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AN EFFICIENT SENSOR ARRAY FOR A LARGE-GAP MAGNETIC LEVITATION SYSTEM

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Abstracts A magnetic levitation control system is nonlinear and very unstable. Thus there should be a stabilizing compensation network and a feedback path. Due to the levitation control a noncontact photoresistor sensor is generally used. One photocell provides a certain amount of variation in length by the ball shadow casted on the cell surface. Furthermore at the boundary of the cell, the linearity of sensitivity deteriorates severely. To overcome the constraints of the length and linearity, an efficient sensor array is deviced and applied in the feedback path of a large-gap magnetic levitation control system. A number of CdS photocells and a summing circuit of the sensor output signals are used for a sensor array. The levitation length of a ball and the transient performances are main objectives of the large-gap suspension system using the sensor array.

Keywords Magnetic Levitation, Photocell, Sensor Array, Robustness, Fuzzy Control

1. INTRODUCTION

A magnetic levitation system(MLS) has a simple structure of balancing gravitational force and the electromagnetic attractive force. It is to keep a metal ball suspended in the air by adjusting the electric field strength of an electromagnet. The current flowing into the electromagnetic coil generates electromagnetic force against the gravitational force. According to difference between the two forces the metal ball goes up and down.

In reality MLS has a characteristic that is highly nonlinear and inherently unstable in operation. The coil current variation will cause the ball to either fall or attach it to the electromagnet. Particularly for a large-gap MLS, use of a noncontact photoresistor sensor and the traditional PID controller is usually not sufficient for a satisfactory performance.

To cope with the nonlinearity due to the wide range operation and the unmodeled system effects, it is generally regarded that fuzzy logic controller plus classical PID algorithm [2, 3, 4, 6] yields the best performance so far.

In this paper we propose a sensor array and an algorithm which are particularly proper for a large-gap MLS employing fuzzy logic controller. Since the photoresistor sensor relies on the ball shadow casted on the cell surface, the effects of the ambient light and temperature, and the difference between individual cell elements should be counted in the feedback sensor system.

2. PROBLEM STATEMENT

As for the typical MLS, shown in Fig. 1, the dynamic equations are well established such as in [3, 5, 6, 7] of transfer function form or state equation. The block diagram of the MLS can be drawn as in Fig. 2 from the system's dynamic equations. Since the system is nonlinear, the equations are linearized at an operating point. As usual, the variables of the operating point are denoted with subscript '0' and the small signals of the operating point are expressed with subscript '1'.

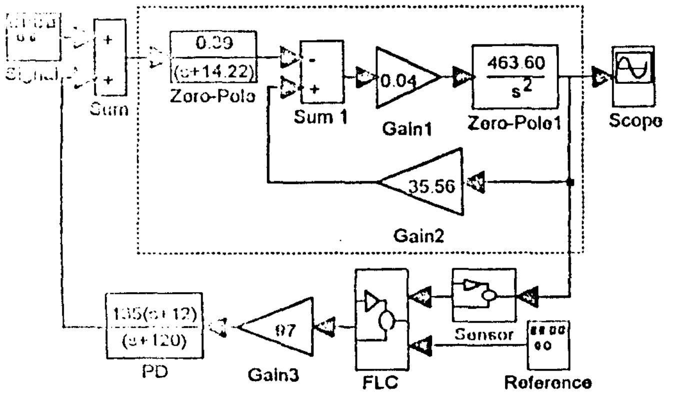


Fig. 1. Magnetic Levitation Control System.

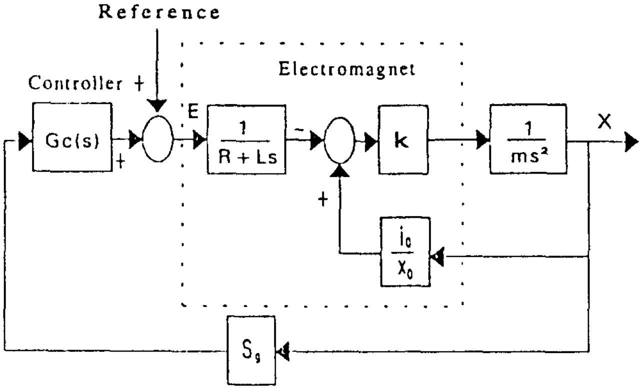


Fig. 2. Block diagram of MLS.

