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MAGNETIC LEVITATION SUSPENSION CONTROL SYSTEM FOR REACTION WHEEL

JITHA RAJAN S

Mangalam College of Engineering, Kerala, India

ABSTRACT

This paper deals with a non linear magnetic levitation suspension control system used for space applications. The system linearization and phase lead compensation techniques are used to control unstable non linear system. The system consists of power amplifier design, compensation of a unstable control system, and electromagnetic design for space craft applications.

Magnetic levitation of a metallic sphere provides a high-impact visual demonstration of many principles in undergraduate educational programs in electrical engineering. plus derivative (PD) compensation strategy is used to implement a plant transfer function.

KEYWORDS: Magnetic Suspension, Reaction Wheel Control, Non Linear Control System

INTRODUCTION

The magnetic levitation control system is considered an interesting and impressive device for reaction wheel control. It will reduce contact and frictional losses. Generally there are two approaches for the design of magnetic levitation. First method is by using eddy current repulsive force. Next method is use of attractive force of electromagnet. Magnetic suspension reaction wheel control is repulsive force of opposite polarity is utilized for providing sufficient magnetic suspension.

In the precision engineering industry, magnetic bearings are becoming increasingly popular [1], magnetic bearings have significant demand on accurate positioning upto nanometric precision, bandwidth, and stiffness. Magnetic bearings have proven to be superior to other approaches to such precision motion control systems since they provide for large travel, high bandwidth/stiffness, and nanometric accuracy.

NONLINEAR SUSPENSION MODEL

In this section, the open-loop dynamics of a simple one degree-of-freedom suspension is presented. This system exhibits the essential issues faced in the design of tractive-type suspensions, that is, suspensions which operate as variable reluctance devices. The only change here is that the system is inverted such that gravity acts to open the air gap.

The system is shown schematically in Figure 1. The details of the electromagnetic theory are worked for the present purposes, the important relations are those for the coil voltage,

$$v_c = \frac{2wd\mu_0N^2}{go+x}\frac{di}{dt} - \frac{2wd\mu_0N^2i}{(go+x)^2}\frac{dx}{dt} + iR$$

Infinitely permeable core is assumed. The parameter *go* can include an additional length to model the finite reluctance of the core, if the core has finite permeability. In the later analysis, this additional length is equal to 20 m.

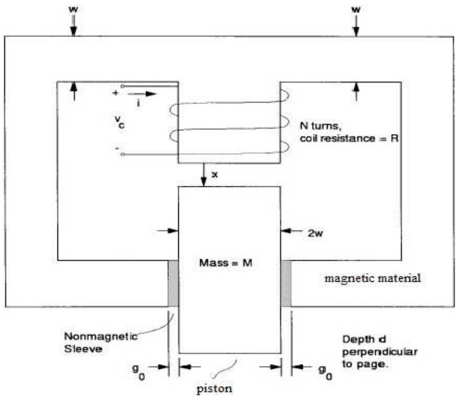

Figure 1

Where, μ_0=4π x 10^{-7} H/m – Permeability of free space,

g= 9.81m/s^2 – acceleration due to gravity

and the -directed force on the mass

$$f_x = -\omega d\mu_0 N^2 (\frac{i}{g_0+x})^2 + M_g - f_d, (x > 0)$$

where the first term is the electromagnet force, the second term is the gravitational force on the piston[2], and the third term is a disturbance force acting on the piston in the direction of the electromagnet force. The parameters, d, g_0, M, R, and N, as well as the variables v_c , *i*, and *x* are defined in Figure 1.

In [3], the core is assumed to be infinitely permeable. If the core has finite permeability, the parameter g_o can include an additional length to model the finite reluctance of the core. In the later analysis, this additional length is equal to 20μ m. The constant $\mu_0 = 4\pi \, X \, 10^{-7}$ H/m is the permeability of free space, and g = 9.81 m/s is the acceleration due to gravity.

