Output Improvement of a Magnetic Levitation Control System

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Abstracts Output performance improvement using fuzzy logic to the conventional control scheme for a magnetic levitation system is presented in this paper. Adverse characteristics of nonlinearity, unstability, system parameter variation, etc. in the levitation system are partially overcome by the general fuzzy control action. Using a PD type compensator, a coarse framework of output performance is provided to the levitation system. Then a fine regulation to the output performance requirement is obtained by the natural description of the control action in the form of fuzzy logic controller. This control action soothes the adverse characteristics of the levitation system. In this way a better output performance can be obtained in a real time experiment.

Keywords Magnetic Levitation System, Fuzzy Logic Control, Performance Improvement, Photocell.

1. INTRODUCTION

A magnetic levitation system(MLS) has a simple structure of balancing gravitational force and the electromagnetic attractive force of the oppositive direction. 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 the difference between the two forces the metal ball goes up and down.

In actual operation MLS has characteristics that are highly nonlinear with an attribute of unstability, very susceptible to the parameter variation. The coil current variation will cause the ball to either fall to the bottom or attach it to the electromagnet. Feedback loop element of the system is a noncontact photoresistor sensor which itself has nonlinear property also.

To cope with such adverse characteristics of MLS, it is generally regarded that fuzzy logic controller plus conventional control algorithms yields the best performance in many control problem aspects.

In this paper we investigate the usefulness of the fuzzy logic control in output performance improvement for a real time MLS experiment. First a phase-lead network is added to provide a stable operation to the linearized model. This is a coarse but basic controller framework for output property requirements. Then a fine correction is provided in the form of a fuzzy logic control to deal with the adverse properties of the MLS. This kind of correction is possible by translating the output performance requirements into the fuzzy logic control rules.

2. MLS SYSTEM MODEL

The dynamic equation governing the metal ball movement in the magnetic field using the variables of current(i) and distance(x) is represented by a nonlinear form. The electromagnetic force produced by an electromagnet is given by eq. (1).

$$f = -\frac{i^2}{2}\frac{dL}{dx} \tag{1}$$

Total inductance L of eq. (2)

$$L = L_1 + \frac{L_0 x_0}{x} \tag{2}$$

consists of the electromagnet coil inductance L_1 and the variation which depends on the ball position. Based on eq. (1) and (2) the dynamic equations are well established such as in [1]. Output position detection and feedback is made by an photoresistor photocell which is idealized by

$$v_s = \beta x \tag{3}$$

where is v_s the sensor output voltage, and β is a sensor gain which is obtained experimentally.

Linearized MLS equation can be represented by a set of following equations.

$$I(s) = \frac{V(s)}{R + sL_1} \tag{4-a}$$

$$F_1(s) = \left(\frac{2CI_0}{X_0^2}\right)I(s) - \left(\frac{2CI_0^2}{X_0^3}\right)X(s) \tag{4-b}$$

$$X(s) = -\frac{1}{ms^2}F_1(s) \tag{4-c}$$

$$V_s(s) = \beta X(s) \tag{4-d}$$

The transfer function between the ball position sensing voltage and the input voltage to the electromagnet coil is given by

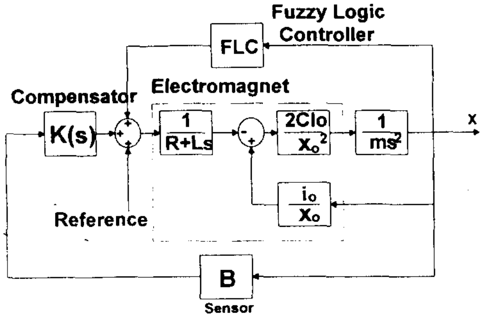

Fig. 1. Block diagram of MLS

$$G(s) = \frac{V_s(s)}{V(s)} = \frac{-2BCI_0/mL_1X_0^2}{(s+R/L_1)(s^2-2CI_0^2/mX_0^3)} \tag{5}$$

Table 1. Parameters of MLS

Parameter		Value
Distance	x_0	0.013 m
Coil current	i_0	0.606 A
Ball mass	m	0.014 Kg
Coil resistance	R	36.3 Ω
Coil inductance	L	2.55 H
Sensor gain	β	296 V/m
Constant	C	6.34×10^{-4} Nm^2/A^2

3. COMPENSATOR DESIGN

The transfer function of eq. (5) with the values of Table 1. is given by

$$G(s) = \frac{-6.11\times10^{-3}}{(s+38.8)(s-38.8)(s+14.2)} \tag{6}$$

The system with simple photoresistive sensor in the feedback path results in an unstable system as shown in the root locus in Fig. 2.

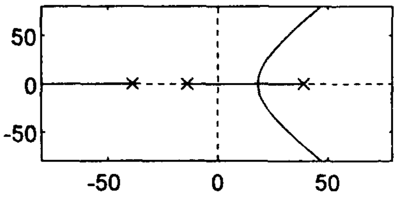

Fig. 2. Root locus without compensation

To stabilize the system a simple phase-lead network of

$$K(s) = K_c\frac{s+10}{s+110} \tag{7}$$

is added as a typical stabilizing controller[1,2]. The resulting root locus is show in Fig. 3.

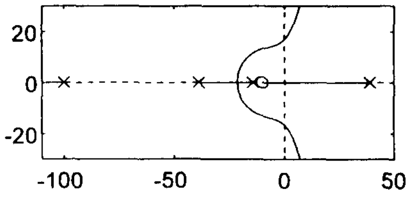

Fig. 3 Root locus of compensated system

Still the range of *Kc* is restricted only to a relatively small interval. But quite a large variation of transient values can be obtained due to the rapid change around the added zero at $s=-10$ as shown in Fig. 3.