The transfer function of the system is given by

$$G(s) = \frac{X_1(s)}{E(s)}$$

$$= \frac{-kx_0}{Lmx_0s^3 + Rmx_0s^2 - Lki_0s - Rki_0} \qquad (1)$$

$$k = 2Ci_0/x_0^2 .$$

The system of eq. (1) with a simple photoresistive sensor in the feedback path results in an unstable system as shown in the root locus in Fig. 3. To stabilize the system a simple phase-lead network of

$$Gc(s) = \frac{135(s+12)}{(s+120)} \qquad (2)$$

is added as a typical stabilizing controller[1, 5]. The resulting root locus is shown in Fig. 4.

The metal ball movement due to the step and sinusoidal reference signals are shown in Fig. 5. The compensated system of eq. (1) and eq. (2) is straightforward and the output performance of the ball movement can be adjusted using the added zero location and the amplifier gain.

Table 1. Parameters of MLS

Parameter		Value
Coil current	i_0	1.067 A
Distance	x_0	0.030 m
Ball mass	m	0.0022 Kg
Coil inductance	L	2.554 H
Coil resistance	R	36.32 Ω
Constant	k	0.04 N/A
Sensor gain	S_g	97 V/m

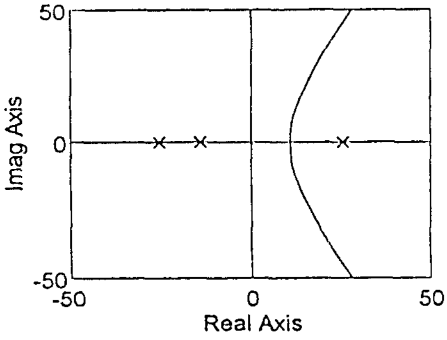


Fig. 3. Root locus of MLS without compensation

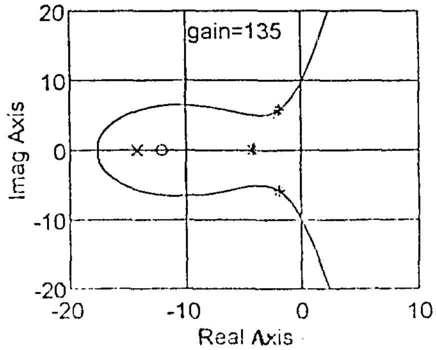


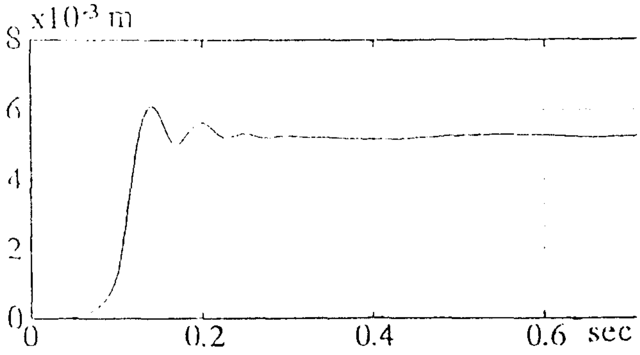
Fig. 4. Root locus of compensated system

But the MLS is essentially nonlinear and inherently unstable. With a simple phase-lead network added, it has a narrow margin of stability due to unmodeled system properties, inexact photoresistor sensor indication, and the difficulty associated with power transistor bias voltage using resistors. This problem becomes serious when the distance of the ball movement increases.

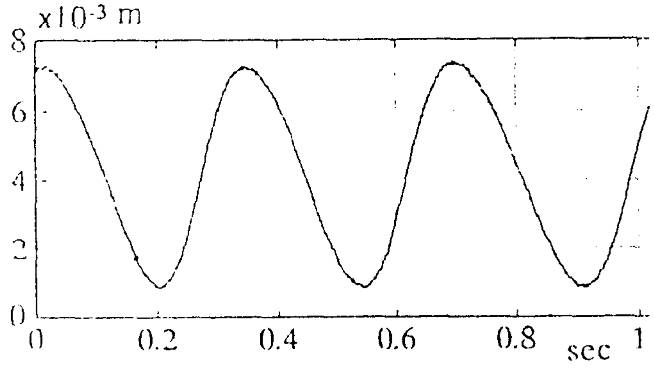
3. LARGE-GAP MLS DESIGN

3.1 Sensor Array

Since the MLS is manipulated after a linearization process, the characteristic of the photoresistive sensor should maintain the linearity between the ball position and its output voltage. To increase the linear characteristic of the sensor for a wide range of operation, a sensor array instead of one CdS cell is used as shown in Fig. 6.



a) Step response



b) Sinusoidal response

Fig. 5. MLS output responses.

