Lab 4: Magnetic Levitation

I. Objective

The goal of this project is to design an analog controller for the system shown in figure 1. **We want to design an analog compensator such that the DC gain is 1 A/1 mm and the phase margin is 60 degrees.**

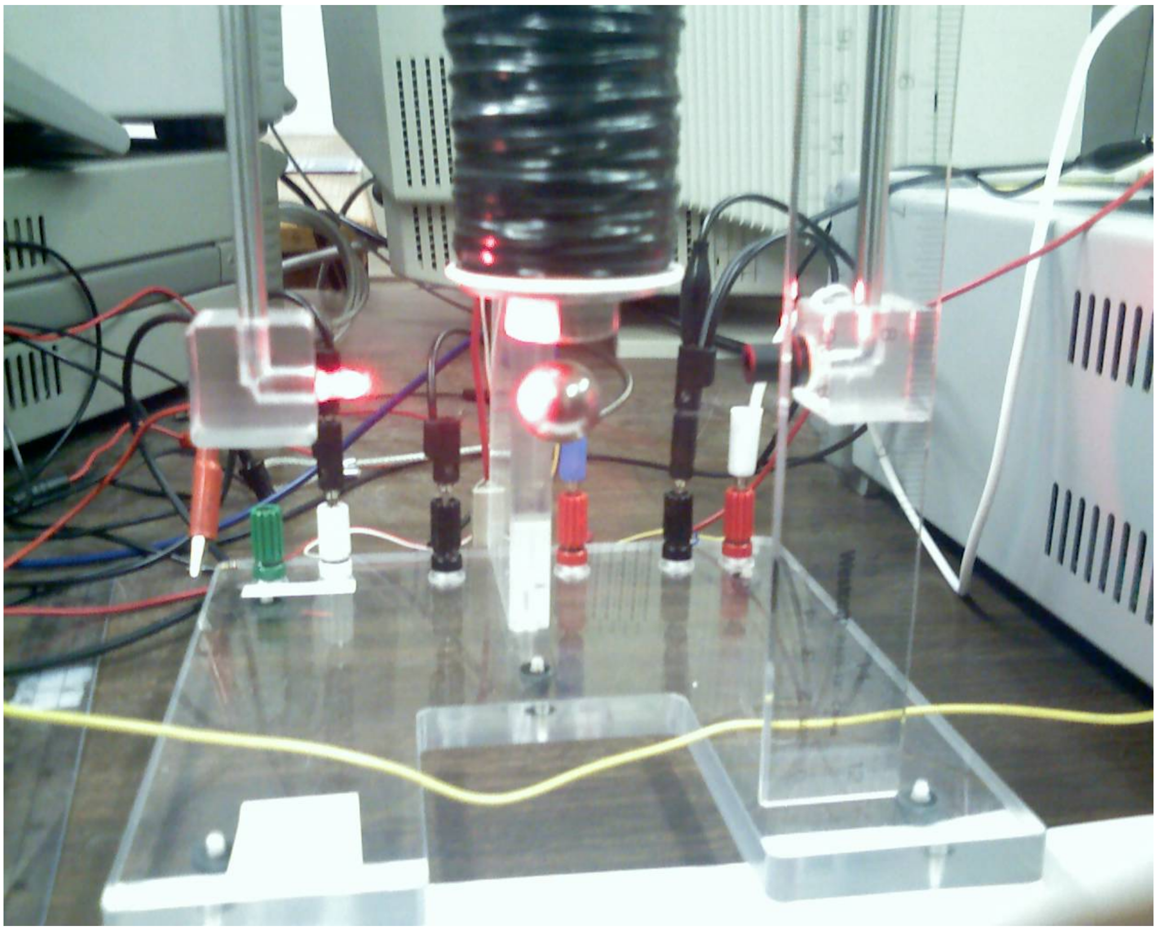

Figure 1: Magnetic Levitation System

II. Software and equipment

1. Computer with MATLAB and Simulink (any in lab)
2. ee128 student account
3. Magnetic Levitation System
4. DC power supply
5. Current amplifier

III. Theory

1. System setup and block diagram

A high level block diagram of the system is shown in figure 2:

