Magnetic Levitation System

The ECP Magnetic Leviation (MagLev) design (See Fig. 1) features two high field density rare earth magnets and high flux drive coils to provide more than 4 cm. of controlled levitation range. Laser sensors provide non-contacting position feedback and incorporate proprietary conditioning electronics for signal noise reduction and ambient light rejection. The MagLev apparatus may be quickly transformed into a variety of single input single output (SISO) and multi-input multi-output (MIMO) configurations. By using repulsive force from the lower coil to levitate a single magnet, an open loop stable SISO system is created. Attractive levitation via the upper coil affects an open loop unstable system. Two magnets may be raised by a single coil to produce a SIMO plant. If two coils are used a MIMO one is produced. These may be locally stable or unstable depending on the selection of the magnet polarities and the nominal magnet positions. The plant has inherently strong nonlinearities due to the natural properties of magnetic fields. These may be compensated for in feedforward using derived or provided algorithms so that the control problem may be approached as that of a linear or nonlinear system depending on the desired course of study. Thus this dynamically rich system provides a testbed for experiments ranging from demonstration of fundamental principles to advanced research.

Checkout Procedure

Step 1: With power switched off to the Control Box, enter the ECP program by double clicking on its icon. You should see the Background Screen. Turn on power to the control box - you should see its green LED illuminate[1]. Verify that the magnet is stationary (not levitated) and neither of the coil current LED's on the apparatus are illuminated. The laser sensors should illuminate the magnet in a thin red line on both the upper and lower magnet surfaces.

Step 2: Gently raise the magnet by hand (touch the edges only with clean hands and do not obstruct the laser beam). You should observe a change in the Sensor 1 counts. (The sensor is in an uncalibrated mode. The Sensor 1 value should equal 30000 ± 5000 counts and decrease as you lift the magnet. The Sensor 2 value should equal 0 ± 2000 counts and increase as you lift the magnet.) The Control Loop Status should indicate "OPEN" and the Drive 1 Status, Drive 2 Status, and Servo Time Limit should all indicate "OK".

[1] It is necessary for the Control Box to be powered in order for the sensors to operate.

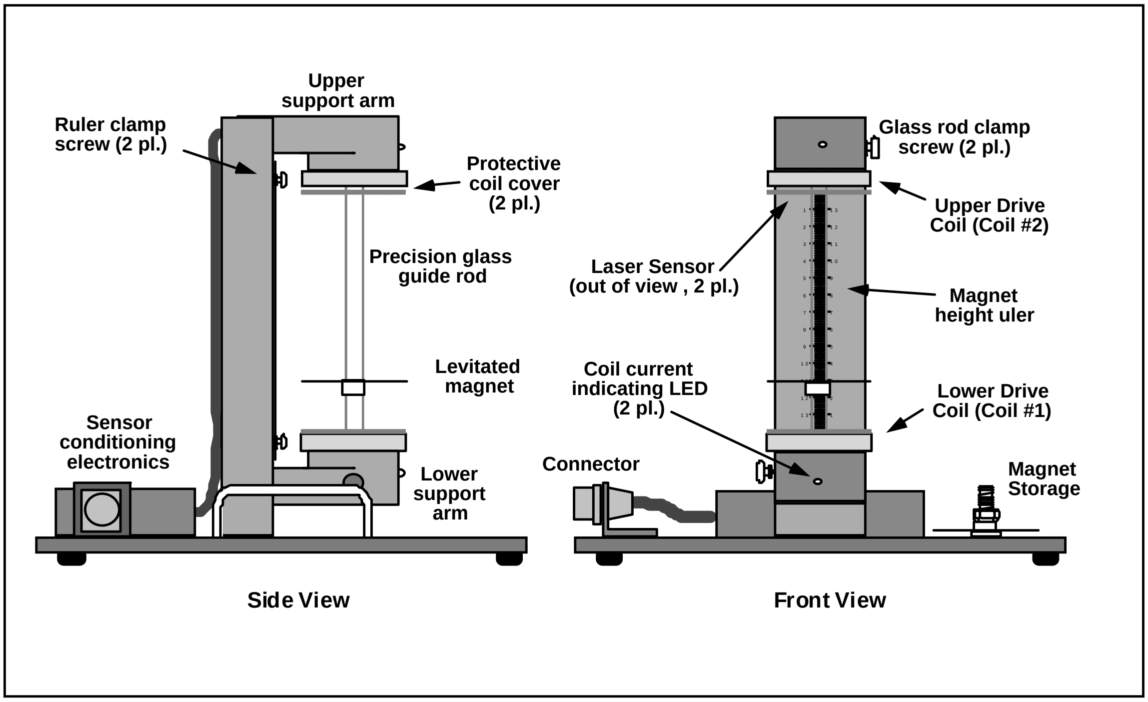

Figure 1: ECP Magnetic Levitation Experiment

<u>Introduction Exercises</u>

A. Read the safety information for the Magnetic Levitation Experiment in Chapter 2 of the equipment manual (See also Appendix B on the course website).

B. Identify the control elements and signals in the MagLev Experiment*.

Sensor:	Actuator:
Controller:	Reference Input:
Actuator Output:	System Output:

*Refer to the Introduction Literature.

<u>Experiment 6.1: System Identification</u>

Follow the procedure in Section 6.1.1of the ECP Manual to calibrate the sensor. Note: Calibration measurements should be taken off the top surface for sensor 1 and from the bottom surface for sensor 2. This may require that the ruler (on the test rig) be adjusted such that the height at the zero position is measured as zero on the ruler.

