Effect of Rotor Eccentricity on Core Loss of High Speed Brushless DC Motor

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Abstract — Considering the reliability, high speed motor is supported by magnetic bearing to realize no-contacting between rotor and bearing. Therefore, the rotor eccentricity is inevitable. Meanwhile, in the design stage, it is necessary to have a detailed analysis of the effect of rotor eccentricity. In this paper, the stator and rotor core loss of the high speed brushless dc motor with 4kW and 60000rpm is analyzed under different rotor eccentricity by means of time stepped finite element analysis. The magnetic field and current waveforms are calculated. The analytical results are useful for the design optimization of high speed BLDC motor.

I. INTRODUCTION

Recently, high speed centrifugal turbo-compressors have been under intensive research and development[1-2]. Compared to conventional compressors, high speed centrifugal compressors have numerous advantages such as light weight, small size, high efficiency, etc. Brushless dc (BLDC) machine, fed by square-wave current, offers obvious advantages of high efficiency compared to other types of motors since there is no excitation power loss. Therefore, BLDC motor can be easily applied for system.

Meanwhile, for the view of reliability, the magnetic bearings are employed to realize non-contacting between rotor and magnetic bearings instead of conventional ball bearing. Consequently, rotor eccentricity is inevitable. The effects of rotor eccentricity on motor performance such as cogging torque and unbalance force in BLDC were studied[3]. However, the effect of rotor eccentricity on the core loss was not reported in detail. Due to high speed, stator slotting, time and space harmonics in the airgap field, significant core loss in the stator and rotor may be caused, which is disadvantageous for the winding insulation and permanent magnet.

In this paper core loss for 4kW, 60000rpm BLDC is investigated under different rotor eccentricity. By means of time-stepped finite element analysis, magnetic field distribution and current waveforms are calculated. The analytical results are useful for the design optimization of high speed BLDC motor.

II. ANALYTICAL MODEL

The BLDC motor with rotor dynamic eccentricity is schematically shown in Fig.1. o_1 and o_2 are the center of the stator and rotor, respectively. The distance g is airgap length under the balanced position. The length d is eccentric displacement between the rotor center and stator center. When BLDC motor operates with magnetic bearing, the rotor eccentricity happen.

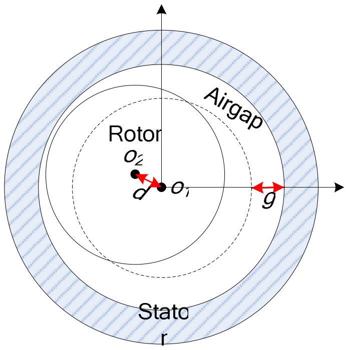

Fig.1 Schematic of rotor eccentricity

Fig.2 shows the three dimension model of high speed BLDC motor for centrifugal compressor. Rated power and rated speed are 4kW and 60000rpm, respectively. In order to obtain a mechanical stabilization under high-speed operation, rotor has a two pole diametrically magnetized permanent magnet (PM). The PM is retained within 1Cr18Ni9Ti sleeve, which has been pressed on the rotor to withstand the centrifugal stress under high speed operation. The detailed parameters of the analyzed motor are presented in Table 1.

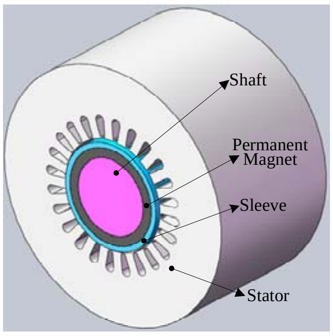

Fig.2 High speed BLDC motor Strcuture

Table1 Parameters of high speed BLDC motor

Parameter	Value / mm
Stator outer diameter	120
Stator inner diameter	52
Sleeve outer diameter	50
Magnet outer diameter	45
Shaft outer diameter	36
Stator core length	70

The core loss can be obtained utilizing a non-linear time-stepped FEM solver. Such a solver can provide an accurate representation of the magnetic field distribution in the magnetic circuit taking into space and time harmonics account.

