6.302 Feedback Systems

Spring Term 2008   Issued : April 22, 2008
Maglev Design Problem   Due : Friday, May 9, 2008

The purpose of this lab is to build and improve a small magnetic levitation (maglev) system. You will be given a kit to build the basic system (which you can keep after checkoff). After building the basic system, you will evaluate the dynamics of the system and design a compensator for it. You are encouraged to also improve other aspects of the system, such as the sensor, the electromagnet, the electronics, and the levitated object. This lab is an open-ended design project, so be creative!

Basic System Construction

The structural features of the basic maglev system are shown in Figure 1. The schematic of the drive electronics is shown in Figure 2. The kit you will receive includes all of the parts shown in the schematic (and listed in Figure 3), but does not include the wooden stand or the object for levitation (you will have to provide your own). For this lab, you will need to build the basic system as shown in the figures.

This kit is based on a low-cost design developed by Guy Marsden [1, 2]. In the basic system, the position of the levitated object is sensed by the SS495 Hall-effect sensor. The output voltage of the sensor drives the input of the MIC502 fan-management chip. The fan-management chip produces a pulse-width modulated (PWM) drive signal to the LMD18201 H-bridge chip. This PWM signal adjusts the average current in the solenoid, which controls the magnetic field.

Please use care in the construction of your system. Read the data sheets for each IC in the schematic to familiarize yourself with the behavior and operation of the circuit. While the EECS Department and National Semiconductor have been generous in making these kits available to you, we cannot afford to donate large numbers of parts to you. We will expect every student who receives a kit to complete the lab. While we will be tolerant of reasonable but destructive errors, we have only a very small supply of spares. Build carefully!

Testing

For the basic system to work, the polarities of the solenoid, the sensor, and the magnet must all be correct. When correct, you should notice that the solenoid repels the magnet when the magnet is too close. You may have to experiment with the polarity of the solenoid winding, the placement of the sensor, and the orientation of the magnet.

An ammeter can assist in verifying correct operation. The input current should be large (up to 0.5 A) if the magnet is too far from or too close to the solenoid. At the operating point, the current consumption for this kit is around 100 mA.

The correct behavior is also very sensitive to the weight of the levitated object. The actual lifting capability of the basic system is very small (about half-a-pencil with the magnet). Be prepared to experiment.

Compensation

Evaluate the dynamics of the system and design a compensator for it. To evaluate the transient behavior of the improved system, you will need to modify the circuit to provide an input signal, as shown in Figure 4. Measure the step response of the system to small input steps.

