Analyzing and Weakening the Cogging Torque of Line-start Permanent Magnet Motor

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Compared with the general permanent magnet synchronous motor, Line Start Permanent Magnet Synchronous Motor (LSPMSM) has the features with two-sided slots of stators and rotors. Due to its complex air gap form, there is no effective method to calculate the cogging torque of this kind of motors at present. This paper presents a new analytical method that the rotor's function can be equivalent to the magnetic motive force (MMF) distribution of air gap which avoids the influence caused by rotor slotting on air gap. Based on the energy method, its analytical method is given to analyze the pole-slot match of stator and the influence of slots number per pole of rotor on cogging torque.

***Index Terms*—Line-start permanent magnet synchronous motor(LSPMSM), cogging torque, Finite element method**

I. INTRODUCTION

THE air gap shape is very complex for line start permanent magnet synchronous motor (LSPMSM) with two-sided slots that increase the difficulty of cogging torque analysis of this kind of motor and it is difficult to use the cogging torque analysis method for PM with one-sided slots. Literature [1] divides the air gap of LSPMSM into stator side and rotor side. Considering the relative position angle between them, the expression of effective length of air gap is achieved by superposition. Then the analytical expression of cogging torque is derived based on the energy method and the mechanism of production of the cogging torque is analyzed. But the complexity of effective length expression of air gap causes the complexity of expression of cogging torque. Due to that, the research on cogging torque from this is difficult.

This paper presents a new analytical method to reduce the cogging torque of LSPMSM, which means the function of rotors is equivalent to the air gap MMF distribution. Therefore the distribution of effective air gap length is only related to the distribution of stator cogging that avoid the difficulty in calculating the effective length of air gap caused by rotor slotting. The analytical expression of cogging torque of LSPMSM was deduced based on the energy method and the clear relation between cogging torque and motor structure parameters was given. Then the influence of pole and slot combination and stator skewed slot on cogging torque was analyzed and the validity of analysis was testified by FEM method. It must be clear that the purpose of analytical method about cogging torque of LSPMSM presented in this paper is not accurately calculating cogging torque, but building the relations between cogging torque and motor structure parameters.

II. ANALYTICAL METHOD FOR COGGING TORQUE OF ROTOR'S EQUIVALENT MAGNETIC MOTIVE FORCE (MMF)

W-type magnetic circuit has been widelyused inLSPMSM.Therefore this paper takes this structure as example and analyses the cogging torque of LSPMSM. As shown in Fig.1, the analysis of other kind of motors is similar.

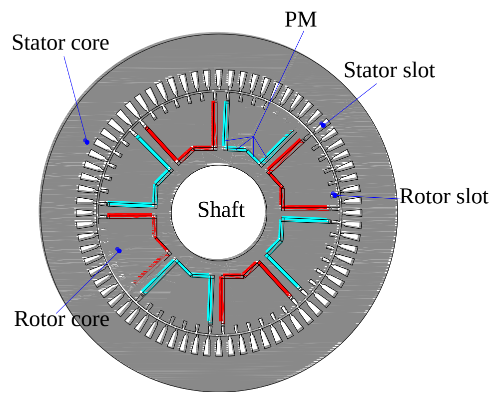

Fig. 1. Scheme of LSPMSM with W-type magnetic circuit.

In order to derive the analytical expression of cogging torque, assume that: 1) the permeability of stator and rotor iron core is infinite; 2) stator and rotor slots are rectangular slots; 3) the position of θ=0 is in the centerline of a specific permanent magnet poles; 4) α is the relative position between stator and rotor.

The cogging torque T_{cog} is defined as:

$$W(\alpha)=W_{airgap}(\alpha)=\frac{1}{2\mu_0}\int_v B^2\left(\theta,\alpha\right)dV \qquad (1)$$

where W is the magnetic field energy in motor, W_{airgap} is the magnetic field energy in air gap of motor, μ_0 is air permeability,$B(\theta,\alpha)$ is the distribution of air gap flux density along surface of armature.

Assuming that the inner surface of stator is magnetic equipotential surface and regarding the function of the whole rotors as distributed magnetic motive force, the distribution of MMF along air gap circle is shown as Fig.2. The distribution of the MMF has considered the influence of slotting rotors and thinks that the MMF is imposed on the air gap caused by air gap and stator slot opening, which effectively avoids the complexity of air gap calculation caused by slotting rotor in the process of cogging torque analysis.

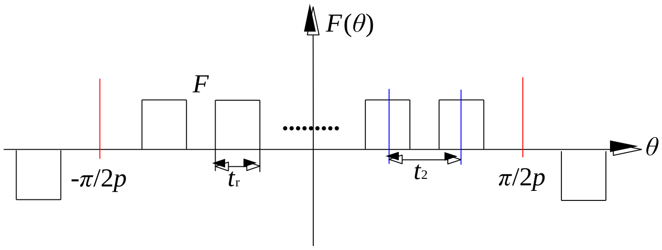

Fig. 2.The distribution of rotor's equivalent MMF.

