Electromagnetically Excited Vibration Calculation for a Three-phase Asynchronous Motor With Finite Element Method

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Keywords: asynchronous motor; radial electromagnetic force; electromagnetic vibration

Abstract. This paper mainly studies the electromagnetic vibration of a the three-phase asynchronous motor under no-load condition. A time-stepping finite element model of the three-phase asynchronous motor was built to calculate the transient electromagnetic field, and Maxwell stress tensor method is adopted to capture the radial electromagnetic force under steady state no-load condition. A 3D structural finite element model of the asynchronous motor was formed. The radial electromagnetic force was exerted on the surface of stator tooth and the electromagnetic vibration was computed. Finally, simulation and experiment results are compared to verify the veracity of simulation analysis. Experimental results show that the method proposed in this paper can be applied to calculate the electromagnetic vibration at motor design stage.

Introduction

Asynchronous motor has been widely used in various fields, especially in petroleum, chemical industry and machinery manufacturing. However, the noise pollution caused by asynchronous motors arouses more and more attention. The vibration of asynchronous motors mainly comes from electromagnetic vibration, mechanical vibration and air vibration[1,2]. The electromagnetic vibration which is generally more dominant is mainly due to the electromagnetic force which excites the stator.

Many scholars have done the research on the electromagnetic vibration of asynchronous motors. The accuracy of electromagnetic vibration calculation depends on electromagnetic force calculation and structural response analysis. In [3] and [4], the electromagnetic force in an asynchronous motor is analyzed, and the frequency of the electromagnetic force which may cause electromagnetic vibration is given. In [5], experimental method was used to study the distribution of electromagnetic vibration in three-phase asynchronous motor at no-load but no numerical validation is given. In [6], a weak-coupled method based on the finite element method (FEM) is presented to analysis electromagnetic vibration of an asynchronous motor but no electromagnetic vibration spectrum is given.

This paper presents a method based on FEM to analytically characterize electromagnetic vibration in asynchronous motors. Firstly, a finite element model of the three-phase asynchronous motor was built, and Maxwell stress tensor method was adopted to capture the time-varying electromagnetic force under steady state no-load condition. Then, a 3D structural finite element model was formed. The time-varying electromagnetic force was exerted on the surface of stator tooth and the electromagnetic vibration was computed. Finally, simulation and experiment results were compared to verify the accuracy of simulation analysis.

Finite Element Simulation of Transient Electromagnetic Field

In order to obtain the electromagnetic excitation force of the motor, a time-stepping finite element model of the three-phase asynchronous motor was built to calculate the transient electromagnetic field.

To simplify calculation model of finite element simulation, the following assumptions were accepted: 1. Ignore the influence of the end effect for the motor shaft is long 2. Suppose that the magnetic circuit and the axial is orthogonal; 3. Magnetic field only exists in the stator.

Table 1 shows the basic parameters of the simulation motor whose rated power is 45kW. According to the parameters of table 1, two-dimensional transient field finite element model is set up as shown in figure 1.

Tab.1 Basic parameters of a 45kW asynchronous motor

Number of phase	3
Number of pole	2
Number of stator slot	36
Number of rotor slot	28
Stator outer diameter	380mm
Stator inner diameter	210mm
Air gap length	1.1mm
Rotor inner diameter	80mm

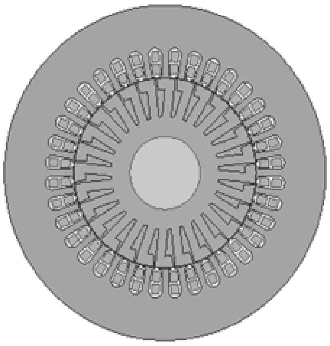


Fig.1 2D finite element model of the asynchronous motor

Electromagnetic vibration is caused by electromagnetic force, which is generated by the interaction between the magnetic flux density waves in the air gap. The electromagnetic force contains radial component and tangential component. The tangential component which makes stator teeth out of shape regionally is a secondary source of electromagnetic vibration, and the radial component is the main source of electromagnetic vibration. Neglecting effects of the tangential component, according to the Maxwell stress tensor method, the radial component Pr in the time domain can be approximated by

$$P_r = B_r / 2\mu_0 \tag{1}$$

where Br is the radial air-gap flux density.

The spatial distribution of the radial electromagnetic force is shown in figure 2, the electromagnetic force on one central point of the stator teeth varies with time is shown in figure 3.

