Current Compensation Controller with Disturbance Acceleration Observer in Bearingless Motor

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Abstract: In order to improve the suspension performance of bearingless motors, the disturbances could be not neglected and some measures should be considered in the design of the controllers. In this paper, a disturbance acceleration observer is adopts based on the suspension model of the consequent-pole permanent magnet bearingless motor. And a suspension current compensation controller is proposed with the observer. In this case, an equivalent disturbance-current is utilized to compensate for the suspension current component caused by the disturbance displacement. Simulations are carried out with several kinds of displacement disturbance sources. The results demonstrate the validity of the proposed controller.

Keywords: Disturbance, Acceleration Observer, Current Compensation, Magnetic Suspension, Consequent-Pole Bearingless Motor

Introduction

Suspension control systems of consequent-pole permanent magnet (CPPM) bearingless motors do not depend on torque control systems due to their special rotor structures. Normally displacement controllers are designed as PID controller in the suspension control systems and the suspension performance would be affected if there are some outside disturbances. Thus optimizing suspension controller is vital for improving static and dynamic performances. One method is the disturbance compensation controller which is to observe the disturbances and to restrict them by compensating corresponding controlled object[1]-[3]. Compensation Controller was designed to reduce the disturbance due to rotor's mass unbalance in a PM bearingless motor[4]. However, there were some disadvantages as following: only sinusoidal disturbance was analyzed, the controller depends on some parameters which are not easy to achieve and the algorithm is too complex to implement.

In this paper, a disturbance acceleration observer is investigated according to the rotor displacement and a suspension current controller based on disturbance compensation is proposed. The simulated results varied the proposed method.

Mathematical model of suspension system

The suspension force and torque models can be derived according to the principle of equivalent magnetic circuit and virtual energy[5][6]. In this paper, the mathematical model of suspension force of CPPM bearingless motor can be expressed as

$$\mathbf{F}_{\mathbf{s}} = k_i\mathbf{i} + k_s\mathbf{q}_{\mathbf{1}} \tag{1}$$

where $\mathbf{F_s} = \begin{bmatrix} F_\alpha & F_\beta \end{bmatrix}^T$ is the suspension force in α and β direction, k_i and k_s are current rigidity and displacement rigidity which depend on the CPPM bearingless motor parameters, $\mathbf{i} = \begin{bmatrix} i_\alpha & i_\beta \end{bmatrix}^T$ is the suspension current vector, $\mathbf{q_1} = \begin{bmatrix} \alpha & \beta \end{bmatrix}^T$ is the radial displacement vector of rotor.

On the other hand, the radial kinematic equation can be achieved based on Newton's laws of motion:

$$m\ddot{\mathbf{q}}_1 = \mathbf{F_s} + \mathbf{F_d} \tag{2}$$

where m is the weight of rotor, $\mathbf{F_d} = [F_{\alpha d} \quad F_{\beta d}]^T$ is the radial disturbance force.

According to functions (1) and (2), the relation of the variables in suspension system can be shown in the following

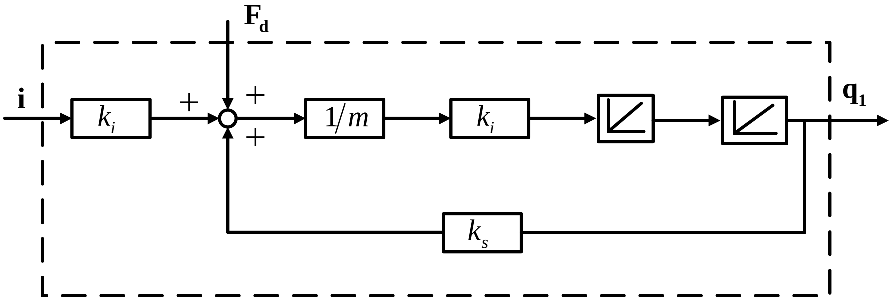

Fig.1 The configuration of suspension system

Disturbance observer design

In the suspension control systems, the suspension performance will be affected by the outside disturbance $\mathbf{F_d}$. Several kinds of displacement disturbance sources can be categorized as following

(1) Constant disturbances

Normally the β direction and the direction of the rotor gravity are same in the suspension system when a bearingless motor is laid on the horizontal. In this case, the rotor gravity could be taken as a constant disturbance. If the rotor gravity is applied in an arbitrary direction, it could be separated into two component forces in α and β direction.

(2) Sinusoidal disturbances, such as centre of rotor’s mass is different from its centre of geometry.

(3) Step disturbances, such as a shock suspension load.

(4) White noise disturbances. They are caused by displacement sensors, power system, outside magnetic field, and so on.

