Study on Characteristics of Rotor Eccentricity for PMSM

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Abstract. Aiming at the permanent magnet synchronous motor (PMSM) with rotor eccentricity fault, two-dimensional static and dynamic eccentric models of PMSM are established respectively based on the finite element software EasiMotor. Through the simulation and the Fourier transform, air-gap flux density and radial electromagnetic force are solved. Simulation results show that the rotor eccentricity is an important influence factor for PMSM used in electric vehicle, which can be reference for further research on rotor-eccentricity magnetic field.

1. Introduction

The rotor eccentricity problem of PMSM is divided into static and dynamic eccentricity [1]. When PMSM is eccentric, the distribution of air-gap magnetic field is not uniform and thus the unbalanced magnetic force is produced, which leads to the unnecessary vibration on the rotor of the motor [2]. For the problem of the rotor eccentricity, a lot of researches have been done by domestic and foreign scholars. In [3], the magnetic field distribution of the air-gap magnetic field in the inner and outer rotors of the PMSM and the unbalanced magnetic force under different permanent magnetizing modes are analysed through the simulation experiment. The results show that the magnetic force of the magnetic field is not in good balance with the magnetic force of the inner rotor and the outer rotor under the condition of the eccentricity of the permanent magnet. The rotor eccentricity model of the surface-mounted PM motor is established in [4], the expression of the undetermined coefficient of the air-gap part is obtained by the global analytical method after analysing the air-gap magnetic field in the eccentricity condition. Document [5] shows that the eccentric pair of poles and slot array meet the specific conditions of the cogging torque and distribution of the large reverberation.

The simulation model of PMSM is built by EasiMotor. The distribution of magnetic field with different eccentricity of PMSM is solved, using finite element method to analyze electromagnetic field and obtain air-gap radial magnetic flux and radial electromagnetic force in different operating states, the influence of rotor eccentricity on the PMSM is studied by the fundamental wave and harmonic amplitudes of the air-gap flux density obtained by Fourier decomposition of radial gap-flux density.

2. Operational Principle

The eccentricity is circumferential when the distribution of air gap is not uniform in the circumferential direction and the axial air gap is ignored. It can be in two cases: the static and dynamic eccentricity. The static eccentricity is caused by the central shifting of the stator and rotor during installation, which is characterized by the constant position of the minimum air gap. The dynamic eccentricity is produced due to the bending of the rotating shaft, the wearing of the bearing, the key
point is that the position of the minimum air gap changes with the rotor rotation. There are two eccentric directions of rotor, one is called the deviated side, the other is called the opposite side, as shown in Figure 1.

![Fig 1](image)

**Figure 1.** The sketch map for static and dynamic eccentricity.

As you can see from Figure 1, the only difference between static and dynamic model is the difference in the centre of rotation. For static eccentricity, the centre of rotation needs to be \((x, 0)\) (\(x\) is eccentric distance), while the dynamic eccentricity is located at the origin \((0,0)\). In finite element analysis, it is necessary to ensure that the centre of circle of the moving boundary is the centre of rotation.

3. Analysis of air-gap flux density

Taking a 4-pole 500W AC PMSM model as an example, the static and dynamic eccentric models of PMSM are established by EasiMotor with the operating frequency of 50Hz. The air gap magnetic field, the output performance and electromagnetic force after eccentricity are simulated and analysed.

To analyse the air-gap magnetic field on the condition of no load, the static and dynamic motor models with the eccentricity of 0, 8.33%, 16.67%, 25% are built respectively, the analysis results are shown in Figure 2 and Figure 3.

As can be seen from Figure 2 and Figure 4, the trend of air-gap flux density variation of PMSM under different eccentricities is basically the same. After the rotor eccentricity, the magnetic density of the opposite side deviates from the magnetic density of the deviated side, which is due to the uneven distribution of the air gap magnetic field along the space. The air-gap width of the opposite side is small, the reluctance is decreased, and the corresponding magnetic flux drop is increased. On the contrary, air-gap width of the deviated side is large, the magnetic drop is larger than the magnetic flux density is decreased.

In addition, after the eccentricity, the air-gap flux is not distributed regularly, and the magnetic flux variation law on both sides is basically the same. The magnetic flux density of the air gap is symmetrically divided into the corresponding position, and the sign is opposite. The air-gap flux density is distorted throughout the circumference.
Figure 2. The air-gap flux at static eccentricity.

Figure 3. The air-gap flux at dynamic eccentricity.

In order to analyse the air-gap magnetic field harmonic distribution after rotor eccentricity, FFT analysis of air-gap magnetic field harmonic distribution is given with an eccentricity of 25% on the condition of static and dynamic motor model, the harmonic content and harmonic amplitude of the air-gap flux density are obtained as shown in Figure 5.
As can be seen from Figure 5, the amplitudes of the original fundamental wave, 3,5,7,9,11th harmonics remain basically unchanged after the rotor eccentricity of the motor, but the amplitude of the harmonics with the $\pm \frac{f}{p}$ order is obviously increased, and the harmonic component in the air-gap magnetic field becomes larger.

4. Analysis of electromagnetic force
Radial electromagnetic force produced in air-gap magnetic field of motor radiates noise from the surface of stator and rotor to the external radiation noise caused by radial electromagnetic force acting on the surface of stator and rotor. In order to analyse the reverberation of the rotor eccentricity on the electricity on the electromagnetic force of the motor, a stator tooth region is selected in the rotor deviated side and the opposite side, as shown in Figure 6.

From Figure 7 and 8, it can be seen that in static eccentricity, the electromagnetic force is periodically distributed with time, and each turn of the pair of poles changes by one cycle. In dynamic eccentricity, the electromagnetic force is not distributed periodically with time, which is due to the change of the minimum air gap position with the rotor motion at any time, which leads to the distortion of the electromagnetic force in time distribution.

When the rotor is eccentric, the larger the eccentricity is, the smaller the air gap is on the opposite side. When the air gap magnetic flux density increases, as the rotor rotates, the time of high magnetic flux density is longer, which causes the width of columnar curved line in the figure to increase. On the other hand, the opposite side of rotor, the larger the eccentricity, the smaller the magnetic density and electromagnetic force, and the shorter the magnetic density action time, this will cause the average electromagnetic force on both sides of the motor to become larger and larger. Because the force distribution is not uniform, the single-side magnetic force is formed, and with the degree of the eccentricity increases, the vibration and noise of the motor will become bigger.
5. Conclusion
In this paper, the eccentric problem of PMSM is analysed by using finite element software. Some conclusions are obtained as follows: due to the rotor eccentricity, the magnetic flux density under the stator pole is no longer symmetrical, which will result in the unbalanced force of the stator pole and the unilateral electromagnetic force. The air gap flux density difference after eccentricity will increase not decrease with the increasing of the winding current, accordingly, the radial force on the stator also decreases with the increase of the current. From the PMSM model, it also shows that the stator deformation is closely related to the force, and different forces will produce different stator deformations, which will cause periodic vibration in different degrees.

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