The pointing performance degrades at the transition of speed cross over due to stiction in ball bearing reaction wheel. Also the friction variation as a function to temperature, speed and operation history makes these wheels unsuitable for ultra high stability requirements of scientific missions. Since there is no physical contact between the stator and rotor elements in a magnetic bearing wheel, it gives improved performance under these conditions. A soft magnetic axis – symmetric piece with “C” shaped cross section which acts as the outer ring, and For equally spaced electro magnet poles each consisting of two coils, stacked between two inner annular soft magnetic rings. The experimental setup for such a contactless suspension system with high rotating torque is given in figure 2.

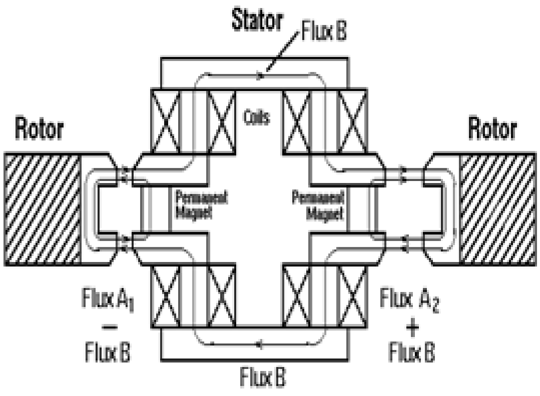

Figure 2

LINEARIZED MODEL

A linear controller based on a linearized model is satisfactory in applications where large disturbance forces are not anticipated. We can derive this linearized model by using standard techniques that is, writing the suspension states and inputs in terms of incremental quantities and operating point. Let us define,

$f_d = \bar{f}_d + \tilde{f}_d$

$x_1 = \bar{x}_1 - \tilde{x}_1$

$x_2 = \bar{x}_2 - \tilde{x}_2$

$i_0 = \bar{i}_0 + \tilde{i}_0$

Where, the tilde indicates the incremental quantity and the over bar denotes the operating point value. The negative sign shows that the linearized plant transfer function from $\tilde{i}$ to $\tilde{x}$ will have a positive sign in the numerator. Here a sensor is used which provides an increasing voltage as the air gap closes.

Let the operating point values of the state variables are $\bar{x}_2 = 0$

$$\frac{\bar{i}}{\bar{x}1} = \sqrt{\frac{Mg - \bar{f}d}{C}}$$

By taking the Jacobians the linearized system equations can be obtained as

$$\sim\bar{x}1 = \sim x2$$

$$\sim\bar{x}2 = \frac{2(Mg - \bar{f}d)}{M\bar{x}1}\,\tilde{x}1 + \frac{2\sqrt{C(Mg - \bar{f}d}}{M\bar{x}1}\,\tilde{i} - \frac{1}{M}\,\tilde{f}d$$

The bias of gravity and disturbance force affects the natural frequency of the system via the term multiplying $\sim i$ and via the term multiplying $\sim x_1$ and the input gain. When $\bar{f}_d = 0$, the linearized poles lies at $\lambda = \pm \sqrt{\frac{2g}{\bar{x}1}}$. In such a gravity biased suspension, we can observe that, there is a right half-plane pole which moves from the origin as the operating point gap $\bar{x}_1$ decreases. We obtain a set of linear, second-order equations used to develop a linear controller for the system. These equations are valid for small perturbations of the operating point. When the system moves, performance of the system will degrade and the the quality of this approximation may decrease.

HARDWARE IMPLEMENTATION FOR LINEARIZATION

The experimental hardware overcomes some disadvantages of the existing system. Eddy currents and hysteresis in the electromagnet are eliminated by using low hysteresis laminated cores. A stable capacitive proximity probe is used instead of the drift prone optical sensor. The position of a magnetic target attached to the endpoint of a shaft is controlled by two electromagnetic actuators. A capacitive-type proximity probe is used to sense the end-point position and attached in a control algorithm implemented on a 90- MHz Pentium-based digital computer at a sampling rate of 5000 Hz. For high stiffness and light weight a graphite composite shaft is used. The current of the coil is controlled by a high-bandwidth closed-loop current source. The total accessible range of motion of the system is 600 m. The operating point air gap at the centre position for each electromagnet is 300 m.