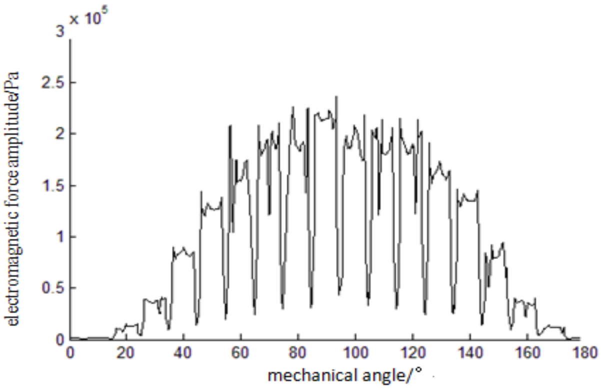


Fig.2 Space distribution of radial electromagnetic force

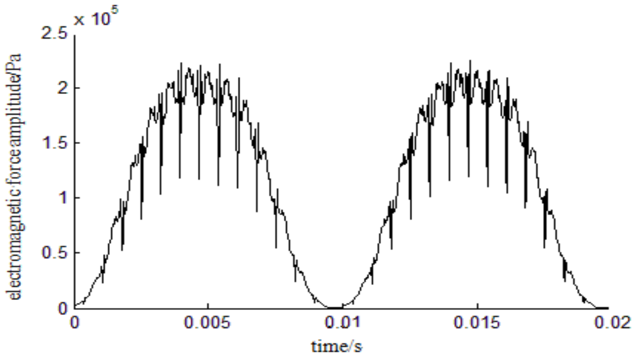


Fig.3 Variation of radial electromagnetic force with time

As can be seen from Figure 2, the radial electromagnetic force acting on one stator tooth is equal in size approximately. However, mutations exist in individual position for this position is influenced by the rotor slot. The air gap permeance changes due to the rotor slot. The radial air gap flux density as well as air gap permeance at slot is small so that the radial electromagnetic force is small at the slot. The radial electromagnetic force mainly acts on the stator teeth. Hence, the radial electromagnetic force is exerted on the surface of stator teeth.

Radial electromagnetic force varies with frequency. In order to obtain the spectral distribution of the electromagnetic force, radial electromagnetic force varying with time is input into a fast Fourier transform (FFT) analyzer. To ensure the accuracy of the spectrum, the time-domain radial electromagnetic force wave is truncated entire cycle. Figure 4 shows the spectrum of the radial electromagnetic force. As clearly shown in figure 4, the radial electromagnetic force decreases with the increase of frequency.

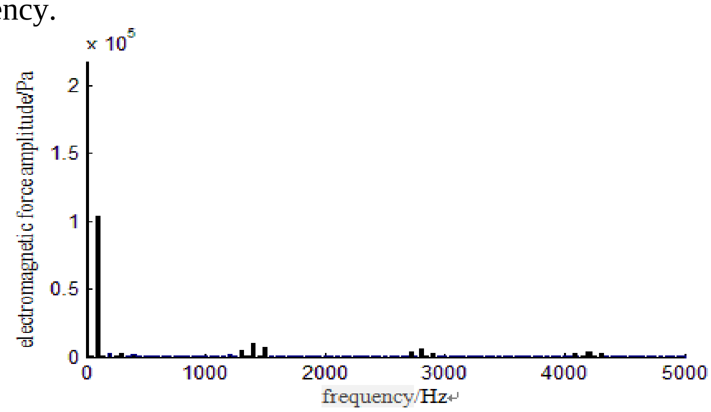


Fig.4 spectrum of radial electromagnetic force

Simulation of Structure

The purpose of the structure simulation is to calculate the vibration response of the motor under the excitation force. A three-dimensional finite element model of the asynchronous motor is established. The radial electromagnetic force is applied to the stator tooth surface, and the electromagnetic vibration response of the asynchronous motor is calculated.

As the motor rotor is solid columnar structure, its rigidity is great and it is not easily deformed. When the motor is under normal operating conditions, the resultant force applied to rotor is zero. The role of radial electromagnetic force to the rotor is not obvious, so neglect the influence of the motor rotor. To simplify the model, connections of motor components are supposed to be bonded and seamless. Small holes and chamfers of the rotor structure are neglected [7]. Figure 5 shows the structure finite element model of the asynchronous motor. Table 2 shows simulation parameters of motor structure.

The vibration of motor is generally passed out through the bottom of the foot, so take one point shown in figure 5 to view the electromagnetic vibration acceleration response. Figure 6(a) shows variation of simulation acceleration with time. Figure 7(b) shows the spectrum of simulation acceleration.