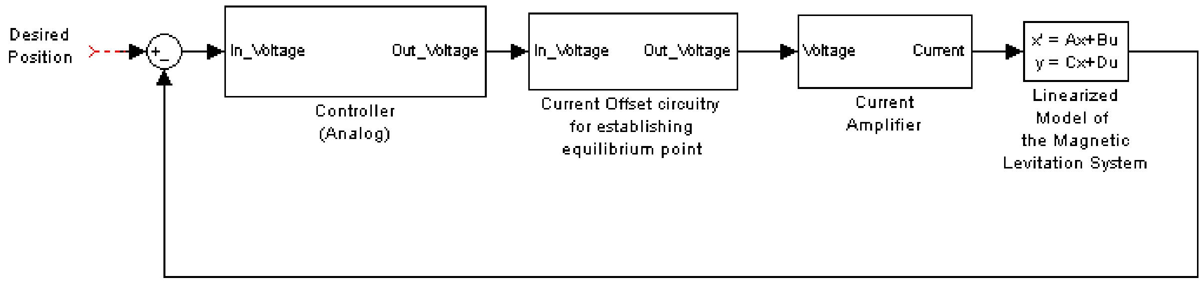

Figure 2: Block diagram of our system

Figure 3 shows the block diagram with circuit level details [1].

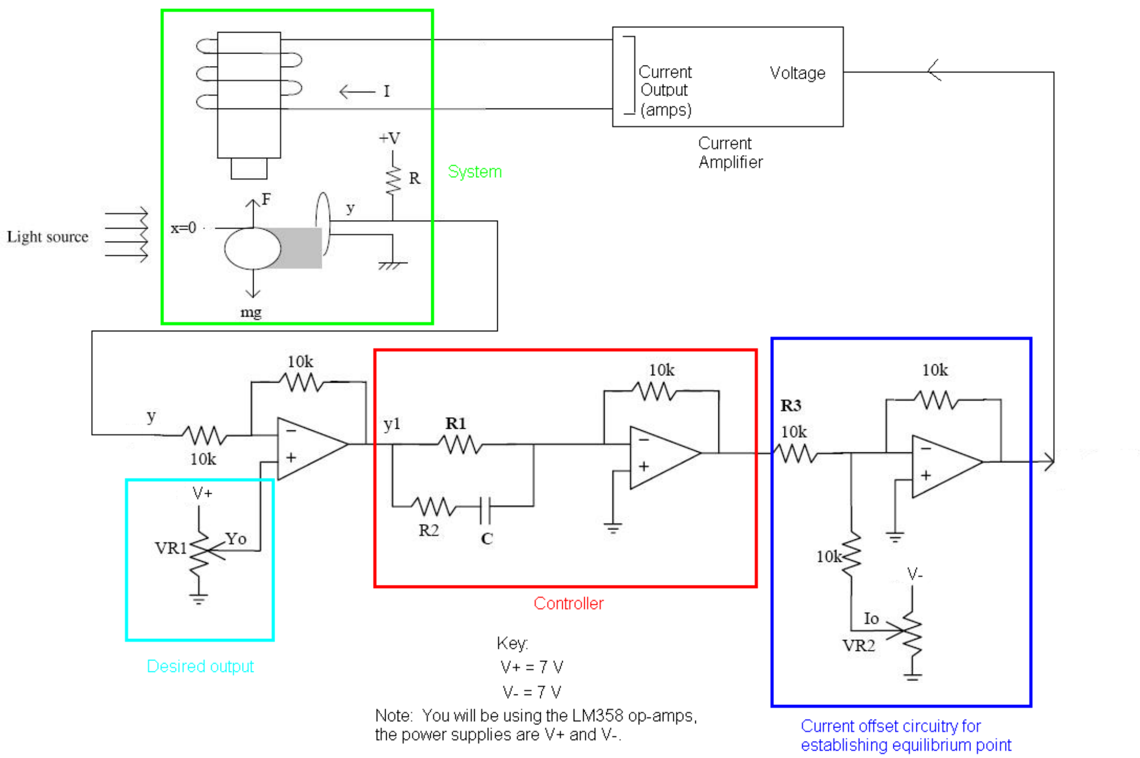

Figure 3: You will be picking values for R1, R2 and C for stable equilibrium

2. System modeling

The equations of motion of the ball are [1]:

$$m\frac{d^2x}{dt^2} = f(I,x) - mg$$
$$y = h(x)$$

where:
- $\boldsymbol{x}$ – ball vertical position (m)
- $\boldsymbol{m}$ – mass of ball (kg)
- $\boldsymbol{g}$ – gravitational constant (m/s^2)