The endpoint of this system is connected to ground by two single axis flexures. The natural frequency of the system is 8 Hz. The force required to accelerate the mass will be dominant at higher frequencies. The bandwidth is 150 Hz in the control system of this hardware.

Linear Controller

This system contains a linear compensation scheme and a 0.2 Ampere current bias to each actuator. The feedback path of the controller has a unity gain dc lead term for stabilizing the loop and a lag term in the forward path, which provides good steady-state performance. The step response of linear controller is same as the nonlinear controller, only the gain term has some variations. The current to each actuator is composed of incremental quantities and bias. The bias is used to bias the squared relationship of force to current. Let us assume that the incremental quantities of current is opposite in sign and equal in magnitude also the biases to the actuators are same. Also assume that the steady state disturbance force is equal to zero.

The equations of the system are derived as follows:

$i_1 = \bar{i} + \tilde{i}\ \tilde{\imath}$

$i_2 = \bar{i}\ \bar{\imath} - \tilde{i}$

Let us assume that $|\tilde{i}| < \bar{i}$. The system is considered as a single-input. Also assume that operating point for the system is $\overline{x_1} = 0$.Applying Jacobians and substituting, we can obtain as,

$$\dot{\widetilde{x_1}} = \widetilde{x_2}$$

$$\dot{\widetilde{x_2}} = \frac{4\overline{C_\iota^2}}{Mx_0^3}\widetilde{x_1} + \frac{4\overline{C_1}}{Mx_0^2}\tilde{\imath} + \frac{f_d}{M}$$

$$\widetilde{x_2}\ \widetilde{x_2}$$

Where, $\frac{4\overline{C_\iota^2}}{Mx_0^3}\frac{4\overline{C_\iota^2}}{Mx_0^3}$- negative destabilizing term.

Thus we obtained that the system is linear in terms of the control current $\tilde{\imath}$ and the bias current affects the incremental gain from current to force.

Nonlinear Controller

We know that the system can be linearized by varying the two coil currents as

$$i_1 = (x_0 - x_1)\sqrt{\frac{\upsilon M}{C}}, i_2 = 0\ (\upsilon > 0)$$

$$i_2 = (x_0 + x_1)\sqrt{\frac{-\upsilon M}{C}}, i_1 = 0\ (\upsilon < 0)$$

The above equation is used to linearize the magnetic force relationship. The suspension can be linearized in terms of the new input υ. Current can apply only to the actuator which generate force in a specific direction.

The PWM Controller

Traditionally, the control of the magnetic suspension system has been achieved with a linear amplifier. Electromagnets are powered with switching pulse, using pulse width modulation (PWM) [4] magnetic strength regulated depends on feedback system. Evidently, by varying the duty cycle of the switch, the coil current can be controlled. In pulse width modulation, the control voltage (v_c) is compared with a repetitive ramp waveform from feedback signal differentiated output. The output of the comparator is applied to the coil. By inspection, the duty cycle is

$$d = \frac{v_c}{v_p}$$

EXPERIMENTAL RESULTS

The performance of the linear and nonlinear controllers over the full operating range of the system are examined by commanding 25 μm steps in the reference position at various operating point air gaps. At the centered position the value of displacement is zero. The actuators pole faces are located at 255μm for the positive and 255 μm for the negative force electromagnets. The nonlinear loop maintains a constant step response and the air gap is reduced by a factor of ten, while the linear loop becomes unstable at an airgap of about 100 μm. This is due to the increase in the unstable natural frequency.

Suspension system consisting of high speed shaft upto 6000 rpm is tested using ‘C’ shaped electromagnetic system as explained above.

