Flux-Regulation Performance for Radial Suspension forces of Bearingless Flux-Switching Motor Huangqiu Zhu, Chenyin Zhao and Yizhou Hua Tue-Af-po2.0606 [70]

School of Electrical and Information Engineering, Jiangsu University, Zhenjiang 212013, Jiangsu, China

In recent years, several structures of the BFSPM motor have been proposed. In order to improve the fault tolerance, a 12/14-type E-core BFSPM motor with the single winding was proposed and a 6/10-type E-core BFSPM motor with the single winding was presented However, in order to realize stable suspension control, it is necessary to establish an accurate mathematical model of radial suspension force which has not been derived systematic. In recent years, several structures of the BFSPM motor have been proposed. In order to improve the fault tolerance, a 12/14-type E-core BFSPM motor with the single winding was proposed and a 6/10-type E-core BFSPM motor with the single winding was presented However, in order to realize stable suspension control, it is necessary to establish an accurate mathematical model of radial suspension force which has not been derived systematic.



Motor configuration

As shown in Figure as below, the configuration of the proposed motor is very similar with that of the traditional FSPM motor, which adopts a three-phase 12/10pole (12-stator-teeth and 10-rotor-poles) configuration. As well as traditional FSPM motor, 12 concentrated armature winding coils and 12 pieces of magnets are all accommodated in stator, and a simple and robust rotor is employed, the stator and rotor laminations are the same, directly inherited from the FSPM machine.

Mathematical model

For the proposed BFSPM motor, radial suspension force is generated by the flux density in the air-gap as well as torque, so the air-gap flux density should be calculated. It is noted that the air-gap MMF should be composed of three components: the MMF of torque windings FT, the MMF of PMs Fmag and the MMF of suspension force windings Fs.

$$B_{srk} = (F_T + F_{mag} + F_s)\Lambda_{srk}, (k = 1, 2, 3, 4)$$

$$\begin{cases}
F_{mag}(\theta) = A_{PM} \sum_{n=1}^{\infty} \{M_{PMn} \sin[(2n-1)p_m\theta]\} \\
A_{PM} = \frac{4F_{PM}}{\pi} \\
M_{PMn} = \frac{\cos[(2n-1)p_m\theta_1] - \cos[(2n-1)p_m\theta_3]}{2n-1}
\end{cases}$$

$$F_s = N_f \sum_{i=1}^6 I_i$$

Background



The figure shows the operation principle of generating the radial suspension force. The PM magnetic flux is generated by the PMs sandwiched in the stator. The suspension magnetic flux is generated when Y-axis suspension force winding current is excited. Oppositely, the flux density in the bottom air gap is decreased since the direction of PM flux is opposite to that of the suspension magnetic flux. Naturally, this superimposed magnetic field results in the radial suspension force Fy acting on the rotor toward the positive direction in the Y-axis.

> Based on the analysis above, the radial suspension force of the BFSPM motor acting on the rotor can be calculated by using the theory of Maxwell stress tensor:

$$\begin{cases} dF_{sr1}(\theta) = \frac{B_{sr1}^{2}(\theta,t)lr}{2\mu_{0}} d\theta \\ dF_{sr2}(\theta) = \frac{B_{sr2}^{2}(\theta,t)lr}{2\mu_{0}} d\theta \\ dF_{sr3}(\theta) = \frac{B_{sr3}^{2}(\theta,t)lr}{2\mu_{0}} d\theta \\ dF_{sr4}(\theta) = \frac{B_{sr4}^{2}(\theta,t)lr}{2\mu_{0}} d\theta \end{cases}$$



In this paper, mathematical models for radial suspension forces novel BFSPM motor are presented. The mathematical models are deduced after overall analysis of the form and features of rotor Maxwell force by simple MMF models and Maxwell stress tensor method. The MMF models of torque windings, suspension force windings and PMs are given. Based on these MMF models, the radial suspension force can be calculated. The calculation results are verified by FEA, and a series of comparisons between the FEA computed and calculated values are conducted, and the results indicate that the calculated values closely agree with FEA results.

