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RESEARCH ON LEVITATION-ROTATION STARTING CONTROL SYSTEM OF BEARINGLESS INDUCTION MOTOR

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The air gap magnetic field of Bearing less Induction Motor (BIM) is superposed by magnetic field of torque windings and levitation windings, it's rotor can be stably levitated in rotating state by decoupling control. But in the starting process, affected by starting current, large amplitude oscillation occurs on the rotor, which directly affects the starting performance of BIM. Based on flux field oriented control strategy, a levitation-rotation starting control method is proposed in this paper, in this way, the levitation and torque control can be decoupled during starting process. The experimental results show that the proposed method can short adjusting time, reduces the number of oscillations, and starting performance of BIM can be improved effectively.

Keywords: Bearing less Induction Motor; field oriented control; decoupling control; levitation starting performance

1. Introduction

Bearingless motor integrates function of rotation and levitation, with synthetic magnetic field effect of two sets of windings in the stator slots, magnetic levitation force can be produced on the basis of electromagnetic torque, individual component of radial bearing can be removed, so it has the advantages of no-friction, no-wear, no-lubrication, no-pollution etc[1] [2] [3].

According to the structural characteristics of rotors, the bearingless motors can be divided into induction type, permanent magnet type and type switch resistance etc. Among them, the induction type bearingless motor (bearingless induction motor, BIM) has the advantages of simple rotor structure, uniform air gap magnetic field, high running reliability, low pulsation of the slot and wide range of weak magnetic regulation. So BIM is easy to realize high speed, high precision and high power [4] [5] [6].

Based on the advantages above, scholars pay more attention to the research of BIM in recent years. Wenshao B etc. studied at the air gap field orientation of BIM, a combination control strategy of air gap field orientation and induction compensation is proposed for levitation system, reliable levitation control and decoupling control performance are achieved[7], Zebin Y et al designed a rotor

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vibration feed forward compensation control system based on coordinate transformation for BIM, the vibration suppression of rotor is realized, and the mass eccentricity caused by mechanical unbalance in high speed operation is effectively solved[8]. Sinervo A etc. studied at vibration suppression characteristics of the elastic shaft of BIM, a control method is proposed to reduce the rotor vibration by using additional stator windings to generate radial forces on the rotor [9], Hiromi T etc. propose a new control system to compensate the delay and the direction error of the levitation force of the squirrel cage rotor, and improve the levitation precision of the rotor under load [10]. The above results show that the researches of BIM technology has developed rapidly in recent years, most of the researches focus on levitation control under rated conditions, but in the starting process, the rotor is affected by the starting torque and starting current, mutual coupling with levitation force, it will cause severe oscillation in rotor levitation control process.

In this paper, based on the analysis of air gap magnetic field, the levitation force model of BIM considering starting torque and eccentric is established, a levitation-rotation starting control method is proposed according to field oriented control. The rotation drive process is separated from the levitation control process during starting, so that the influence of torque on the levitation control is reduced, decoupling control of magnetic levitation force and torque in starting process is realized. On this foundation, an experimental prototype BIM of 4 pole (torque winding) -2 pole (levitation winding) is taken as an example, The experimental results show that the proposed method can improve the levitation control performance of BIM effectively.

2. Mathematical model of BIM starting process

During starting process, the rotor of BIM is in an eccentric state, as shown in Fig.1.

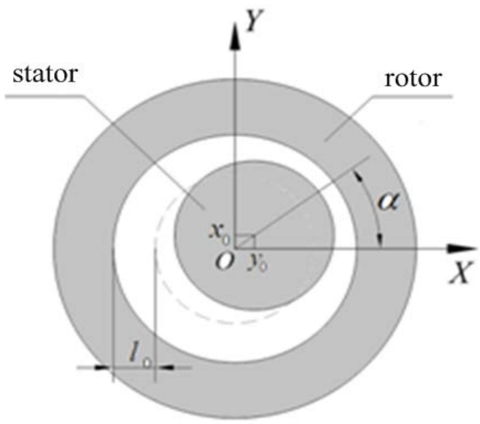

Fig.1. Rotor eccentricity

In Fig.1, l_0 is length of the uniform air gap, α is the eccentricity angle.