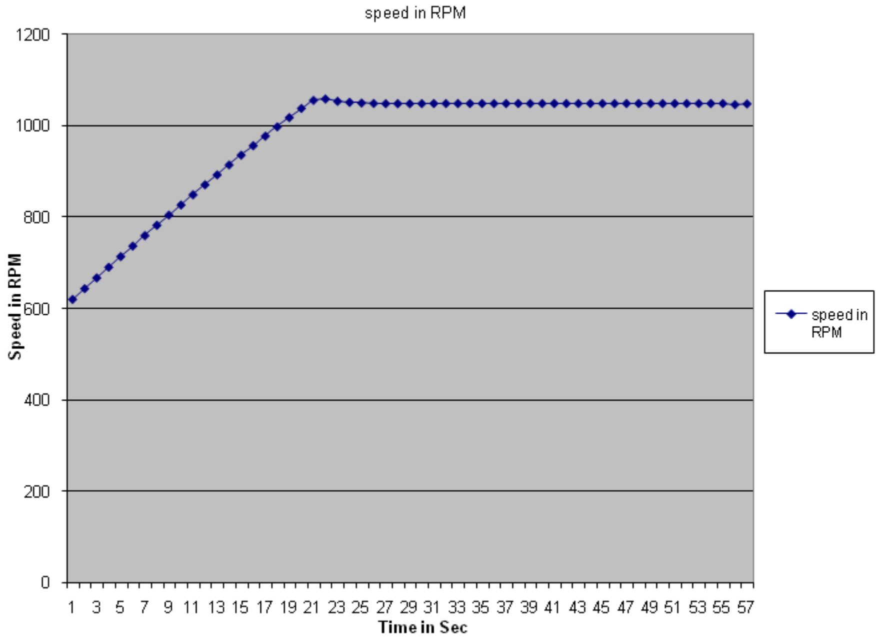

Figure 3

CONCLUSIONS

This technique is useful to get optimum performance from magnetic bearings. Sensors are selected experimentally for the feedback system. The feedback linearization technique is used to design control loops for nonlinear systems. This feedback linearization gives excellent performance to the system. It is very important to implement control algorithms which are robust with respect to modelling for practical applications. These models can also be verified experimentally, as described in [5].

RESULTS

The single degree of freedom stage described in this paper is a useful test bed for exploring alternative control techniques to get optimum performance from magnetic bearings. The technique of feedback linearization is of great utility in designing control loops for nonlinear systems such that the closed-loop systems are well-behaved despite large variations in operating point. Although feedback linearization gives excellent performance, it requires very accurate plant models. Specifically, we observed in earlier experimental work that any modeling errors in the actuator constant C for the single dof system described in this paper led to sustained oscillations as the pole face was approached even with a feedback linearizing controller. For practical applications, it is very important to implement control algorithms which are robust with respect to modelling errors and plant uncertainties. This is a good topic for further research. Sampling rates for discrete-time implementations have been shown to be important, especially at small air gaps.

REFERENCES

1. M. Dussaux, “The industrial applications of the active magnetic bearings technology,” in *Proc. 2nd Int. Symp. Magn. Bearings*, 1990, pp. 33–38.
2. H. Anschutz-Kaempfe, “Gyroscopic apparatus,” U.S. Patent 1589039,1926.
3. H. H. Woodson and J. R. Melcher, Jr., *Electromechanical Dynamics— Part I*. New York: Wiley, 1968
4. V. Vorperian, “Simplified analysis of PWM converters using model of PWM switch. 1. Continuous conduction mode,” *IEEE Trans. Aerosp. Electron. Syst.*, vol. 26, pp. 490–496, May 1990.
5. T. Poovey, M. Holmes, and D. L. Trumper, “A kinematically coupled magnetic calibration fixture,” *Precision Eng.*, vol. 16, no. 2, pp. 103–107, 1994.