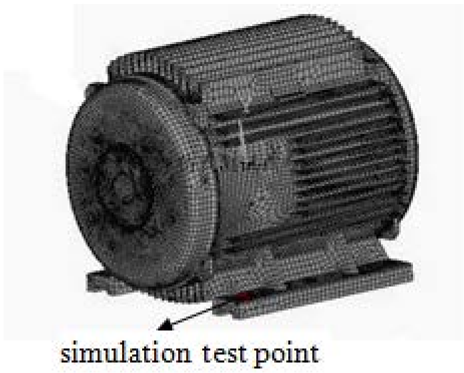
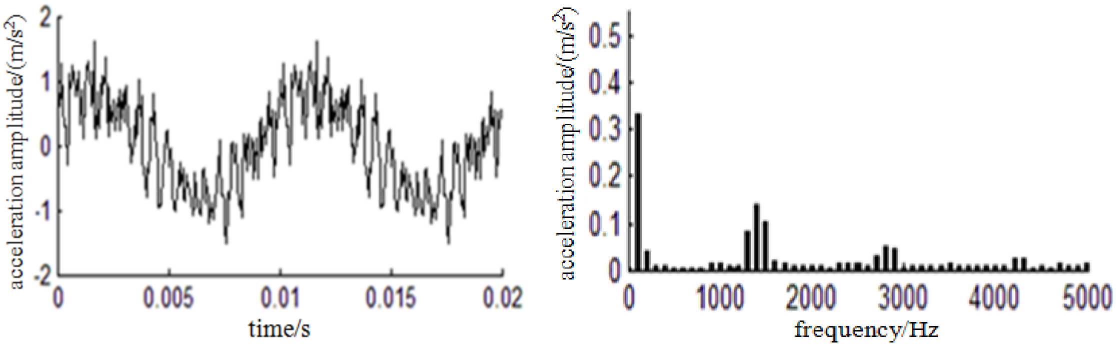


Fig.5 Structure finite element model of the asynchronous motor

Tab.2 Simulation parameters of motor structure

Components	Modulus of elasticity/GPa	Poisson ratio	Density/(kg/m^3)
Stator	200	0.26	7650
Shell	210	0.3	7850
End cover	210	0.28	7100



(a) (b)

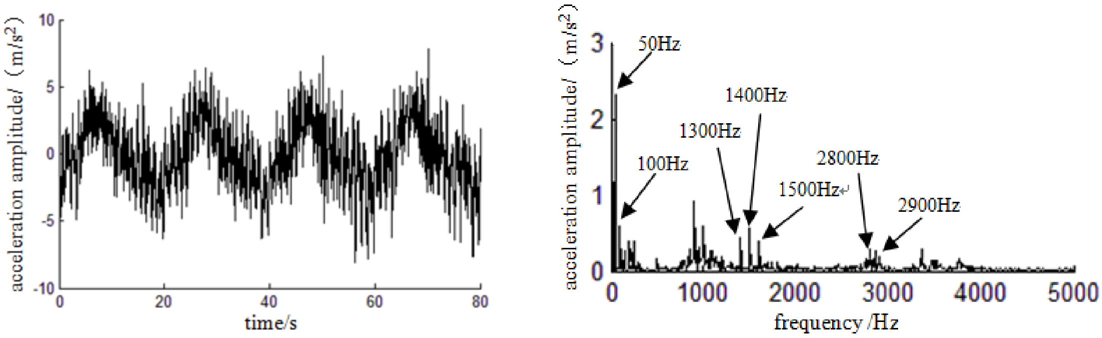
Fig.6 simulation electromagnetic vibration acceleration response

As shown in figure6 (b), the amplitude is smaller at higher frequency. Compared with figure 4, the electromagnetic vibration component is generated at the same frequency of the radial electromagnetic force.

Experimental Validation

In order to verify the accuracy of the electromagnetic vibration calculation, the vibration experiments are carried out in the 45kW prototype. The Austrian DEWESoft vibration tester and supporting software are used to collect vibration signal and the vibration signals are analyzed. Vibration tester and the experimental prototype are shown in figure 7. Motor vibration experiments are carried out under no-load conditions. To compare with the simulation results, the acceleration sensors are placed in the corresponding position with simulation test point. Figure 8(a) shows variation of tested acceleration with time. Figure 8(b) shows the spectrum of tested acceleration.

Fig.7 The asynchronous motor and vibration tester



(a) (b)

Fig.8 Tested electromagnetic vibration acceleration response

As shown in figure 8 (b), the acceleration component at 50Hz is apparent, which is caused by the dynamic imbalance. Compared with simulation acceleration spectrum, the tested acceleration spectrum is more abundant. This is because the motor vibration not only includes electromagnetic vibration, mechanical vibration also exists. At the same frequency, the simulation acceleration amplitude is smaller than the tested acceleration amplitude. The simulation for the motor is ideal while such problems as loose contact may exist in motor structural, which will lead to increased vibration acceleration. Above all, the result of electromagnetic vibration simulation is effective.

Conclusion

This paper presents a method based on FEM to analytically characterize electromagnetic vibration in asynchronous motors. Firstly, calculate the radial electromagnetic force. Then, apply the radial electromagnetic force to the motor structure and the electromagnetic vibration response of the asynchronous motor is calculated. Validated with experiment, results show that the method presented in this paper is accurate and effective, and can be used in the design of motor to analyze electromagnetic vibration.

Acknowledgement

In this paper, the research was sponsored by Program for LNIRT in university (LT2013006).

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