The magnetic flux density of the two sets of windings current synthesis magnetic field can be written as

$$b(\theta,t)=b_4(\theta,t)+b_2(\theta,t) \tag{1}$$

Where b_4 is flux density of 4 pole (torque windings), b_2 is flux density of 2 pole (levitation windings).

According to Maxwell equations, the electromagnetic force of rotor surface can be written as

$$dF_n(\theta,t)=\frac{b(\theta,t)^2 dS}{2\mu_0}=\frac{b(\theta,t)^2 rLd\theta}{2\mu_0} \tag{2}$$

Where S is the rotor surface area, r is the rotor radius; L is the effective length of rotor core, $\mu_0$is Vacuum permeability.

Because of the rotor eccentric, the Lorenz force of the rotor surface is no longer 0, which can be shown in fig.2

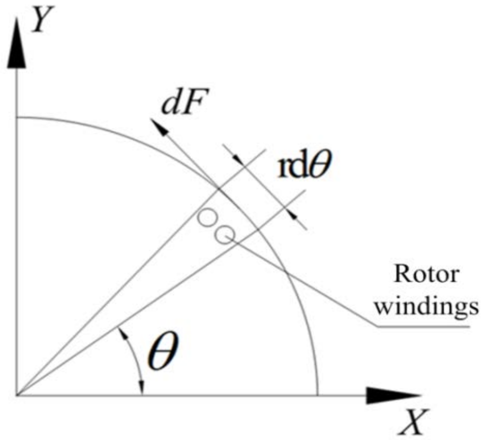

Fig. 2. Rotor skin-deep current

The induced electromotive force on the rotor surface can be written as

$$e_r=-b_4 Lrs\omega_4=-B_4\cos(2\theta-\omega_4 t-\varphi_4)\left[1+\varepsilon\cos(\theta-\alpha)\right]Lrs\omega_4 \tag{3}$$

Where s is slip ratio, ω_4 is electric angle of torque windings, φ_4 is initial phase angle of torque windings, B_4 is amplitude of flux density. Then the rotor surface current can be written as

$$i_r(\theta)=j_{\mathrm{r}}d\theta=\frac{2\pi e_r}{\rho_{\mathrm{r}}}d\theta \tag{4}$$

Where j_{r} is current density, ρ_{r} is conductivity of rotor.

The Lorenz force on the rotor surface can be written as

$$dF_\tau(\theta,t)=b_4(\theta,t)i_r(\theta,t)Ld\theta \tag{5}$$

From equation (1) ~ (5), the electromagnetic force of the rotor in starting can be written as

$$dF(\theta,t) = dF_n(\theta,t) + dF_\tau(\theta,t) \tag{6}$$

Integrate along X and Y axis, the electromagnetic force components in the X, Y direction can be written as

$$\left.\begin{aligned} F_y &= \frac{\pi r L}{2\mu_0}\left[B_4 B_2 \sin(\varphi_4 - \varphi_2) + \varepsilon B_4{}^2 \sin\alpha\right] - \frac{r\pi L^2\omega}{2\rho_r} B_4^2 \varepsilon s \cos a \\ F_x &= \frac{\pi r L}{2\mu_0}\left[B_4 B_2 \cos(\varphi_4 - \varphi_2) + \varepsilon B_4{}^2 \cos\alpha\right] - \frac{r\pi L^2\omega}{2\rho_r} B_4^2 \varepsilon s \sin a \end{aligned}\right\} \tag{7}$$

Where B_2 is amplitude of flux density, ε is Eccentricity of rotor, φ_4 is initial phase angle of levitation windings.

From equation (7), electromagnetic force in the starting process is composed of three items，the first item is controllable levitation force，the second term is single side force, and the third item is the radial force produced by the starting torque, which can be called derived force by torque, its intensity is proportional to $\varepsilon\ s$, and the direction is $a + 90°$.

Based on above conclusions, the influence of the starting torque on levitation process can be reduced by limiting ε. First, the static levitation can be realized by DC current control, so rotor is stably controlled in a balanced position, and then the rotation is driven by AC current. Since the small eccentricity, the effect of derived force by torque is less; it can effectively improve the levitation performance of the rotor during starting.

