MAGNETIC BALL BEARING CONTROL MATTE SLIDE CONTROLLER DESIGN

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GENERAL INFORMATION

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KEYWORD

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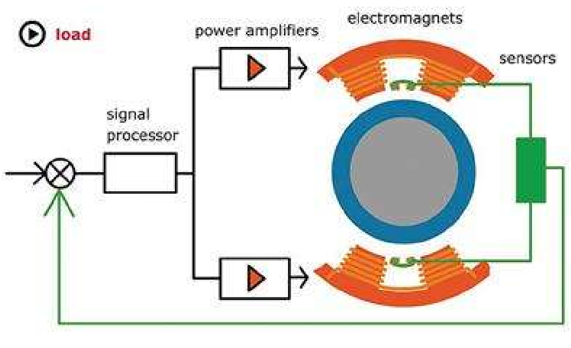
ABSTRACT

Magnetic ball bearing systems are applied in many different fields in industry and some aviation fields. In this system, the magnetic ball bearing serves as a conventional ball bearing, but the very obvious difference between these two types is that the object is held fixed or movable between two or more magnetic poles of the electromagnet. When the current flows through the coils of the magnet, a magnetic force is generated, which lifts and suppresses the forces in different directions so that the object is always in the desired position. Based on the characteristics of slide control combined with fuzzy control, the control model can be simplified, avoiding the limitations encountered by conventional control methods. The sliding control method combined with dimming control with fixed drive control for nonlinear systems and fast response will overcome limitations such as easy slippage and inaccurate operation, especially in the case of position changes and external interference impacts

1. INTRODUCTION

Magnetic ball bearing systems are widely applied in various fields in industry and some aviation fields. Typically, high-speed equipment such as motors with up to 60000 revolutions per minute, high-speed compressors, turbines

(a)



(b)

Figure 1. Application in turbocompressor (a) and magnetic ball bearing control principle (b)

The advantages of magnetic ball bearings are no need for lubricating oil, low noise, high operating speed, no mechanical friction,... Magnetic ball bearings are non-linear, unstable systems so a relay system is required to stabilize the system. The simple model of magnetic ball bearing, is the voltage control or current control model (H.Lee, V. Utkin et al., 2007).

Advantages of magnetic ball bearings: - Low friction force. - Can work at high speed. - Application for places where high speed is required. - No noise. - No vibration. - No need for grease. Disadvantages of magnetic ball bearings: - Difficult to control. - The price is quite high. - Complex fabrication and maintenance (Chien et al., 2009)

In practice, the use of magnetic ball bearings can have more than one pole to increase the efficiency in control. Similar to the single-pole type, other types also develop on the basis of a basic pole. The only difference is that these poles are not in the same direction but deviate from each other depending on the number of poles designed to be used. The basic magnetic ball bearing structure consists of: two coils wound on a steel core placed opposite each other in the middle of the ball bearing shaft (Rotor), with a mass of m, between the two coils and the rotor with an air gap (Abdul et al., 2008). Based on the properties of the magnetic material and the magnetic field generated by the current to generate the force. When the two initial currents i1 and i2 are applied to the two electromagnets, two forces are generated that depend on the current and the number of loops on each coil. These two forces will act on the rotor with two different force values in two opposite directions, making the rotor shift in the direction of stronger impact force. Therefore, in order for the rotor to go to the desired position, change either i1 or i2 or both currents to create a magnetic field and create another F1 and F2 force to translate the rotor to the desired position. (Chien et al., 2009)

