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Analytical Calculation for Predicting the Core Loss of Surface-Mounted Permanent Magnet Machine

Feng Yanli[a*], Zhang Chengning[a]

[a]*National Engineering Laboratory for Electric Vehicle, Beijing Institute of Technology, Beijing100081, China*

Abstract: The core loss is an important component in the design of machine. In the paper, a new analytical model of flux density at various operating point for surface-mounted permanent magnet synchronous machines is proposed by the equivalent magnetic circuit method. Based on the analytical model of flux density, the core loss was calculated by Bertotti's formula. In order to verify the accuracy of the proposed analytical method for core loss, experiment and finite element Analysis (FEA) are used. It shows that the analytical results for core loss can keep consistency well with the experimental result and FEA results. Thus, the analytical model for core loss is suitable for machine optimization.

Keywords: flux density; core loss; Bertotti formula; surface-mounted permanent magnet synchronous machines

1. Introduction

The core loss calculation is of great significance for the design of the surface-mounted permanent magnet synchronous machines (SPM), in order to determine the efficiency. With the wide working range of electrical machine, the core loss calculation at each operating point is complicated and time-consuming because of the nonlinearity of magnetic field. Thus, the core loss analysis over the full range of operation is the key technology in the design of machine [1-2].

At present, both the analytical and computational methods have been developed to predict the core loss. The literature [3] analyzed the numerical calculation of core loss on a novel axial flux machine with segmented-armature-torus topology based on the Bertotti's formula. The waveform of real flux density was obtained using 3D FEA and the harmonic flux density waveform in each finite element was obtained by Fourier transformation. However, the computation is complicated and time-consuming. The literatures [4-5] presented a simplified voltage model to calculate the core loss within a field orientated controlled brushless permanent magnet machine based on the superposition of magnetizing and demagnetizing loss component. However, the simplified voltage model ignored the stator resistance, so the core loss would cause some errors. Meanwhile, the core loss has been greatly influenced by the changing flux density, so the accurate calculation of flux density is also important. The literatures [6-8] analyzed the magnetic

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[*] Corresponding author. Tel.:13718151518.
E-mail address: fengyl1208@163.com.

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characteristics of SPM, and established the analytical method using magnetic circuit analysis, which could directly calculate the average air gap flux density. However, the accuracy of analytical model is limit without considering the saturation effect of iron material.

In order to improve the computation efficiency and accuracy of the core loss, it is necessary to obtain a new analytical model of core loss. The paper presents a new analytical model of flux density at various operating point using the equivalent magnetic circuit method, and the core loss was calculated by Bertotti's formula based on the analytical model of flux density. Finally, the experiment and FEA are used to verify the accuracy of the proposed analytical method.

2. Basic structure and analytical model of air-gap flux density

2.1. The equivalent magnetic circuit analysis

In the paper, SPM has been chosen to demonstrate the approach. Given the motor flux distribution properties, the flux can be divided into three sections which are shown in Fig.1.That includes the flux source for one magnet pole, the air gap flux for one magnet pole and the leakage flux which cross through one magnet pole and two magnet poles. Given the flux distribution indicated in Fig.1 and the Ohm's law equivalent of magnetic circuit, the equivalent magnetic circuit is shown in Fig.2.

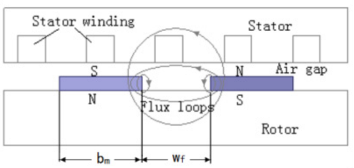

Fig. 1. The flux distribution of motor

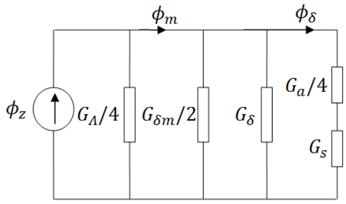

Fig. 3. The simplified equivalent magnetic circuit

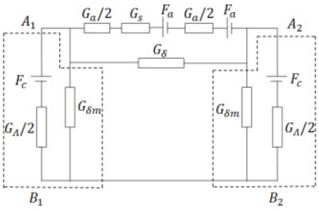

Fig. 2. The equivalent magnetic circuit

The variables of Fig.2 are defined as follows:

G_Λ is the leakage permeance for magnet pole, G_a is the permeance for air gap, G_s is the permeance for stator, $G_{\delta m}$ is the leakage permeance through one magnet pole, G_δ is the leakage permeance through the two magnet poles nearby and air gap, F_c is the magnetomotive force for one magnet pole, F_a is the winding magnetomotive force per phase.

Then thevenin theorem and nortons theorem are applied to simplifying the equivalent magnetic circuit, respectively. Consequently, the simplified equivalent magnetic circuit is shown in Fig.3. Assumed the winding turns per phase is N, the magnet flux and total air gap flux is

$$\begin{cases} \phi_z = \left(\sqrt{\left(\frac{\phi_r}{2G_\delta+\frac{G_{\delta m}}{2}++\frac{G_\Lambda}{4}} - NI_d\right)^2 + \left(NI_q\right)^2}\right)\left(\frac{G_\Lambda}{4}+\frac{G_{\delta m}}{2}+G_\delta\right) \\ \phi_m = \frac{\emptyset_z\left(\frac{G_sG_a}{4G_s+G_a}\right)}{\frac{G_\Lambda}{4}+\frac{G_{\delta m}}{2}+G_\delta+\frac{G_sG_a}{4G_s+G_a}} \end{cases} \tag{1}$$