To observe these disturbances mentioned above, a kinetic function of CPPM bearingless motor is deduced,

$$\begin{cases} \mathbf{q_1} = \mathbf{y} \\ \dot{\mathbf{q}}_\mathbf{1} = \mathbf{q_2} \\ \dot{\mathbf{q}}_\mathbf{2} = \dfrac{k_s}{m}\mathbf{q_1} + \dfrac{k_i}{m}\mathbf{i} + \dfrac{1}{m}\mathbf{F_{db}} \\ \dot{\mathbf{q}}_\mathbf{3} = \dfrac{\dot{\mathbf{F}}_\mathbf{db}}{m} \end{cases}, \tag{3}$$

where $\mathbf{y} = [\alpha \quad \beta]^T$ is the radial displacement vector of rotor, $\mathbf{q}_2$ is the radial speed vector, and $\mathbf{q}_3$ is the radial disturbance acceleration vector.

Based on the traditional disturbance observer[7][8], a disturbance acceleration observer (DAO) is proposed as

$$\begin{cases} \mathbf{e} = \mathbf{y} - \mathbf{z_1} \\ \dot{\mathbf{z}}_\mathbf{1} = \mathbf{z_2} + \tau_1\mathbf{e} \\ \dot{\mathbf{z}}_\mathbf{2} = \mathbf{z_3} + \tau_2\mathbf{e} + \lambda_1\mathbf{z_1} + \lambda\mathbf{i} \\ \dot{\mathbf{z}}_\mathbf{3} = \tau_3\mathbf{e} \end{cases}, \tag{4}$$

where $\mathbf{z_1}$, $\mathbf{z}_2$ and $\mathbf{z}_3$ are the state vectors in DAO, τ_1, τ_2, and τ_3 are adjustable parameters, λ_1 is the compensation parameter of disturbance suspension force, λ is the parameter of suspension current.

Obviously the displacement-related state vector $\mathbf{q}_i$ (i=1, 2, 3) can be achieved via the state vector $\mathbf{z}_i$ in the DAO if these parameters above are optimized. Meanwhile the disturbance acceleration can be observed no matter what kind of disturbances. On the other hand, because the state vector $\mathbf{z}_1$ is equivalent to the filter result of the radial displacement vector, $\mathbf{z}_1$ should be utilized as a displacement feedback to restrain the noise caused by sensor to reduce. The functional block diagram of disturbance acceleration observer is shown as Fig. 1

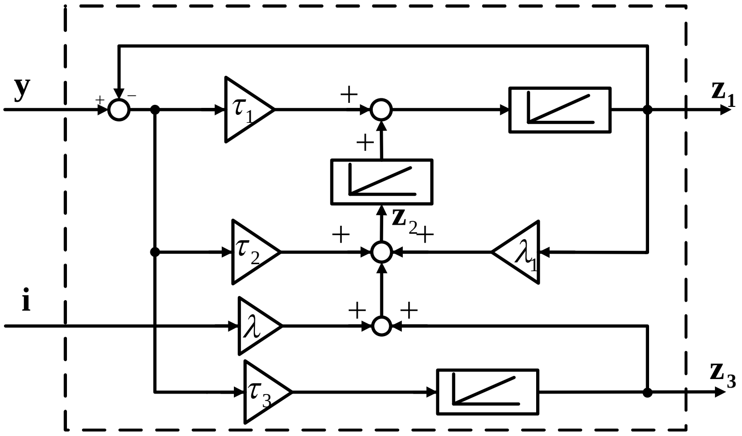

Fig.1 The functional block diagram of DAO

However, the observed disturbance acceleration $\mathbf{z_3}$ of DAO can not be adopted directly in the suspension system of CPPM bearingless motor because the desired variable is the suspension current vector. Thus, the relation must be analyzed between the disturbance acceleration and suspension current. Based on the relation between the suspension force and current as

$$\mathbf{F(i)} = k_i \cdot \mathbf{i} . \tag{5}$$

Similarly as above, the equivalent disturbance current depends on the displacement disturbance acceleration. The desired suspension current should be achieved as following

$$\mathbf{i}^*_{\mathbf{db}} = k_a \mathbf{a}_{\mathbf{db}} , \tag{6}$$

where $k_a = m / k_i$.

Here, the equivalent disturbance-current is utilized to compensate for the suspension current component caused by the disturbance displacement. The control system based on the DAO and the disturbance-current compensation (DCC) is shown in Fig. 2