Due to the PWM drive to the electromagnet, the output of the sensor may include a lot of ripple. You may wish to filter out this ripple with a low-pass filter before the oscilloscope. Note that this filter does not go inside the feedback loop (for obvious reasons), but goes between the sensor output and the scope.
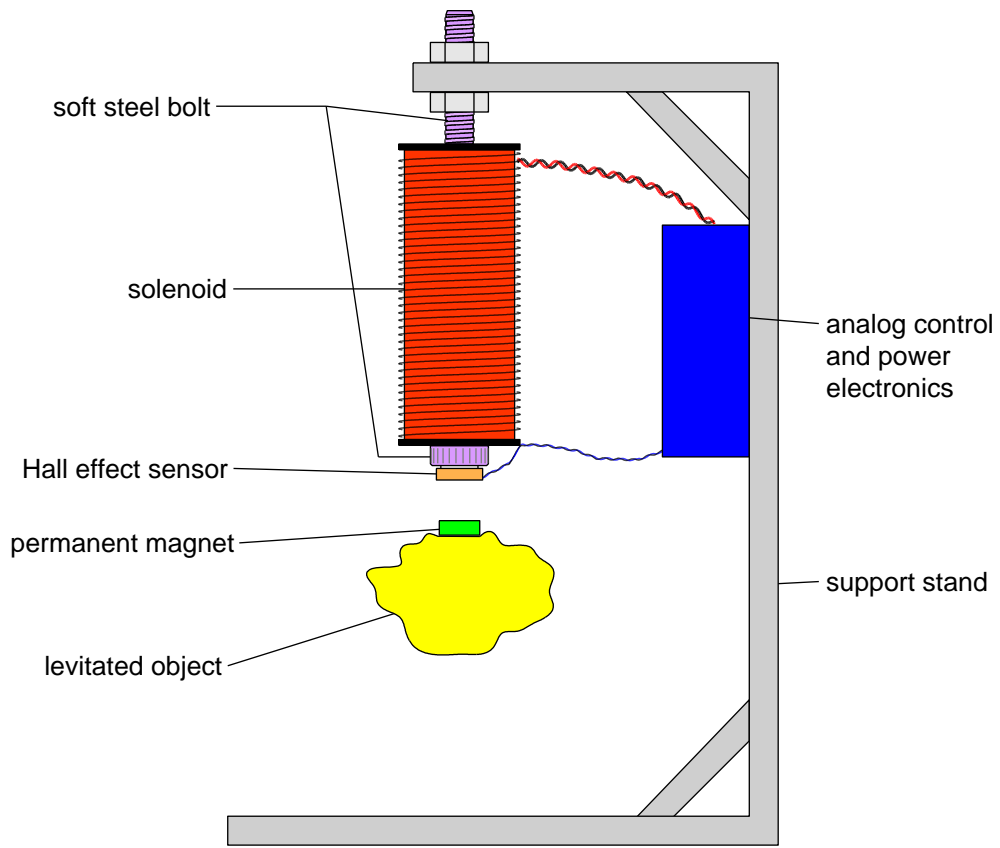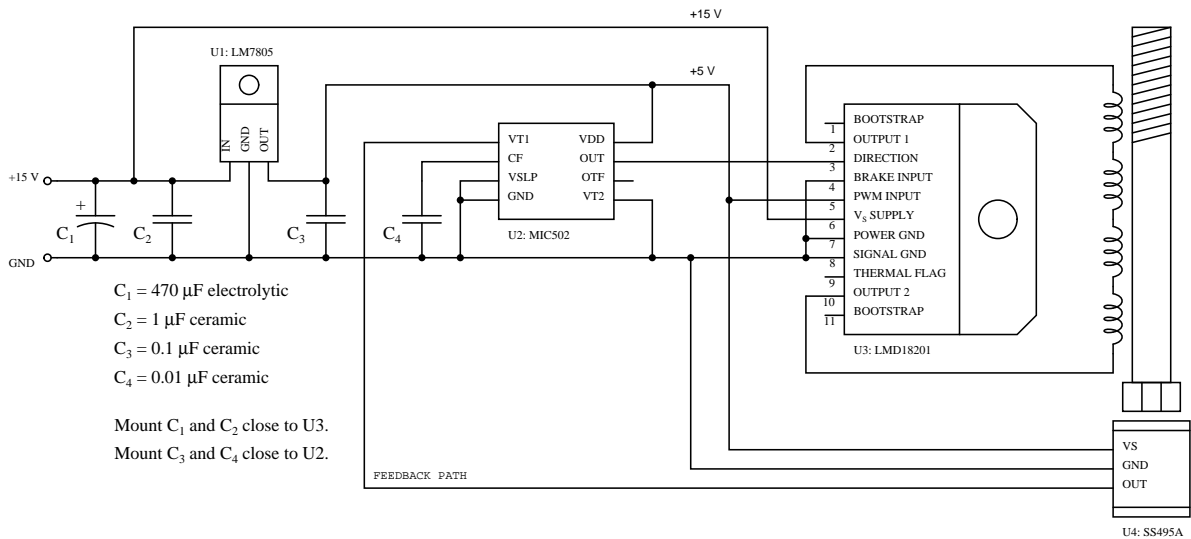
Figure 1: An assembled magnetic levitation system

Figure 2: Schematic of magnetic levitation system

|		
U1	LM7805	voltage regulator
U2	MIC502	fan-management IC
U3	LMD18201	motor H-bridge IC
U4	SS495A	Hall-effect sensor
C1	470 μF	electrolytic capacitor
C2	1 μF	ceramic capacitor
C3	0.1 μF	ceramic capacitor
C4	0.01 μF	ceramic capacitor
	prewound solenoid	
	soft-steel carriage bolt	
	neodymium magnets (2)	
	heatsink for LMD18201	
	small circuit board	

Figure 3: List of kit contents
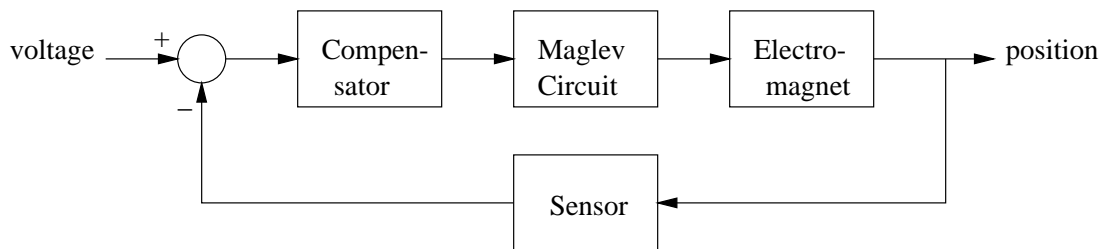
Figure 4: Block diagram of modified magnetic levitation system

Design a simple dominant-pole, lag, or lead compensator to stabilize the system and improve the transient response. Design for a peak overshoot of less than 20% in the step response.