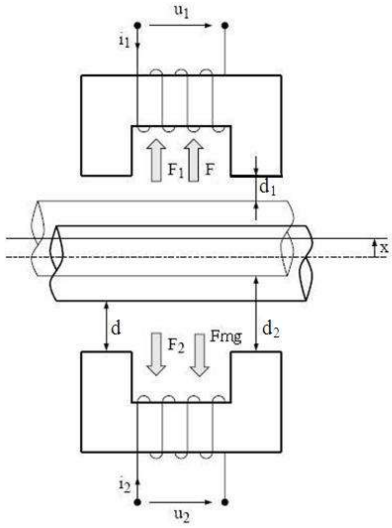


Figure 2. Mathematical Model of Magnetic Ball Bearing System

2. METHODOLOGY

In order to keep the rotor in a balanced position, we can apply current or voltage to the two coils. Here, we control the current. When two currents i1 and i2 are applied to two coils, two forces will be generated that depend on the current, the number of turns on each coil. In the static or non-electrical state, the rotor will be completely deviated towards the electromagnet 2 (as shown in Figure 1.2), so we have to control two different currents for the two windings and also depend on the external force acting on the rotor (H.Lee, V. Utkin et al., 2007). We have the equation of equilibrium force as follows:

$$m\frac{dx^2}{dt^2} = F_1 - F_2 + F - F_{mg} \quad (1)$$

$$\dot{x}_2 = \frac{\mu_0 N^2 A}{4*m}\left[\left(\frac{i_1}{d_1}\right)^2 - \left(\frac{i_2}{d_2}\right)^2\right] + \frac{1}{m}F_s \quad (2)$$

$$F_1 = \frac{\mu_0 N^2 A}{4}\left[\left(\frac{i_1}{d_1}\right)^2\right] \quad (3)$$

$$F_2 = \frac{\mu_0 N^2 A}{4}\left[\left(\frac{i_2}{d_2}\right)^2\right] \quad (4)$$

$F_s = F - F_{mg}$

We have the voltage equation of the Electromagnet of the system

$$u_1 = Ri_1 + L_s\frac{di_1}{dt} + \frac{K}{2}\frac{d}{dt}\left(\frac{i_1}{d_1}\right) \quad (5)$$

$$u_2 = Ri_2 + L_s\frac{di_2}{dt} + \frac{K}{2}\frac{d}{dt}\left(\frac{i_2}{d_2}\right) \quad (6)$$

Equation of Balance of Force:

$$m\frac{dx^2}{dt^2} = F_1 - F_2 + F - F_{mg} \quad (7)$$

$$\dot{x}_2(t) = \frac{\mu_0 N^2 A}{4*m}\left[\left(\frac{i_1}{d_1}\right)^2 - \left(\frac{i_2}{d_2}\right)^2\right] + \frac{1}{m}F_s \quad (8)$$

With:

$$F_1 = \frac{\mu_0 N^2 A}{4}\left[\left(\frac{i_1}{d_1}\right)^2\right] \quad (9)$$

$$F_2 = \frac{\mu_0 N^2 A}{4}\left[\left(\frac{i_2}{d_2}\right)^2\right] \quad (10)$$

$F_s = F - F_{mg}$

In which:

m: Rotor mass (Kg)

X: Air Clearance Variability (m)

D: Air gap at the balanced position (m)

v : Rotor displacement velocity (m/s)

μ0: magnosity (H/m)

A: Magnetic polar cross-section (m^2)

N: Number of wire loops in each reel

i1: current through electromagnet coil 1 (A)

i2: current through electromagnet coil 2 (A)

F: Rotor Load Interference (N)

Fmg: Gravity

F1, F2: The force generated by the current i1 and i2 (N)

$$K = \frac{\mu_0 N^2 A}{4*m} \quad (11)$$

$d_1 = d - x$; $d_2 = d + x$

The selected state variables are as follows:

$$x_1(t) = x(t)$$
$$x_2(t) = \dot{x}(t) = \dot{x}_1(t)$$
$$x_3(t) = \ddot{x}(t) = \dot{x}_2(t)$$

(12)

State variable equation of magnetic ball bearing system:

$$\begin{cases} \dot{x}_1(t) = x_2(t) \\ \dot{x}_2(t) = K\left[\left(\dfrac{i_1}{d - x_1}\right)^2 - \left(\dfrac{i_2}{d + x_1}\right)^2\right] + \dfrac{1}{m}F_s \end{cases}$$
$$x(t) = x_1(t)$$

