

**King Fahd University of Petroleum & Minerals**  
**Department of Electrical Engineering**

EE 380 – Control Engineering

Experiment # 9

**Magnetic Levitation System**

**OBJECTIVES**

1. To study the Magnetic Levitation Systems.
2. To use the MLS to study an analogue control strategy based on classical lead controllers.

**APPARATUS**

1. Feedback Magnetic Levitation System consisting of
  - a. The 33-210 levitation unit
  - b. The 33-301 Analogue Control Interface module
2. IBM Compatible PC.
3. Storage Oscilloscope or X-Y Plotter.

**INTRODUCTION**

Magnetic Levitation Systems [MLS] have gained considerable interest due to their great practical importance in many engineering fields. From the control engineering point of view, an MLS is a quite complex system since it presents nonlinearities and it is naturally unstable, in the sense of BIBO. The easiest way to handle this system is to consider only small variations around a given operating point. This allows one to apply all the well-established arsenal of linear control systems.

Model and Parameters

The Magnetic Levitation System experimental laboratory setup is represented in Figure 1.

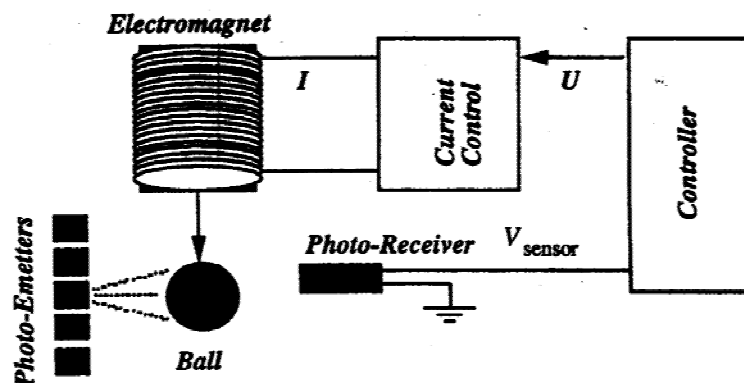


Fig. 1 Magnetic Levitation System

The controller consists of a lead compensator with the possibility to change its characteristics (bandwidth, gain, etc.). It is also possible to implement a controller, using computer driven software.

The photo-sensor to measure the ball position is infrared-based. It allows the measurement of the distance of the ball from the electromagnet by providing a voltage  $V_{sensor}$  such that :

$$V_{sensor} = -\gamma (X - X_o), \quad \gamma > 0$$

Where  $X_o$  is the nominal operating point.

Therefore, since  $V_{sensor} = 0$  for  $X = X_o$ , we get

$$\Delta V_{sensor} = -\gamma \Delta X$$

The current  $I$  through the electromagnet is controlled by an inner-loop and is related to the voltage controller output  $U$  by the expression

$$I = 0.15U + I_o$$

Where  $I_o$  is the nominal current corresponding to the nominal operating ball position  $X_o$ .

Therefore, the relation between current variations and control variations is

$$\Delta I = 0.15 \Delta U$$

The displacement of the ball is governed by the following electromechanical equation:

$$m \ddot{X} = mg - k \frac{I^2}{X^2}$$

Where

- $m$  is the mass of the levitated object which is a ball
- $g$  denotes gravity
- $X$  is the distance of the ball from the electromagnet
- $I$  is the current through the electromagnet
- $k$  is a coefficient

The voltage  $U$  will constitute the control variable of the Magnetic Levitation System, i.e. the output of the controller.

The above nonlinear model can be linearized around the nominal operating point  $(X_o, I_o)$  as

$$m \Delta \ddot{X} = \lambda \Delta X - a \Delta U$$

where  $\Delta I$  has been substituted by  $0.15\Delta U$ .

This yields the following transfer function

$$\Delta X(s) = -\frac{a}{ms^2 - \lambda} \Delta U(s); \quad a = \frac{0.3kI_o}{X_o^2}; \quad \lambda = \frac{2kI_o^2}{X_o^3}$$

The constant  $k$  can be determined from the equilibrium conditions around  $(X_o, I_o)$  which are given by setting the derivatives of the nonlinear model equation to zero yielding

$$mg = k \frac{I_o^2}{X_o^2}$$

which gives  $k = \frac{mgX_o^2}{I_o^2}$

Finally, the transfer function  $G(s)$  of the considered system is

$$G(s) = \frac{\Delta V_{\text{sensor}}(s)}{\Delta U(s)} = \frac{a\gamma}{ms^2 - \lambda}$$

### Analogue Control

The analogue controller consists of a lead compensator with the transfer function:

$$C(s) = \frac{1 + s\frac{1}{c}}{1 + s\frac{1}{d}}; \quad 0 < c < d$$

The maximum phase lead provided by  $C(s)$  is

$$PM = \sin^{-1} \frac{\frac{d}{c} - 1}{\frac{d}{c} + 1} \quad \text{which occurs at } \omega_M = \sqrt{cd}$$

with this compensator, the open-loop transfer function of the controlled system is

$$C(s)G(s) = \frac{a\gamma}{ms^2 - \lambda} \frac{d}{c} \frac{s+c}{s+d}$$

To obtain the phase margin  $PM$ , we have

$$\frac{a\gamma}{m\omega_0^2 + \lambda} \frac{d}{c} \frac{\sqrt{\omega_0^2 + c^2}}{\sqrt{\omega_0^2 + d^2}} = 1; \quad PM = \tan^{-1} \frac{\omega_0}{c} - \tan^{-1} \frac{\omega_0}{d}$$

