BOOK OF ABSTRACTS

LDIA 2011

The Eighth International Symposium on Linear Drives for Industry Applications

Eindhoven, the Netherlands - July 3-6, 2011

Organized by

TU/e Technische Universiteit **Eindhoven** University of Technology

2 DOF Suspension System by Variable Flux Control Using a Rotary Disk Magnet

Koichi Oka[1], Akira Tsurumi[1] Gota Nakamura [1] and Feng Sun[2]

[1]Kochi University of Technology, Miyanokuchi 185, Tosayamada-cho, Kami-city, Kochi, 782-8502, Japan
[2]Seiyang University of Technology, Address, City, State, Postal Code, Country
email: oka.koichi@kochi-tech.ac.jp

ABSTRACT

This paper describes a 2 DOF magnetic suspension system for a stick type object using a rotary geared motor and a disk magnet. In this system, the suspension force is provided by a disk-type permanent magnet and is controlled by a magnetic flux path control mechanism. This suspension system must control two degrees of freedom of a stick for complete noncontact suspension. A vertical displacement and a horizontal rotation of the object should be controlled. This paper proves the feasibility of the noncontact suspension system for such a system by controlling these two movements simultaneously. A theoretical analysis will be done on the model of this suspension system and a numerical simulation validate the feasibility of the system.

1 INTRODUCTION

Magnetic suspension is technology for supporting or manipulating objects without contact by means of magnetic forces. Magnetic suspension system has many advantages, which are no contact, no friction, no dirt and lubrication free. Using these advantages, many magnetic suspension mechanisms have been proposed [1]. Electromagnetic suspension systems are widely used that control the coil current. Recently, however, mechanical magnetic suspension systems have been developed [2]. As one of the mechanical control suspension system, a new type of mechanical suspension mechanism is proposed [3]. However, the complete noncontact suspension of a stick does not realized.

This paper discuss what is necessary for complete noncontact suspension. We can already perform the 2 DOF suspension system for the suspension system with variable flux path mechanism [4]. Another conditions for complete noncontact suspension are investigated. First, the suspension principle with variable flux path mechanism is explained, and a prototype system is introduced. Structural examination is carried out and necessary DOF of control is verified. A model for the suspension system is introduced and the linear control theory proves the feasibility of complete suspension. Finally, a simulation result validate the suspension system.

2 SUSPENSION SYSTEM

2.1 Principle of suspension

The principle of this magnetic suspension system can be understood in Fig. 1. A schematic diagram showing a disk PM, two F-type iron cores and a rectangular suspension object. Figure (a) shows that the magnetic poles of the PM are aligned in the vertical direction. In this case, the facing angle of the N pole and S pole to each core are same, so all magnetic flux from the N pole is absorbed into the S pole. As there is no flux flowing through the suspension object, no attractive force generates.

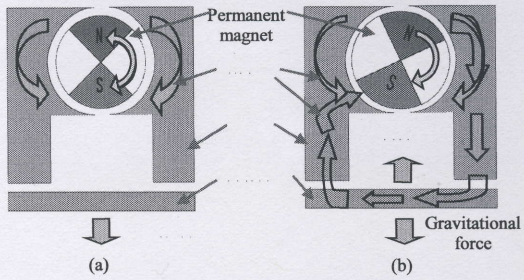

Figure 1: Principle of suspension mechanism with variable flux path.

Figure (b) shows the PM rotated a certain angle. The facing area of the N pole becomes bigger than the S pole in the right core. Some of the flux in the right core flow through the suspension object and the attractive force is generated. According to this process that is called variable flux path, the attractive force is changed from zero, maximum, and zero, maximum to zero as the PM rotates in one revolution.

2.2 Experimental prototype of suspension system

An experimental prototype of the proposed magnetic suspension system was constructed. The prototype consists mainly of a disk PM, a rotary actuator containing a reduction gear and an encoder, a pair of F-type perm alloy cores, a rectangular perm alloy suspension object and two eddy current sensors. The disk PM, which is in the center of the F-type cores, is a neodymium magnet and magnetized in the radial direction. The control system of the magnetic suspension system is a DSP controller, shown in Fig. 2. According to the signals from the sensors and encoder, the DSP controller calculates the current to control the rotary actuator that drives the PM.

Now, we can not realized complete noncontact suspension using this device. We use a linear guide for the suspended object and the DOFs of the object were restricted in only vertical direction.