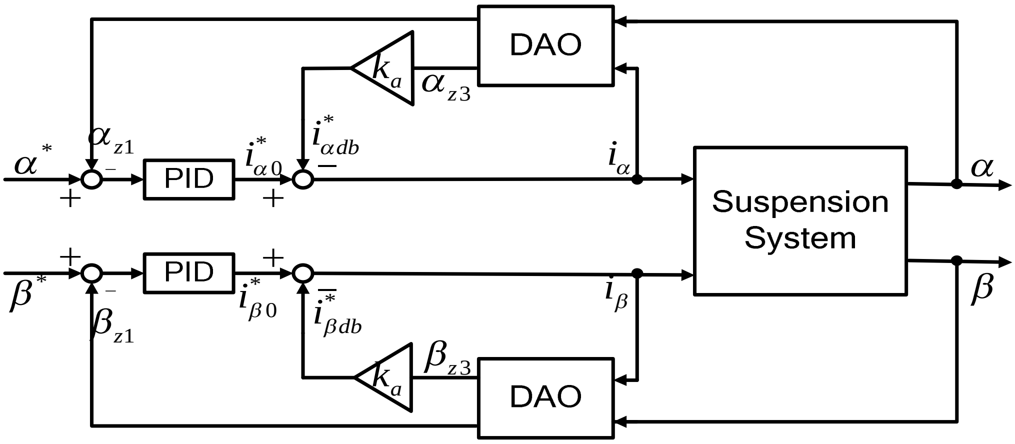

Fig.2 The functional block diagram of the DCC

Simulation Results

To verify the proposed control algorithm, different disturbances were injected into the radial displacement in the motor model of CPPM bearingless motor and the simulation results are showed in Fig. 3- Fig. 6.

In Fig. 3(a) - Fig. 6(a), that the disturbance acceleration curve was following the actual curves shows whichever the disturbance acceleration could be achieved by the DAO. In Fig. 3(b) - Fig. 6(b), the fluctuation of the radial displacement with the compensation algorithm was less than the displacement fluctuation without the compensation algorithm.

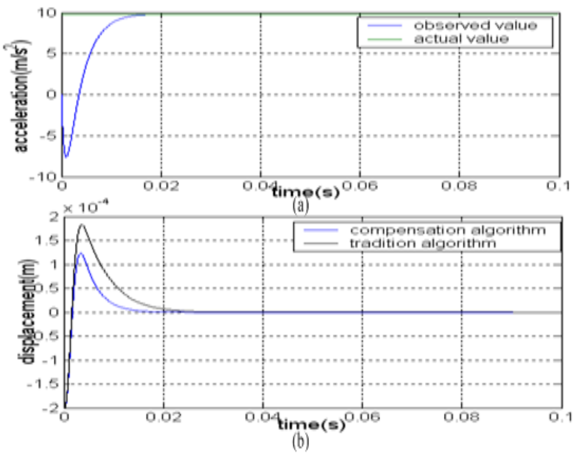

Fig.3 Simulation results with constant disturbance

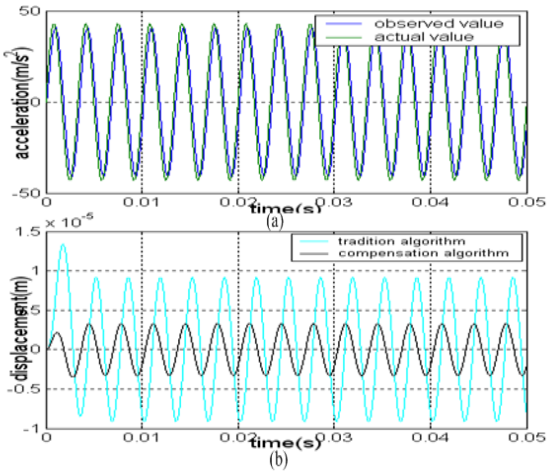

Fig.4 Simulation results with sinusoidal disturbance

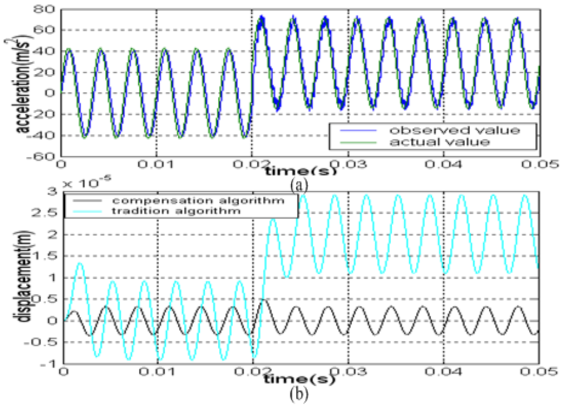

Fig.5 Simulation results with step disturbance

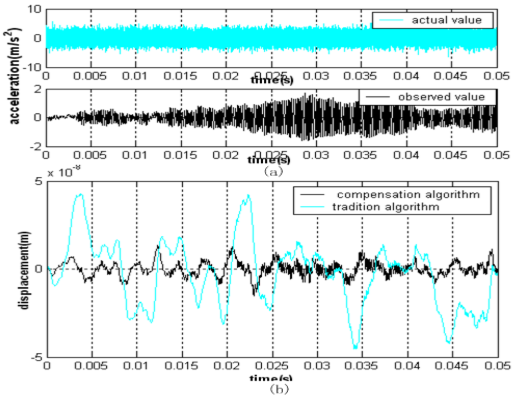

Fig.6 Simulation results with white noise disturbance

Conclusions

To observe the displacement disturbances in the CPPM bearingless motor, a disturbance acceleration observer is adopted. And a current controller is designed to compensate for the disturbance component of the suspension current. Compared to the traditional algorithm, the performances of suspension could be improved by the DCC with the DAO in the suspension system. The simulation results have verified the proposed strategy.

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