$B(\theta,\alpha)$ can be expressed as:

$$B(\theta,\alpha)=\Lambda\cdot F(\theta) \tag{2}$$

Among which, Λ is the air permeability and $F(\theta)$ is rotor equivalent MMF. This article is not for the precise calculation of cogging torque. So a specific value of F is not given.

Then, Λ can be expressed as:

$$\Lambda=\frac{\mu_0}{\delta(\theta,\alpha)} \tag{3}$$

where, $\delta(\theta,\alpha)$, as the effective length distribution of air gap along circumference, it is only related with the distribution of stator slots. Using motors with one-sided slots can simplify the analysis of cogging torque[2]. Plug formula (2) and (3) into formula (1), and it can be obtained that:

$$W_{airgap}(\alpha)=\frac{\mu_0}{2}\int_V F^2(\theta)\left[\frac{1}{\delta(\theta,\alpha)}\right]^2 dV \tag{4}$$

If the Fourier expansion of $F^2(\theta)$ and $[1/\delta(\theta,\alpha)]^2$ can be got, the expression of magnetic field energy of motor will be obtained, so as the expression of cogging torque.

The cogging torque expression of LSPMAS without considering stator skewed slot can be got:

$$T_{cog}=\frac{\pi\mu_0 Q_1 L_a}{4}(R_1^2-R_2^2)\sum_{n=1}^{\infty} nG_n F_{\frac{nQ_1}{2p}}\sin nQ_1\alpha \tag{5}$$

where, L_a is the axial length of motor's iron core; R_1 and R_2 respectively are the stator internal radius and rotor external radius; n is the integral that makes $nQ_1/2p$ is integral.

III. The Influence of Slot-Pole Match on Cogging Torque

In this paper, a LSPMSM with 10kw and 6 poles is regarded as example to study the influence of pole-slot match on cogging torque of motor. Its structure is shown in Fig.1.The finite element method is used to calculate the cogging torque waveform of different stator slot-pole matches, as shown in Fig. 3. The corresponding relation between waveform and slot-pole matches is shown as Table I.

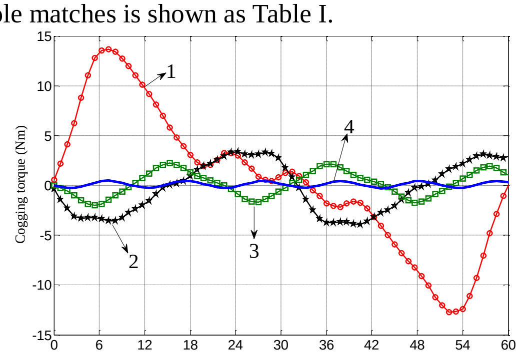

Fig. 3.Cogging torque waveform with different stator slot-pole matches.

TABLE I
CORRESPONDING RELATION BETWEEN WAVEFORM AND STATOR SLOT-POLE MATCHES

Waveform	Q_1	p	N_p	T_{cog} amplitude(Nm)
1	36	6	1	13.64
2	33	6	2	3.45
3	34	6	3	2.13
4	35	6	6	0.43

It can be seen from the Fig.1 that the rotor slot number is the integral time of pole number, which means the slot number per pole of rotor q_2 is integer. Because the permanent magnets are built in the rotor core. If the slot number of rotor per pole is fraction, it may cause serious flux leakage. While if the slot number of rotor per pole is integer, a flux barrier will be produced between rotor slots and permanent magnets that can limit flux leakage. Therefore in this paper, the analysis of cogging torque in LSPMSM is only limited to the integral slot of stator per pole. Change the slot number per pole q_2 of prototype one, and use the finite element method to calculate and get the corresponding cogging torque waveform with different q_2, shown in Fig.4. The corresponding relation between waveform and q_2 is shown in Table II.

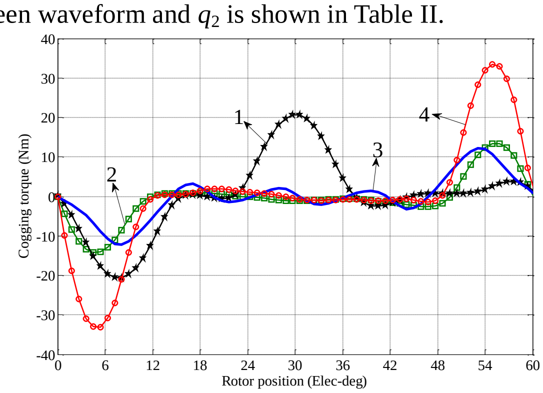

Fig. 4. Cogging torque waveform with q_2

TABLE II
CORRESPONDING RELATION BETWEEN WAVEFORM WITH Q_2

Waveform	q_2	T_{cog} amplitude(Nm)
1	3	20.63
2	4	13.41
3	5	12.22
4	6	33.57

IV. Conclusion

This paper presents a new method to analyze the cogging torque of LSPMSM. The rotor's function can be equivalent to the MMF distribution and the expressions of cogging torque with or without considering stator skewed slots are deduced based on the energy method. The influence of pole-slot match on cogging torque is analyzed and the effect of stator slots number and the slots number per pole of rotors on cogging torque are mainly expounded.

References

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