3 COMPLETE NONCONTACT SUSPENSION

For complete noncontact support, all six degrees of freedom (DOF) of the suspended object should be consid-

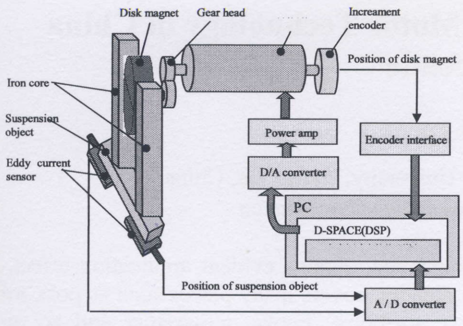

Figure 2: Configuration of suspension system.

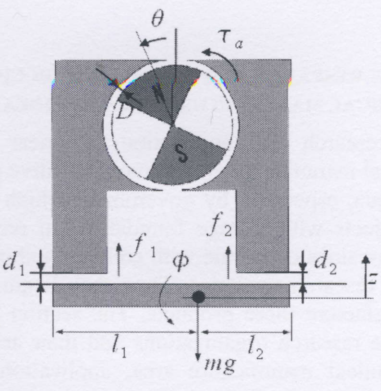

Figure 3: Symbols and model of suspension system.

ered about stability. For consideration, symbols of the suspension system are shown in Fig. 3. The z axis is defined as the vertical direction which is from down to up in the sheet and the y axis is defined from the left to the right in the figure and the x axis is the axis through the sheet.

3.1 *Consideration of necessary control DOF*

The translation along the x axis and the y axis have restoration forces by the magnetic lateral force. Same force restores the rotation motion about the z axis. And the rotation about the x axis can be stabilized by the round shaped stick object. Consequently, the DOFs which should be controlled are the translation along the z axis and the rotation about the x axis.

3.2 *Modeling and controllability of system*

To model of the system, the two equations of the motion are derived as

$$m\ddot{z} = f_1 + f_2 - mg \tag{1}$$

$$I\ddot{\phi} = -f_1 l_1 + f_2 l_2 \tag{2}$$

We assume the attractive force between each core and the faced part of the suspended object as

$$f_i = k\frac{\sin^2\theta}{d_i^2}. \tag{3}$$

The state variables are the displacement z, the rotation ϕ, and their derivatives. The state space equations can be obtained by linearization as

$$\dot{x} = Ax + bu \tag{4}$$

$$y = Cx \tag{5}$$

The conditions of equilibrium are balance of the force and the moment. Considering these conditions, the determinant of the controllability matrix can be obtained as

$$64k^6\cos^4\theta_0\sin^8\theta_0\left(\frac{1}{d_{10}^2}+\frac{1}{d_{20}^2}\right)^4\left(\frac{l_1}{d_{10}^3}-\frac{l_2}{d_{20}^3}\right)^2. \tag{6}$$

The controllability depends o the last parenthesis. It means the different air gaps are required.

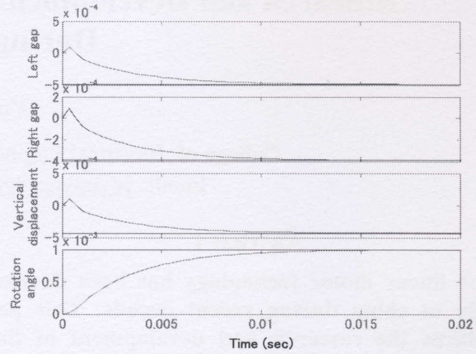

Figure 4: Simulation result of complete noncontact suspension system.

3.3 *Numerical simulation*

A numerical simulation was carried out to validate the feasibility. The feedback gains are calculated by the LQR methods. The result is shown in Fig. 4 and verify the complete noncontact suspension system.

4 Conclusion

Conditions of the complete noncontact suspension system with variable flux path mechanism for stick shaped object can be obtained by the linear control theory and it has been verified by a numerical simulation. Examinations on experimental prototype is required.

References

[1] B.V. Jayawant, "Electromagnetic levitation and suspension techniques," *Edward Arnold, London*, 1981.

[2] K. Oka and T. Higuchi, "Magnetic Levitation System by Reluctance Control: Levitation by Motion Control of Permanent Magnet," *Int. J. of Applied Electromagnetics in Materials*, Vol. 4, pp. 369–375, 1994.

[3] F. Sun, K. Oka, and Y. Saibara "Magnetic Suspension System by Flux Path Control Using Rotary Actuator," *Int. J. of Applied Electromagnetics and Mechanics*, IOS Press, Vol. 33, pp. 769–776, 2010.

[4] F. Sun, K. Oka, and T. Takechi "Simultaneous Noncontact Suspension of Two Iron Balls Using Flux Path Control Mechanisml," *Proc. of Int. Conf. of Motion and Vibration Control 2010*, 2010.