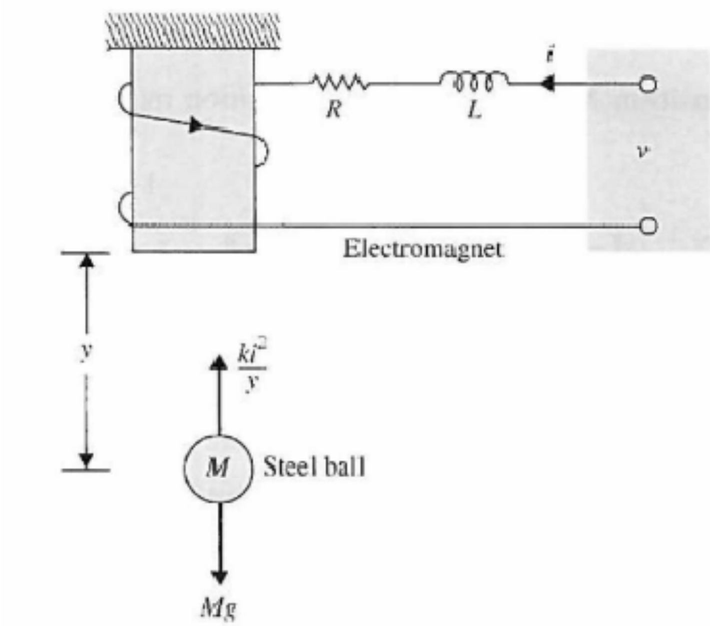
Project: Magnetic Levitation



Consider the magnetic-ball suspension system shown in the figure. The objective of the system is to keep the steel ball suspended at a fixed distance from the end of the magnet by controlling the current of the electromagnet, $i(t)$, using the input voltage $v(t)$. The dynamic equations of the system are

$$M\frac{d^2y(t)}{dt^2} = Mg - \frac{ki^2(t)}{y(t)}$$

$$v(t) = Ri(t) + L\frac{di(t)}{dt}$$

(Note that these equations are different from those provided in the notes.) The state variables are defined as:

$x_1(t) = y(t), x_2(t) = \frac{dy(t)}{dt}$, and $x_3(t) = i(t)$

The system parameters are as follows:
$R = 1\Omega$, $M =$ ball mass $= 1$ kg, factor $k = 1$, $L = 0.01$H, and $g = 9.8\text{m/sec}^2$. The equilibrium point is $y_0 = 0.5$m.

Obtain expressions for $\frac{dx_1(t)}{dt}$, $\frac{dx_2(t)}{dt}$, and $\frac{dx_3(t)}{dt}$ as a function of x_1, x_2, x_3, and input v. Linearize the system equations around the equilibrium point ($y_0 = 0.5$m). Define new state variables Δx_1, Δx_2, and Δx_3 as the original state variables minus the equilibrium values. That is, $\Delta x_1 = x_1 - x_{10}$, $\Delta x_2 = x_2 - x_{20}$, and $\Delta x_3 = x_3 - x_{30}$,

* This project was developed by Dr. Ahmed Sultan for the EE391 course (2008-2009)

where x_{10}, x_{20}, and x_{30} are the equilibrium values of x_1, x_2, and x_3, respectively. Note that, at equilibrium, the derivatives with respect to time are equal to zero. In the linearized equations for $\frac{d\Delta x_1}{dt}$, $\frac{d\Delta x_2}{dt}$, and $\frac{d\Delta x_3}{dt}$, use $\Delta v = v - v_0$, where v_0 is the value of the input at equilibrium.

For reason of economy, we can install <u>one sensor only</u> in the system to directly measure only one of the state variables. Design a state feedback controller such that state observer has poles at -100, -101, and -102. The controlled system should have one pole at -20. The other two poles are complex conjugate and must be chosen in the region $-10 \leq \text{Re}(s) < 0$, and $-10 \leq \text{Imag}(s) \leq 10$. Assume that Δx_1, Δx_2, and Δx_3 start with a value of 0.05. (Since $\Delta x_1(0) = 0.05$m, this means that the initial position of the magnetic ball is 0.05 m away from the equilibrium position.) Also assume that the initial state estimation errors are all equal to -0.1 (negative 0.1). The design specifications are:

(a) Maximum deviation from equilibrium position should not exceed 0.055m.

(b) Settling time (2 percent) should be less than 0.45 sec. Settling time here is defined as the time beyond which the absolute difference between position and the point of equilibrium is always less that a certain fraction (2% in our case) of the peak value. Matlab instruction 'lsiminfo' can be used to get the peak response and settling time.

1. <u>Your Matlab code should include **how** you get the C matrix of the system and the two complex conjugate poles</u>.

2. Your Matlab file should start with the following four lines:

```
% Name:
% Section:
%Seat Number:
clc;clear all;close all;
```

If your code does not include these four lines, your project will not be considered.

3. In your code, the matrices of the linearized system should be named A, B, C, and D. The pole with positive imaginary part that satisfies the design constraints should be called desired_pole, the settling time variable should be named settling_time, and the maximum deviation variable should be named maximum_deviation. <u>Print out on the screen all these variables</u> in the order: A, B, C, D, desired_pole, settling_time, and maximum_deviation. (Just write the name of each variable on a line alone at the end of your code.)

4. Your output should include <u>one figure only</u>. Draw the deviation of the position of the ball from equilibrium (using black color) as a function of time from 0 to 0.8 sec. On the same figure, draw the deviation of position (using red color) assuming perfect knowledge of the state variables (i.e., the controlled system without observer and assuming that the states are perfectly known).