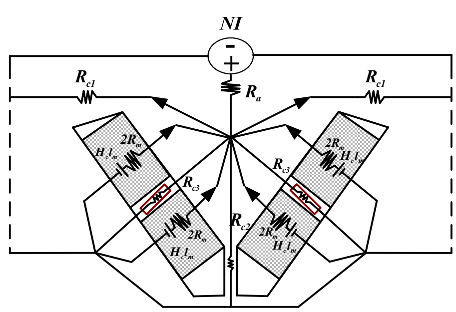
III. COMPARISON RESULT AND DISCUSSION

A. Equivalent Magnetic Circuit Comparison

The influences of the armature-reaction demagnetization field on the permanent magnetic field can be analyzed by using equivalent magnetic circuits[7], as in Fig.2.



(a)Before magnet segmented



(b)After magnet segmented

Fig. 2. Equivalent magnetic circuits of LSPMSM before- and after- its magnets segmented

Due to that the iron gap reluctance R_{c3} is smaller than the permanent magnet reluctance R_{m}, more of the armature-reaction demagnetization field by *NI* pass the iron gap, and the permanent magnetic field is mostly preserved.

B. Performance comparison

There are almost no differences in starting performances between the model before segmented and the model after segmented, and the magnetic potential of the magnet is not weakened after segmented, just as the back EMF in Fig.3.

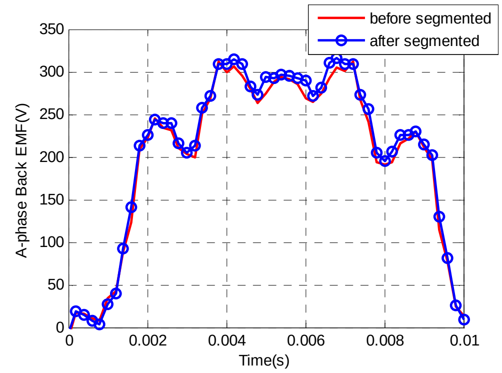


Fig. 3. Back EMF comparison

C. Anti-demagnetization comparison

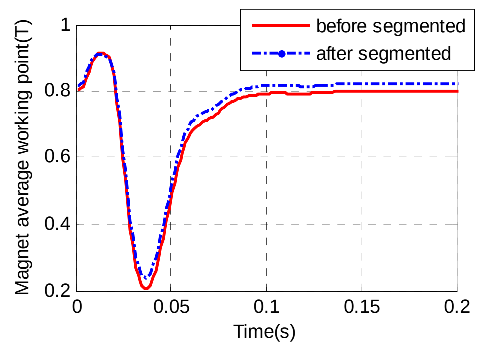


Fig. 4. Magnet average working point flux density comparison

Fig.4 compared the magnet average working point flux density of the two models, we can see that during the starting process, the lowest point of the magnet is improved from 0.20T to 0.24T after the magnet segmented, which shows that the model after magnet segmented has the better ability of anti-demagnetization.

D. Conclusion

Segmented magnets in LSPMSM has better ability of anti-demagnetization. If possible, the related experiments will be carried out to verify the analysis result.

IV. REFERENCES

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