In the Magnetic Levitation System, the transfer function of the lead-compensator is under the form

$$C(s) = K \frac{1 + s \frac{1}{\omega_1}}{1 + s \frac{1}{\omega_2}}$$

$K$  being the controller gain and

$$\omega_1 = \frac{1}{a}, a = R_1 C_1, \omega_2 = \frac{1}{b}, b = R_2 C_2$$

### Initial Set-Up

#### For ANALOG OPERATION

1. Place the 33-210 levitation unit on a level surface and allow sufficient room for the 33-301 Interface module, PC and mouse. Plug the mains power lead into the rear of the 33-210.
2. The system is capable of operation without any control software in stand alone mode.
3. Connect the Control output socket directly to the drive input socket. Set the Gain control to its midway position. Connect a Digital Voltmeter between the Set Point socket and ground and adjust the Set point control until DVM reads approximately 0V. Place one of the spheres in the position shown in Fig. 1 and verify that the sphere levitates. [N.B. Ensure that the detectors are not obscured by your hand when placing the sphere.]

#### For COMPUTER CONTROL

4. Before the 33-210 can be operated via MATLAB, It is necessary to connect up the 33-301 Interface module to the PCL-812 Advantek Card using connector CN2 (when you view the Advantek Card fitted into a PC, CN2 is the lower connector). The connectors are keyed and can only be inserted one way.
5. Familiarize yourself with the front panel of the 33-210. Ensure that the supplied RC network is fitted to the Network 1 position and the resistive network fitted to Network 2. The RC network has a 1mF capacitor in series with a 100W resistor and Network 2 is a 22kW resistor. Refer to Fig. 2 which shows the correct connections.
6. On the 33-210, remove the connection between "control output" and "Drive i/p", and connect  
 "DA1" to "Drive i/p",  
 "AD2" to "Control o/p",  
 "AD1" to "Measured value", and  
 "DA2" to "disturbance input".
7. Connect  $\pm 15$  V and the ground sockets on the 33-301 and the 33-210 together, observing polarity.

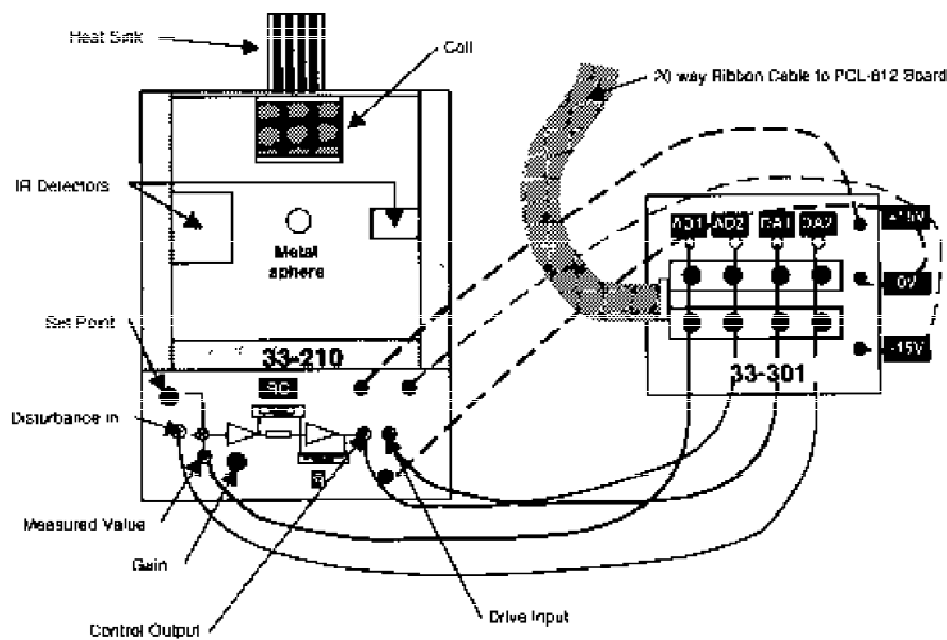


Fig. 2 The MAGLEV system, showing the 33-210 levitation unit and the 33-301 Interface module with lead connections.

## PROCEDURE

The ANALOG CONTROLLER can be used with computer interface to generate desired trajectories and to collect data. This task is achieved by MAGLEV software.

1. Start MATLAB and type "ml" at the command prompt . Main menu of MAGLEV software will appear.
2. Double click on the "Parameters of the Controller", then select the "Discr.Analog" radio button followed by "start Alg".
3. Double click on the block "Internal Generator" to set the desired reference signal for the metallic ball. Choose "square" signal and adjust its parameters:

period 1 = 1	period 2 = 1
period 3 = 1	period 4 = 1
level 1 = 0.5	level 2 = 0
level 3 = 0.5	level 4 = 0

4. To pass the above values to real time Kernel, click on "set".
5. To view the system responses, click on "Stethoscope". Press "Get data buffer". Now select "Plot position of the ball" and "Plot desired position. Press "collect data (10 secs)" and wait for 10 seconds. Plots of the desired position and the current position of the ball will appear on the stethoscope.
6. To print these results, switch to MATLAB command prompt and type "ml\_read" (to save data) and then type "ml\_plot". A MATLAB figure will appear which can be printed.

7. Repeat for different excitation signals e.g., triangular, random, and sinusoidal. [Note: select appropriate input parameters]. Obtain the print out of the results in each case.

### **DISCUSSION**

1. Show your result neatly. Give the history of each experiment on a separate sheet of paper and align all your plots vertically.
2. Describe the influence of the Gain on the dynamics and the position error.