3. Field oriented levitation starting control

From equation (7), the controllable levitation force can be written as:

$$\begin{cases} F_{0y} = K[\psi_{4y} i_{2x} - \psi_{4x} i_{2y}] \\ F_{0x} = K[\psi_{4x} i_{2x} - \psi_{4y} i_{2y}] \end{cases} \tag{8}$$

Where $K = \dfrac{2.7^2 \pi N_2 \mu_0}{8l^2}$ is Current stiffness coefficient for levitation windings, ψ_{4x}, ψ_{4y} is Components of the 4 pole torque windings flux on the X and Y axes, i_{2x}、i_{2y} is components of the 2 pole levitation windings current on the X and Y axis

On the basis of torque winding, the *d*-*q* coordinate system is a coordinate system in which electric angular velocity and current rotate synchronously; the angle between the *q* axis and the X axis is $\theta = \omega t + \varphi_4 + \pi/2$, as shown in Fig.3

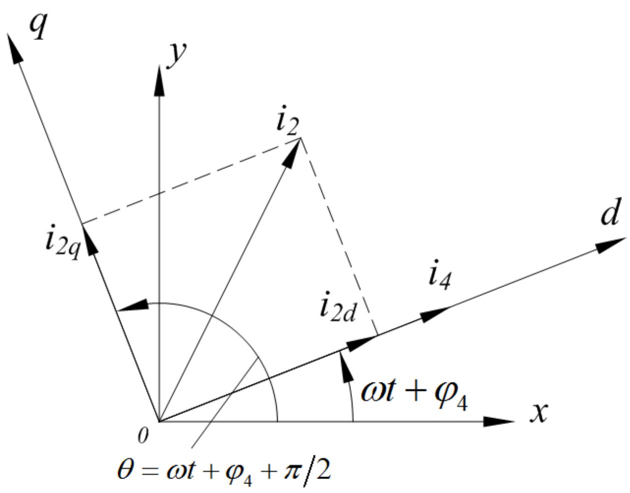

Fig.3. Relationship between reference and current vectors

Converts the windings current in the X-Y coordinate system to e *d*-*q* coordinate system, as shown in equation (9):

$$\begin{bmatrix} i_{2d} \\ i_{2q} \end{bmatrix} = \frac{1}{K} \begin{bmatrix} \psi_{4d} & -\psi_{4q} \\ \psi_{4q} & \psi_{4d} \end{bmatrix} \begin{bmatrix} F_x \\ F_y \end{bmatrix} \tag{9}$$

The BIM levitation control system based on torque windings field oriented control can be shown in Fig.4.

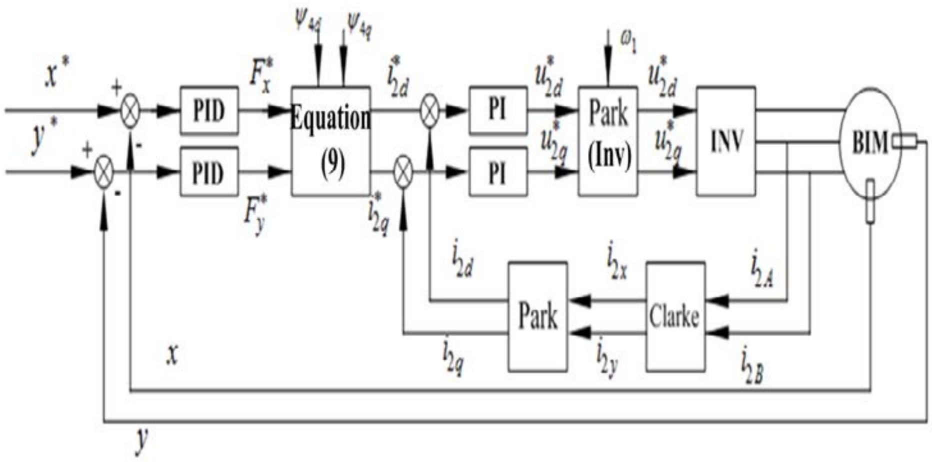

Fig.4. System diagram of levitation control

4. Experiment and result analysis

BIM experimental platform is shown as Fig.5, the rated power of prototype is 0.55kW, rated speed is 1500r/min, the maximum radial load force is 100N, and clearance of the protective bearing is 0.1mm.