Modifications

You are encouraged to improve other aspects of the system. Modifications to consider include sensor selection and placement, the electromagnet size and design, the characteristics of the levitated object, and the design of the power electronics.

For example, one aspect of the design which can be improved is the position sensor. The Hall-effect sensor detects the strength of the magnetic field produced by the magnet on the levitated object. However, because the Hall-effect sensor is directly below the electromagnet, its output will depend not only on the the distance between the sensor and the permanent magnet but also on the strength of magnetic field generated by the solenoid.

The large maglev system analyzed in lecture uses a photo-detector to sense position [3, 4]. In this approach, the steel ball levitates between a collimated light source and the photo-detector to produce a shadow, as shown in Figure 5. This sensor scheme is simple and reliable and can produce a close-to-linear estimation of position. However, it requires careful alignment and additional parts, including a light bulb or LED, a photo-detector (CdS cell), focusing optics, and assorted electronics.
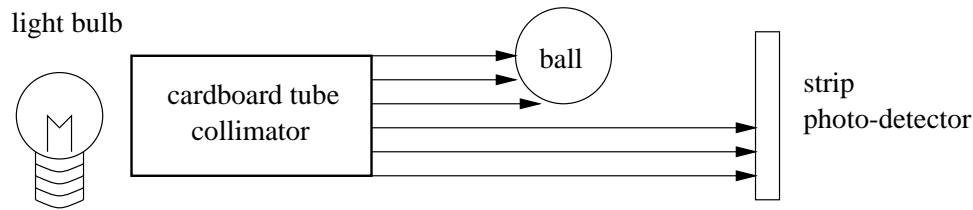
3

Figure 5: Diagram of simple light sensor system

Lab Report

Write a report that completely documents your design. In particular,

1. Describe your efforts to evaluate, characterize, and model the basic system. Provide bode plots and transfer functions, if appropriate.

2. Document all changes that you made to the basic system, such as sensor type and location, the electromagnet coil design, the type of levitated object, the power electronics, and (of course) the compensator.

3. Provide complete schematics of any circuitry that you changed in or added to the basic design and describe its function.

4. Describe the behavior of your improved system. Provide step responses, bode plots, and transfer functions.

5. Include references to any books, articles, datasheets, or web sites that you used in your research and design.

Your report should be complete, detailed, and neat. Using your report, a reasonable technician should be able to recreate your design and results.

Contest

At checkoff, you must demonstrate your improved system to the TAs. A number of system characteristics will be tested and evaluated. Prizes will be awarded for the best designs in the following categories:

Best Transient Response	20% extra credit
Widest Dynamic Range	20% extra credit
Best Disturbance Rejection	20% extra credit
Heaviest Object Lifted	10% extra credit
Lowest Power Consumption	10% extra credit
Most Artistic System	Tosci's gift certificate

All entrants must be ready for checkoff starting at 4pm on May 11. Lab reports must be complete at this time. Late entrants will be disqualified.

1. **Widest Dynamic Range:** Largest periodic movement of the object, measured with a ruler, for a square-wave or sine-wave input.

2. **Best Disturbance Rejection:** Largest ratio between heaviest object levitated to lightest object levitated, using the same number of magnets.

3. **Heaviest Object Lifted:** Weight of object, maximum of one magnet.

4. **Lowest Power Consumption:** Measured with ammeter on the single 15-V supply.

5. **Most Artistic System:** Beauty is in the eye of the beholder.

Each student may enter up to two categories. Decisions of the judges are final, and may be arbitrary.

Acknowledgements

References

[1] Guy Marsden, "Levitation!" Nuts and Volts Magazine, vol. 24, no. 9, pp. 58–61, September 2003. Available online at `http://www.arttec.net/Press/N&V/Levitation.html`

[2] K.A. Lilienkamp and K.H. Lundberg, "Low-cost magnetic levitation project kits for teaching feedback system design," *2004 American Control Conference,* Boston, MA, June 20, 2004.

[3] H.H. Woodson and J.R. Melcher. *Electromechanical Dynamics — Part I.* New York: Wiley, 1968. pp. 193–200.

[4] J.K. Roberge. *Operational Amplifiers: Theory and Practice.* New York: Wiley, 1975. pp. 214–217.