(13)

The magnetic ball bearing control system includes:

- Rotor with a mass of m = 6kg
- Two electromagnets are formed from loops of wire wrapped around a steel core with coil resistance R=10Ω
- Inductance L = 0.1H
- Number of wire loops N=600
- Air clearance at equilibrium d = 0.00053 m
- Pole cross section A = 0.000225 m^2

- Magnetic coefficient μ0 = 0.0000004*pi

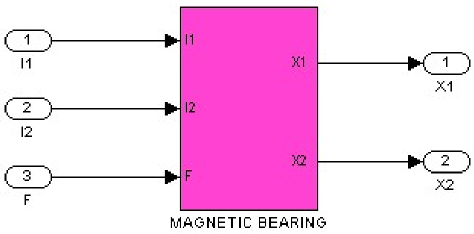


Figure 3. Block diagram depicting the magnetic ball bearing system

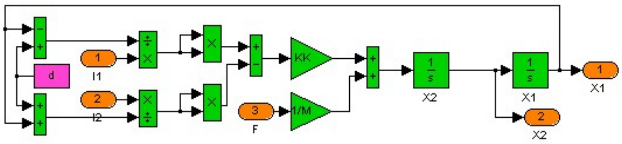


Figure 4. Simulation diagram of a magnetic ball bearing system using Simulink/Matlab

3. BLUR SLIDE CONTROL

Design of translucent slip controller for magnetic ball bearing system

We have the law of sliding control:

$$u(t) = -\frac{1}{\tau k}\left[x_2(t) + \alpha sign(s)\right]$$

(14)

Since the sign(s) function causes chatting, we change the component *αsign(s)* by matte processing

Step 1: Identify the language variables in and out

Input: S

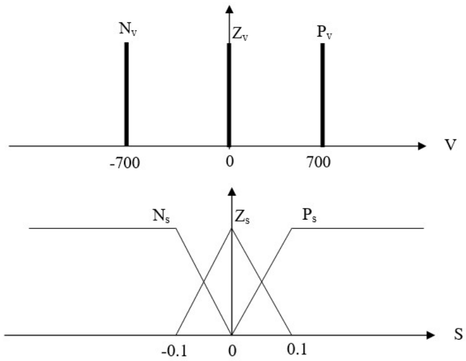
Output: $v = \alpha sign(S)$

Step 2: Determine the fuzzy set for each in-out variable

Language variables

S={negative, zero, positive}={Ns, Zs, Ps}

V={negative, zero, positive}={Vv, Zv, Pv}



Develop control laws Fuzzy control system built according to Sugeno fuzzy law

-If S is Ns then v is Nv

- If S is Zs then v is Zv

-If S is Ps then v is Pv

Manifestation of the Amendment Law

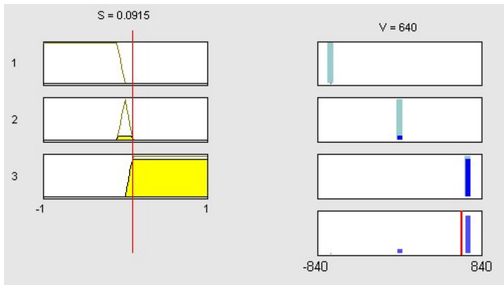


Figure 5. Manifestation of the Amendment Law

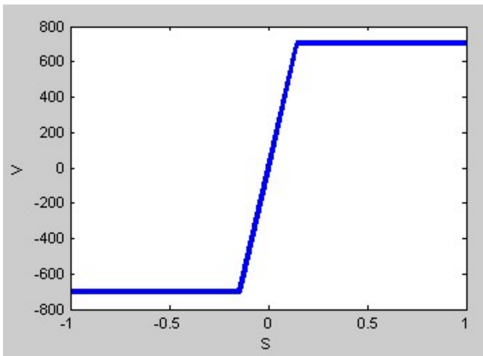


Figure 6: Developing Governing Laws

Step 3: Choose the constituent and unambiguous law

- Choose the constituent law according to the Min-Max rule

- Deblurring in the medium method

Sliding Dimming Controller Diagram”