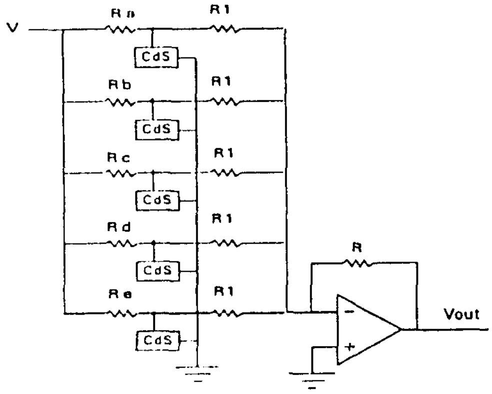


Fig. 6. A CdS cell sensor array.

The values of the gain of each CdS cell depend on

- number of cells used
- relative size of ball shadow

The least squares approximation algorithm may be used to calculate the gains. One example of five-cell and 2.5 size shadow is considered to show the linearity sensor characteristic which is shown in Fig. 7.

Table 2. Cell gains

g_1	g_2	g_3	g_4	g_5
2.1	2.2	3	4	5

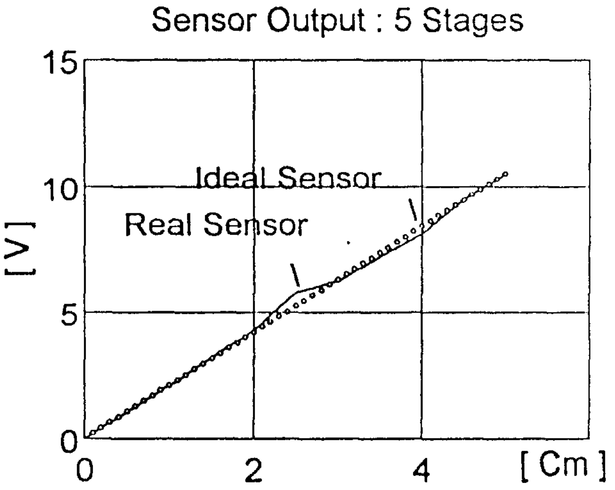


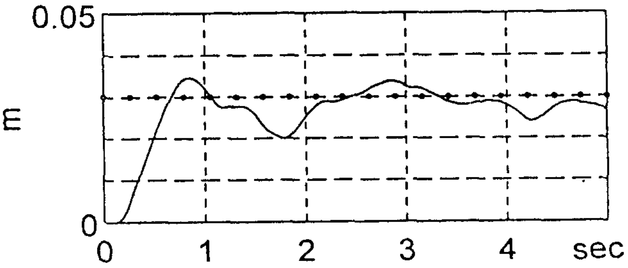
Fig. 7. Linear property of the sensor array

3.2 PD+FLC controller

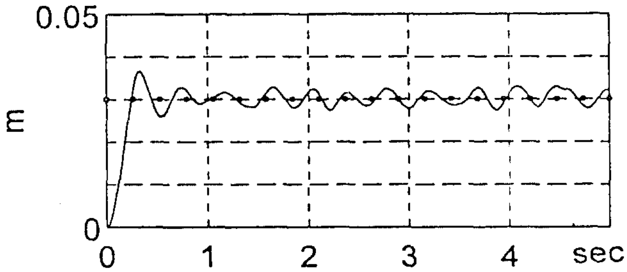
In addition to the conventional phade-lead or PID controller, a fuzzy logic controller[2, 3, 6] is utilized to increase robustness of the MLS performance. The problems to be accommodated by the fuzzy logic type controller are

- nonlinear property of MLS
- system parameter variation due to temperature changes
- inexactness of the sensor gains
- measurement noise