$\boldsymbol{I}$ – current (A)
$\boldsymbol{f(I,x)}$ – magnetic force (N) as a nonlinear function of x and I
$\boldsymbol{y(x)}$ – output voltage (V) as a nonlinear function of x

You will need to do a system identification process in order to determine the system model. This is unlike your previous labs where you were given the system parameters.

You will notice that the most difficult part of the project is the system identification. But the point of the project is to expose you to control systems design in the real-world, so the effort is worth it!

IV. Prelab

1. Week 1

For week 1, there is no prelab.

2. Week 2

1. Derive the transfer function of your system based on your data from week 1.
2. Plot the open-loop pole-zero diagram of your system.
3. Based on the open-loop pole-zero plot of your system, decide if you need a lead or a lag compensator.
4. From your lab data, you know the DC gain of your controller.
5. Now, design the controller to meet the specifications from the objective.

V. Lab

1. Week 1

In lab, you will identify the parameters for the magnetic levitation system and come up with the system model.

1. The $x = 0$ position should be set at about 6 mm from the bottom of the electromagnet. [1]
2. Remember to have proper SI units (example: convert grams to Newtons).
3. Measure the range of variation of the resistance of the photo-resistor as the ball's shadow covers from none to all of the resistor surface. Using this data, determine a suitable resistor value R to use in series with the photo-resistor (see figure 3, V_+ = 7 V and the photo-resistor is rated @ 250 mW power dissipation). [1]
4. To find $h(x)$: Move the ball over the entire range (shadowing from none to the entire photo-resistor surface). Record the output voltage y versus ball position x. Plot the data and find the slope of the curve at $x = 0$. [1]
5. To find $f(I,x)$: Find out the value of I that renders 0 N at the position $x = 0$. Then, take force readings about $x = 0$ and $I = I_o$. [2] That is:

$$\begin{aligned} m\frac{d^2x}{dt^2} &= f(I,x) - mg \\ &= f(I_o,x) + K_i i + K_x x - mg \\ &= K_i i + K_x x \end{aligned}$$

Thus, the linearized model of your system is:

$$\frac{d^2x}{dt^2} = \frac{K_x}{m}x + \frac{K_i}{m}i$$
$$y = ax$$

6. The DC gain of your system is the gain of your controller (K_p) multiplied by the gain of the current amplifier (K_a). Notice the gain from the offset circuitry **should not** be included in the model (Why?). Now, we want the DC gain of our circuit to be 1 A/mm. Experimentally determine K_a (should be approximately 1 A/V) and then use this to find K_p such that $K_p * K_a = 1$ A/mm. [1]

7. Week 2

Implement the controller that you designed for your prelab. To balance the ball [1]:

1. Place the ball at the zero position. Adjust the pot in the first amplifier in figure 3 such that $y_1 = 0$.
2. Now remove $R_3 = 10k$. Adjust the pot in the current offset amplifier such that the ball is just balanced by the electromagnet. Now, re-install R_3 and slowly remove the support.

VI. Revision History

Semester and Revision	Author(s)	Comments
Fall 2008 Rev. 1.1	Justin Hsia	Reformatted write-up
Summer 2008 Rev. 1.0	Bharathwaj Muthuswamy	1. Formatted write-up into different sections. 2. Typed up solutions

VII. References

1. Lab 5 and Lab 6 handout from EE128 fall 2006.
2. Franklin, Gene F., Powell, David J. and Emami-Naeini Abbas. *Feedback Control of Dynamic Systems.* 5th Edition. 2006, Prentice-Hall Inc.