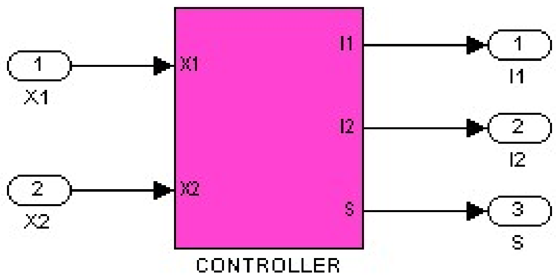


Figure 7. Block diagram depicting the slide controller

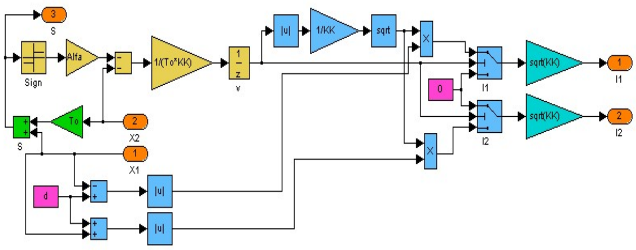


Figure 8. Simulation diagram of a slide controller using Simulink/Matlab

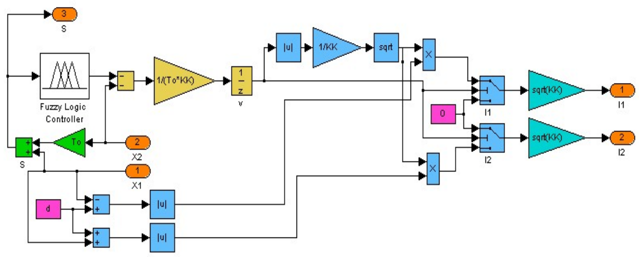


Figure 9. Simulation diagram of a fuzzy slip controller using Simulink/Matlab

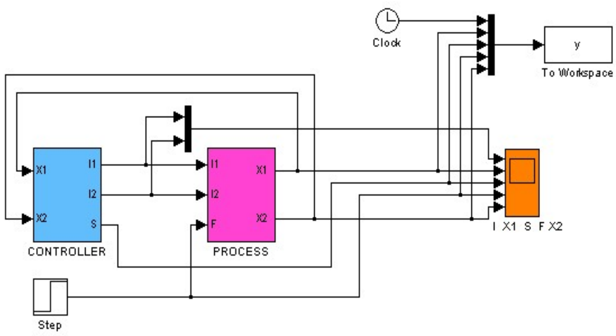


Figure 10. Diagram simulating the dim slip controller of a magnetic ball bearing system

Simulation results:

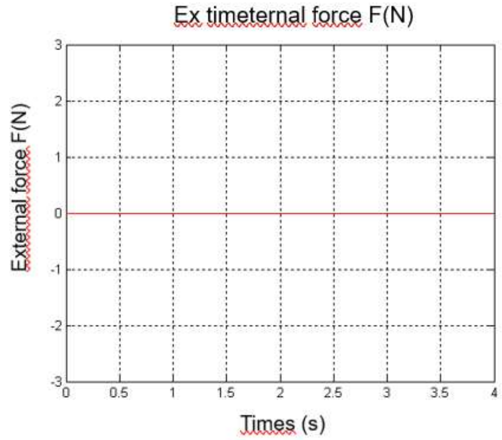


Figure 11. External force acting on the sliding surface

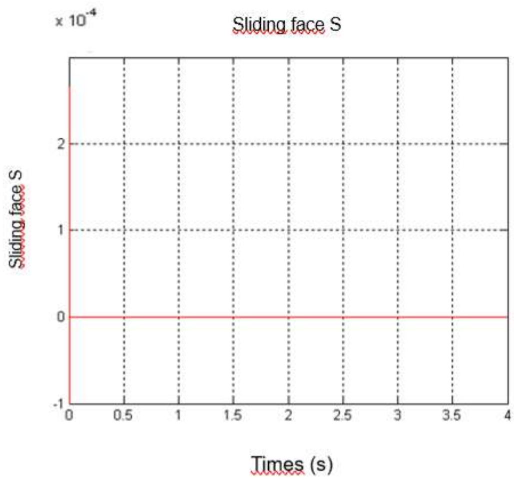


Figure 12. Sliding surface when there is no external force

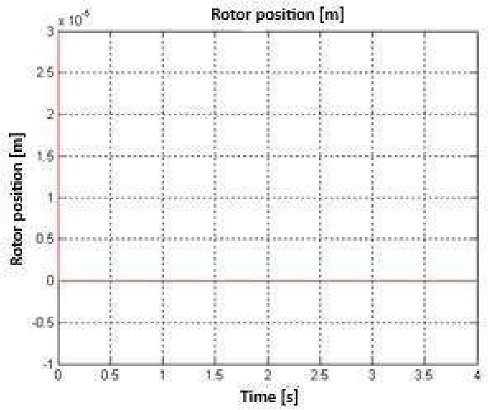


Figure 13: Rotor position when there is no external force acting

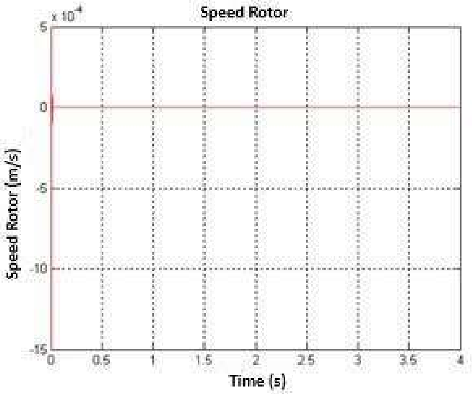


Figure 14: Rotor speed when there is no external force

The position, velocity, and sliding surface when there is no external force acting with the rotor mass m=6 kg and set at the position x0=d/2.

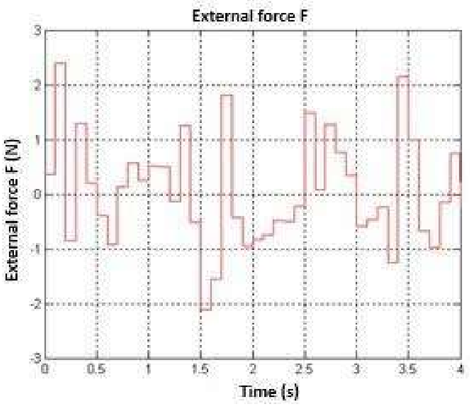


Figure 15: External force impact

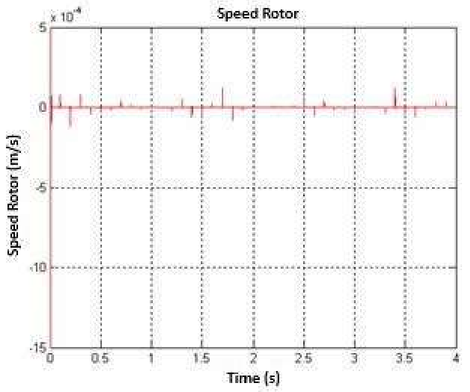


Figure 16: Rotor position when external force impacts

Position, velocity, sliding surface when there is an external force acting with rotor mass m=6 kg and set at position x0=d/2

Comments when replacing the sign function with fuzzy processing:

1. When the Rotor is in the d/2 position, the weight m=6kg and there is no external force acting

- The phase trajectory of the system moves quickly in terms of the sliding surface and follows the sliding surface, without chattering as when we use the sign function.

- The rotor velocity only fluctuates strongly at the initial time t = 0 to bring the rotor to the equilibrium position, then stabilize at the position = 0.