Since the system eq. (5) relies on the linear terms only, discrepancy between eq. (5) and the real MLS becomes noticeable when the range of ball movement increases. To accommodate the system nonlinearity and the relatively small range of stability, fuzzy logic type controller is added to the conventional PD controller.

Fig. 4 shows a circuit for the MLS experiment. It includes a low pass filter for the noise problem.

The electromagnet is made of 0.8 mm diameter coil around 35 sheets of iron plate(Thickness : 0.5 mm, Width 1.5 cm, Length : 16.3 cm). Coil input voltage is 50 V and transistor current has a range of 300~600 mA in Fig. 4.

Proper coil current is made by using NPN type transistors 2SC3552 and a CdS cell of diameter 2.3 cm. Fig. 5. and Fig. 6. show the resistive and voltage properties of the CdS cell.

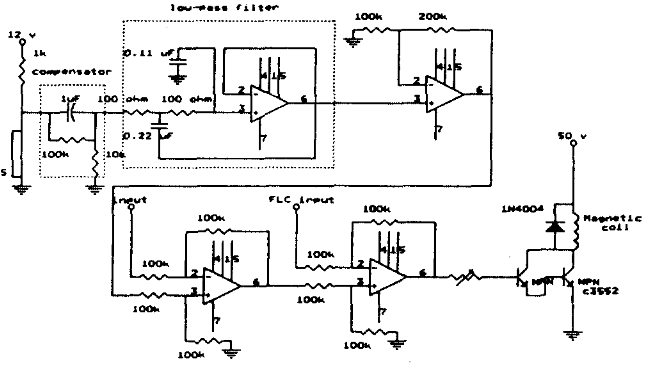

Fig. 4. Circuit diagram of MLS

Desired transient performance improvement is represented as a set of fuzzy logic rules such as Table 2. It also depends on the MLS properties and the system time constant requirement restricts the computation time of FLC.

Table 2. FLC control rules

Change of OVS \ OVS	NB	NE	ZE	PO	PB
NB	PB	PB	PO	PO	PO
NE	PB	PO	ZE	ZE	ZE
ZE	PO	ZE	ZE	ZE	NE
PO	ZE	ZE	ZE	NE	NB
PB	NE	NE	NE	NB	NB

OVS: Output Voltage of Sensor

4. AN MLS EXPERIMENT

4.1 Magnetic Levitation System

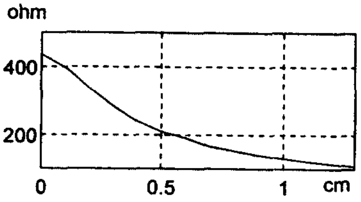

Fig. 5. CdS resistive characteristics

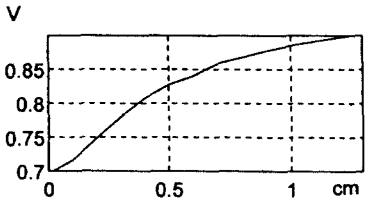

Fig. 6. CdS voltage characteristics

4.2 Experimental results

The metal ball movement due to the step reference signal with a PD controller only is shown in Fig. 7. It can be adjusted using the added zero location and the amplifier gain.

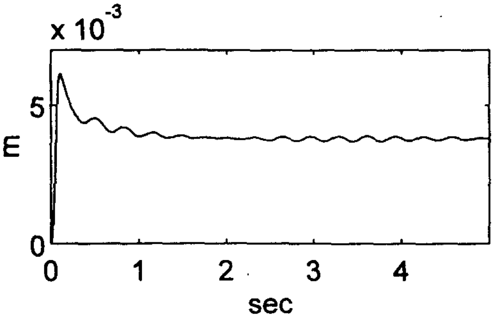

Fig. 7. Step response when PD is used

Unsatisfactory large overshoot and oscillation continues in output response in Fig. 7. It is due to the system design value of operating point, x_0=1.3 cm, but the real output value is set at x=0.4 cm. Fig. 8. and Fig. 9. show the step and sinusoidal output responses when PD+FLC controller is used. It is clear that the transient and steady state performance improves in the sense of reduced oscillation.

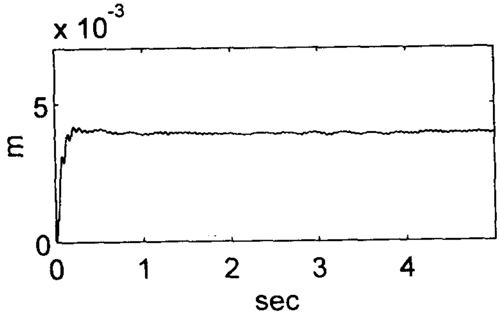

Fig. 8. Step response when PD+FLC is used

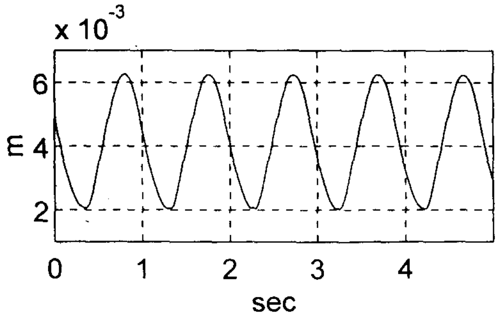

Fig. 9. Sinusoidal response when PD+FLC is used

5. CONCLUSION

To overcome the adverse characteristics of nonlinearity, unstability, system parameter variation, etc. in MLS, a control algorithm based on PD+FLC is used. A coarse framework of output performance is provided to the system by using a PD type compensator. Then a fine regulation to the performance requirement is obtained by the fuzzy logic control action.

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