Use the following table for calibration data:

Neglect measurements with Sensor #2

Table 6.1-1 Sensor Calibration / Linearization Data			
Magnet Position for Sensor #1 (cm)	Y_{1raw} (Sensor 1, counts)	Magnet Position for Sensor #2 (cm)	Y_{2raw} (Sensor 2, counts)
0.00		0.00	
0.50		-0.50	
1.00		-1.00	
2.00		-2.00	
3.00		-3.00	
4.00		-4.00	
5.00		-5.00	
6.00		-6.00	

Follow the procedure in 6.1.2 to gather the data needed to complete the table below.

Table 6.1-2 Actuator Calibration / Linearization Data	
Magnet Position (cm)	u_{1raw} (Uncompensated Control Effort, counts)
0.00	
	4000
	5000
	6000
	8000
	10000
	12000
	14000
	18000
	22000

Do Exercise A and find the coefficients e, f, g, and h for both sensors. Use the MATLAB program sensocal.m to calculate the coefficients; once determined write the determined coefficients in the table below. Note: In the instructions for Exercise A, after the first equation is given, the sentence should read "…having units 10,000 times smaller." Print out the curve-fitting plot generated by the Matlab program and include it in your report.

Ignore e*, f*, g* and h* entries.

Calibration Coefficients				
Sensor #1	e* =		e =	
	f* =		f =	
	g* =		g =	
	h* =		h =	
Sensor #2	e* =		e =	
	f* =		f =	
	g* =		g =	
	h* =		h =	

Experiment 6.2: PD Control of the system to an equilibrium point

This section will explore the control of a nonlinear system using a simple linear proportional and derivative (PD) controller:

$$C(s) = k_p + k_d s$$

where k_p is the proportional control gain and k_d the derivative control gain.

You will use and modify the control program given below to conduct the experiment. A copy of the program in this structure (Program Files\ECP Systems\MV\6.2.alg) is stored in the PC that you can load in and modify according to various steps of the experiment.

```
;*****************DECLARE VARIABLES******************
#define y1cal q2
#define y1rawo q3
#define kp q4
#define kd q5
#define kdd q6
#define Ts q7
#define y1str q8
#define pos_last q15
#define u1str q16
#define u1o q17
#define u1 q18
;**********************INITIALIZE*********************
Ts = 0.000884 ;must also set Ts in dialog box.
control_effort1 = 0
control_effort2 = 0
;Specify Parameters
u1o = 5000 ;gravity feedforward
y1rawo = 13000; sensor#1 reading at static equilibrium corresponding to u10 value above
kp = 0; proportional control gain
```

```
kd = 0; derivative control gain
kdd = kd/Ts
;*************BEGIN REAL-TIME ALGORITHM**************
begin
y1str = sensor1_pos-y1rawo; position error
u1str = kp*(y1str) +kdd*(y1str-pos_last) ;CONTROL LAW
pos_last = y1str
u1 = u1str + u1o ;Add gravity offset
control_effort1 = u1
q10 = -y1str ;reverse polarity for plotting
q11 = -cmd_pos ; reverse polarity for plotting
end
```

(1) Set kp and kd to zero and control effort u1o to 5000 in the program. Run the program to observe the disk to reach its equilibrium position. Press the disk down to the bottom (or raise it up) and then let go a couple of time to feel and observe how the system responds.
Rotate the magnetic disk slightly to free it up from possible static friction that may prevent it from reaching its equilibrium. Then take the following readings from the PC:

Disk equilibrium position from the bottom plate = ______ cm
Sensor#1 accounts = ____________
Control_effort1 = _________ volt

Use the data acquisition of the PC system to record and plot two seconds of the motion of the disk with the disk pressed down against the bottom plate to begin with:

Plot of the disk response on Page ____
Estimate the time to settle into equilibrium = ______ sec.
Estimate the frequency of the response = _____ Hz

(2) Edit your control program by entering the sensor value above into the program as y1raw0. Next, set kp to a small positive value such as 0.1 to examine the effect of a proportional control of the system. Run the program to observe the disk to reach its equilibrium position. Press the disk down to the bottom (or raise it up) and then let go a couple of time to feel and observe how the system responds.
Briefly describe below how the system responds compared to that in (1):

(3) By trial and error with the program, determine the maximum value of kp to make the system vibrates up and down like an undamped free vibration when you press the disk down (or raise it up) and let it go. A larger kp than this would make the system unstable with the disk bang-bang the bottom plate (some gentle touch is OK). Use the data acquisition of the PC system to record two seconds of the free vibration with the disk pressed down against the bottom plate to begin with.

max. kp = _______
Plot of the "undamped" vibration on page ____
From the plot, determine the frequency of the vibration = _____ Hz
Note the difference of the frequency from that in (1): faster ____ or slower ____

(4) Finally, explore how the addition of the derivative control component may stabilize and damp out the free vibration observed in the last step of proportional control alone. You may try a small positive value for kd such as 0.0001 to begin with and observe its effect on the free vibration when you press down or raise up the disk. Then you increase the kd value to a point where the free vibration will damp out most quickly and reach the equilibrium fairly fast. If you use too large a kd value, it would cause the control effort to go over the limit. Experiment this and determine what you consider the best kd value for the stabilization. Use data acquisition to record the damped response with the disk pressed down against the bottom plate to begin with.

Best kd = _______
Plot of the damped vibration in Page ____
Estimate time to settle into equilibrium = ______ sec.
If measurable from the plot, estimate the frequency of the vibration = _____ Hz
Note the difference of the settling time from that in (1): longer ____ or shorter ____
Note the difference of the frequency from that in (3): lower ____ or higher ____