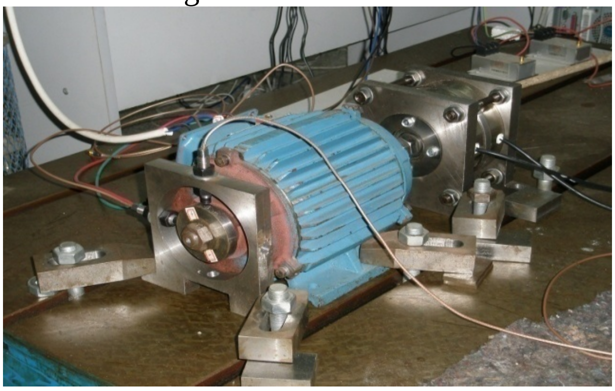

Fig.5. BIM experimental platform

Displacements fluctuation curve of the rotor during starting is detected and recorded by sensors, the displacements control process of the rotor under the general starting control is shown in Fig.6, the displacements control process of the rotor under the levitation rotating starting control is shown in Fig.7.

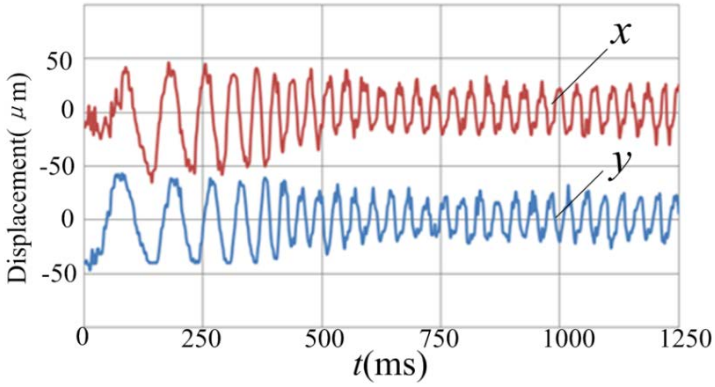

Fig. 6. Displacements under the general starting control

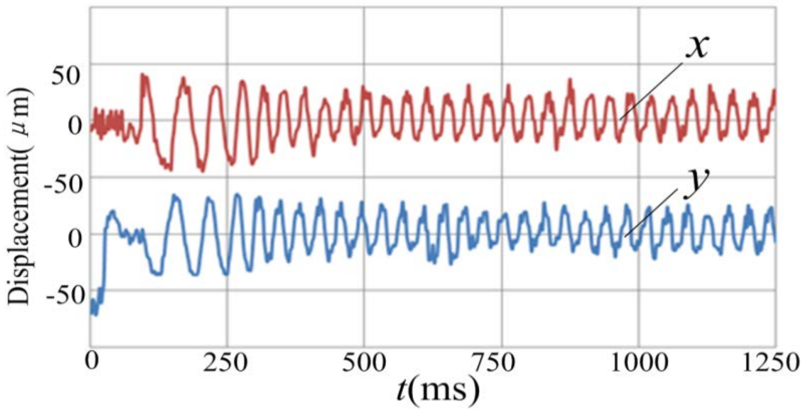

Fig.7. Displacements under the levitation rotating starting control

Both Fig.6 and Fig.7, the initial position of the rotor is x=0, y=-0.05mm, after levitation control adjustment, the displacements wave range is less than 0.04mm, the rotor separated from the protective bearing completely, the levitation of the rotor is realized. But in Fig.6 the starting time for the levitation control adjustment process is 0.4s, and it has 6 times of oscillation. The levitation-rotation starting Control is shown as Fig.7, it takes 0.1s to realize static levitation (levitation accuracy is 0.01mm), then rotate, in this way the starting time is only 0.3s and oscillation is 4 times.

5. Conclusion

During the starting process the Lorenz force on the rotor's surface is no longer uniform distribution because of eccentricity, derived force by torque is thus generated, which is perpendicular to the Controllable levitation force, it is the main factor affecting the rotor oscillation during starting process.

Derived force by torque is proportional to Eccentricity, during starting process; the influence of derived force by torque on the levitation control can be reduced by limiting eccentricity of the rotor.

By levitation-rotation starting control method proposed in this paper, levitation control process can be separated from rotation starting process. First, the eccentricity of the rotor is controlled within a certain range (10%) by static levitation control, and then rotates. The starting performance of BIM is improved, compared with the general starting process, the levitation rotating starting control time is shorter by 30%, and the overshoot is reduced by 10%.

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