- When the rotor is located at the d/2 position, the u(t) control signal will control the current i1,i2 to quickly return the ball bearing to the balanced position, without oscillation and stability at the balanced position.

2. When the Rotor is at the d/2 position, the mass is m=6kg and there is an external force acting

- The phase trajectory of the system also quickly moves towards the sliding surface and follows the sliding surface, no chattering occurs.

- The rotor velocity also fluctuates strongly only at t=0 to bring the rotor to the equilibrium position, the velocity only fluctuates slightly when there is an external force to adjust the rotor to the equilibrium position.

- The control signal quickly brings the rotor to the balanced position with a very fast response time and no oscillation.

4. CONCLUSION

The simulation results show that:

- Use a dim slide controller to control the magnetic ball bearing system for good, sustainable response when changing parameters and for external interference.

- The dim slide controller has a fast response speed, no over-the-top, no oscillation.

- Eliminate the chattering phenomenon of the sliding controller

REFERENCES

Abdul Rashid Husain, Mohamad Noh Ahmad & Abdul Halim Mohd Yatim (2008), Chattering-free Sliding Mode Control for an Active Magnetic Bearing System. *World Academy of Science, Engineering and Technology*

Chien-An Chen, Huann-Keng Chiang & Jing-Chung Shen (2009), Sliding Mode Control of a Magnetic Ball Suspension System, *Vol. 11, No. 2*

H.Lee & V. Utkin (2007). Chattering suppression methods in sliding mode control system *.Annual Review in Control, vol. 31, pp. 179-188*

L.X.Wang (1997). A course in fuzzy sysmms and control. *Prentice Hall*

O.Omidvar & D.L.Elliott (1997) Neural sysmms for control. *Academic Hall..*

Oscar Castillo & patricia Melin. Type-2 Fuzzy Logic: Theory and Application, vol.223, Spinger.

Peter Vas (1994). Sensorless Vector and Direct Torque Control.*Oxford University.*

Qilian Liang & Jerry M.Mendel (2000). Interval Type-2 Fuzzy logic Systems: Theory and Design. *IEEE Transaction on fuzzy system, vol.8, No.5.*

J.Yen & R.Langari (2002). Fuzzy logic, Inmlligence, Control and information. *Prentice Hall*

Wilfrid Perruquetti & Jean Pierre Barbot (2002). Sliding Mode Control in Engineering. *Marcel Dekker*

THIẾT KẾ BỘ ĐIỀU KHIỂN TRƯỢT MỜ CHO HỆ THỐNG ĐIỀU KHIỂN Ổ BI TỪ TRƯỜNG

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THÔNG TIN CHUNG

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TỪ KHOÁ

Điều khiển;

Logic mờ;

Bi từ;

Matlab;

Simulink.

TÓM TẮT

Hệ thống ổ bi từ trường được ứng dụng trong nhiều lĩnh vực khác nhau của công nghiệp và một số lĩnh vực hàng không. Trong hệ thống này, ổ bi từ trường hoạt động như một ổ bi thông thường, nhưng sự khác biệt rõ ràng giữa hai loại này là vật thể được giữ cố định hoặc có thể di chuyển giữa hai hoặc nhiều cực từ của nam châm điện. Khi dòng điện chạy qua các cuộn dây của nam châm, một lực từ được tạo ra, nâng và điều chỉnh các lực theo các hướng khác nhau để vật thể luôn ở vị trí mong muốn. Dựa trên các đặc điểm của phương pháp điều khiển trượt kết hợp với điều khiển mờ, mô hình điều khiển có thể được đơn giản hóa, tránh các hạn chế gặp phải ở các phương pháp điều khiển thông thường. Phương pháp điều khiển trượt kết hợp với điều khiển mờ cùng với điều khiển truyền động cố định cho các hệ thống phi tuyến và phản hồi nhanh sẽ khắc phục các hạn chế như dễ trượt và hoạt động không chính xác, đặc biệt trong trường hợp thay đổi vị trí và tác động của nhiễu bên ngoài.