The model was coupled to external electric circuit supplied by a voltage source. Therefore, the current in the stator has to be calculated according to the voltage source and the related parameters. The stator winding current *I*, vector potential *A*, and the terminal voltage *U* are introduced as [4]:

$$\int_s \frac{dA}{dt} ds + (R_c + R_o)I + L_o \frac{dI}{dt} = U \tag{1}$$

where R_o represent the stator phase resistance, L_o is the stator leakage inductance, R_c represent the resistance of the winding in the finite element region and *S* is the contour along the winding.

The stator core loss can be calculated as:

$$w = k_e f^2 B + k_h f B^2 \tag{2}$$

where, *f* is frequency, *B* is the induction density, k_e is eddy-current loss coefficient, k_h is hysteresis loss coefficient.

The rotor eddy current was calculated at each time step. Then the power loss was derived from:

$$P = \int \frac{J^2}{\sigma} \mathrm{d}s \tag{3}$$

where *P* is the ohmic power per meter depth, and *J* is the induced current density.

III. RESULTS AND DISCUSSION

Three eccentric ratio *ε*, which is explained by *d*/*g*, is divided into three types such as 0, 0.3 and 0.6. Fig. 3 to Fig.5 show phase current waveform, airgap magnetic density and rotor eddy current loss by means of time-stepped FEM, respectively. Table.2 shows the stator core loss comparison with different rotor eccentricity. It can be noted that with the increase of rotor eccentricity, the stator core loss is almost same. However, with the increase of rotor eccentricity, the rotor eddy current loss increase, which cause higher rotor temperature and demagnetization of PM.

Table.2 Stator core loss with different rotor eccentricity

Rotor eccentricity	Core loss / W
0	314
0.3	313.6
0.6	314.6

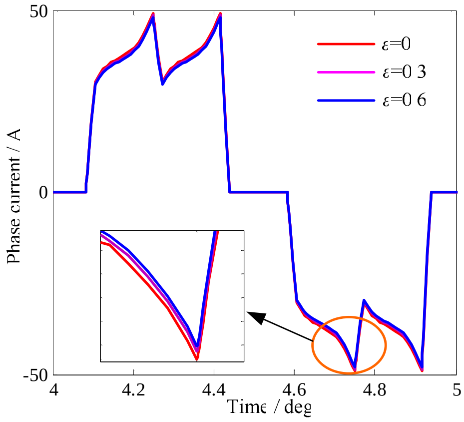

Fig.3 Phase current waveform with different dynamic eccentricity

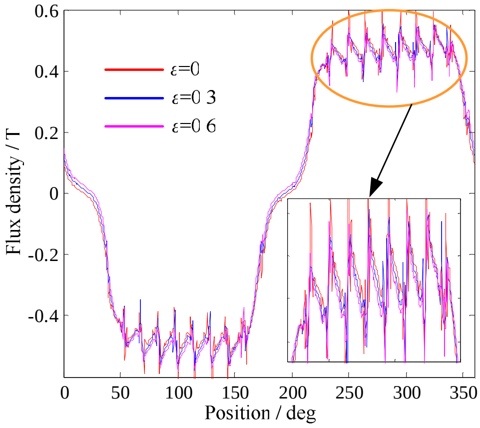

Fig.4 Airgap magnetic density with different rotor eccentricity

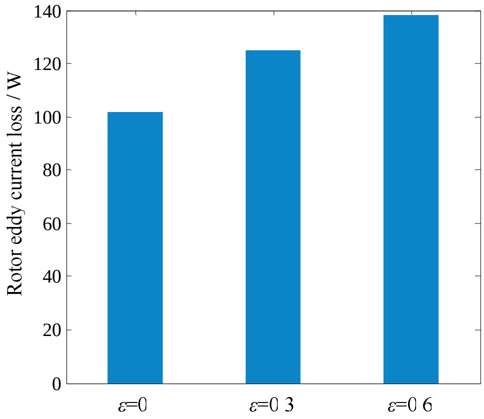

Fig.5 Rotor eddy current loss with different rotor eccentricity

IV. REFERENCES

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