The schematic diagram of the proposed system is shown in Fig. 1. The comparison of the performances of PD and PD+FLC, shown in Fig. 8, makes it clear that transient response as well as robustness in measurement noise are improved by the addition of FLC.



a) PD controller(2% noise added)



b) PD+FLC controller(2% noise added)

Fig. 8. MLS output responses

Using the fuzzy rule-based controller, an error signal(E) and its change in E(ΔE) are input data. As

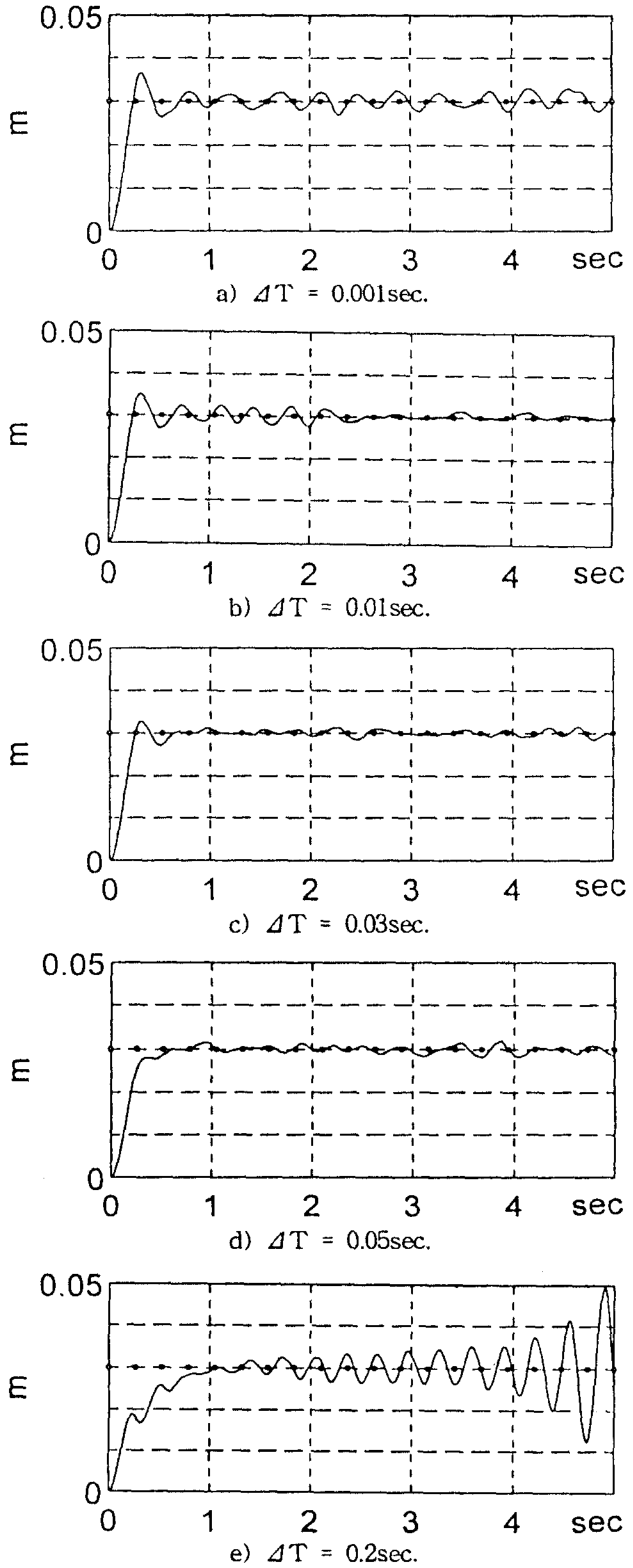


Fig. 9. Output responses with various ΔT (2% noise added)

the time difference(ΔT) in calculation of ΔE changes, the output responses are affected as shown in Fig. 9. Particularly with the constraint of output measurement noise added, a certain amount of ΔT should be kept to improve the noise immunity.

4. CONCLUSION

To overcome the nonlinear property and to improve the robustness in large-gap MLS, a sensor array which has better linearity and wide operating range, and a controller algorithm based on PD+FLC are used. In the application of fuzzy rules, a certain amount of time delay in calculation of error signal changes should be maintained to improve the measurement noise effects on system output responses.

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