**Lab 2: Coil Gun**
Tuesday March 1, Wednesday March 2, 2011

- **There are pre-lab questions & plots due *before* you begin the lab (section 3 of this handout). Please have one of the TAs check you off for the pre-lab when you come to the lab.**

- Please have one of the TAs check you off for the lab before you leave the lab.

- The lab reports will be collected on Friday at the end of class on March 11, 2011.

Introduction

In this lab, we will characterize a coilgun launcher. A coilgun is a device that accelerates a ferromagnetic projectile using the magnetic force. The projectile initially sits inside of a solenoid so that its magnetic field is co-axial with the solenoid. To "fire" the projectile, current is pulsed through the solenoid. The B-field created by the solenoid pushes the projectile out of the coil.
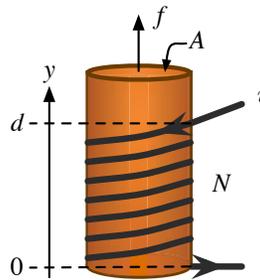
The first part of this lab is to characterize your magnet using the measurement setup provided. If you are careful, you should be able to predict the height of your projectile within five percent. In the second part, you will use a launcher and measure the actual height. You should work in assigned groups.

1 Theory

From the lecture on coil guns, we know that we need to measure two quantities to predict the height your magnet will reach. The first is the current through the coil and the second is $d\lambda/dy$ (λ=flux linkage).

$$mgh = \int_0^d f(y) \cdot dy = \int_0^d i(y) \left[\frac{d}{dy}\lambda(y) \right] dy \tag{1}$$

Unfortunately, it is difficult to measure $\lambda(y)$. Instead, we measure $d\lambda(t)/dt$ as a function of time, and then divide by the magnet's velocity. This approach is very convienent because we recognize $d\lambda(t)/dt$ as back emf.

$$\frac{d}{dy}\lambda(y) \;=\; \frac{d\lambda}{dt} \cdot \frac{dt}{dy} \tag{2}$$

$$=\; V_{\text{Bemf}}(t) \cdot \frac{1}{v(t)} \tag{3}$$

To find $i(y)$, we will measure $i(t)$ and calculate an average current over the brief period of time that the magnet is rising out of the coil. We will assume that $i(y) = i_{\text{avg}}$ over the region of the integration.

Once we have measured these three quantities, $V_{\text{Bemf}}(t) = d\lambda/dt$, $v(t) = dy/dt$, and i_{avg}, we can use MATLAB to perform a numerical integration to find the total energy imparted to the magnet.

1.1   Measure $V_{\text{Bemf}}(t) = d\lambda/dt$ and $v(t) = dy/dt$ using the test station

Using the four coil test station, drop your magnet through the tube and observe the voltage response on the four coils. The voltage that you see is the back emf. The distance between the peaks is indicative of velocity. You will want to set the trigger so that you see all four peaks. You should repeat the magnet drop a few times to make sure you have a reproducible data.
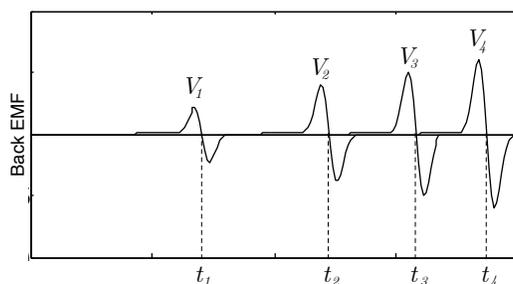

Figure 1: Voltage waveform for four coil test station.

You should save this back EMF data, which will be a list of data points of the form (V_{Bemf}, t). You will also need to know the position of the peaks, y_1 through y_4, to find the velocity of the magnet. Measure these with the meter stick.

- Measure y using a meter stick. Each y corresponds to the center of the coil.

Coil #	Height [m]
1	
2	
3	
4	

The data from the oscilloscope can be saved to a CompactFlash card and transfered to a computer. Unfortunately the oscilloscope's file format is not liked by MATLAB, but Excel is a good intermediary. Open the data file in Excel, adjust the column labels, and save it as a `*.cvs`. [You will have saved 4 files for 4 channel waveforms. `t` column is same in all the waveforms, but voltages are different. Save all voltages and one time data in a single file. The first row has to have column labels as `t`, `V1`, `V2`, `V3`, and `V4`.] You can now read the new file into MATLAB using the procedures described in the prelab (Exercise 3).

Using MATLAB, find $d\lambda/dy$ by dividing $V_{\text{Bemf}}(y)$ by the velocity. Note that this calculation is detailed in the prelab.

- Import your data into MATLAB using `File → Import Data...`.

- Plot V_{Bemf} as a function of t. The zeros of the voltage waveform correspond to times when the magnet was in the center of the coil.

- Using your plot or looking through the data, find t_1 through t_4.

- Plot y as a function of t. You should have four points on this curve. The derivative of this curve is velocity.
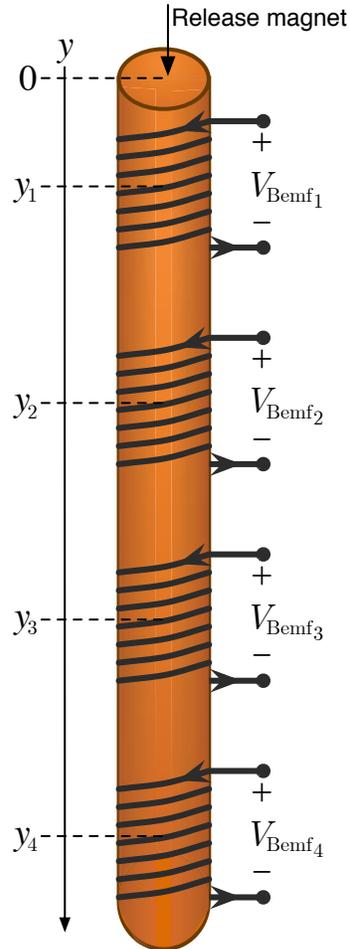
Figure 2: Four coil test station for measuring $d\lambda/dy$.

- Find the constant of acceleration, a, such that $y(t) = at^2/2 + v_o t + y_o$. You know that a should be slightly less than 9.8 m/s^2 because of friction. **Make sure the acceleration you found is at least 8 m/s^2. Have one of the TAs check before you leave the lab.** If you find that the acceleration you calculated is too small, repeat the measurement process. **Acceleration measured is: _____.**

- Use $v = dy/dt$ to find $v(t)$.

- Divide $V_{\text{Bemf}}(t)$ by $v(t)$ to find $d\lambda/dy$.

- Plot $d\lambda/dy$ as a function of y.

1.2   Measure i_{avg} and the height of the magnet launched at the current probe station

We need to know how the current through the coil varies as a function of position. Our intuition tells us that it will not be a constant because the back emf will reduce the total voltage drop across the coil, and thus reduce the current through it.

Figure 3 shows a simulated waveform for i, as well as the magnet height. The current spikes when the switch is first closed; but as the magnet accelerates, its motion produces a back EMF that reduces the total voltage drop across the coil and the current dips. As the magnet leaves the coil (at around 5 ms), the current recovers. The average current is the average from 0 to 5 ms, or roughly 16 A. The magnet accelerates initially (as indicated by the parabolic path), and then flies freely (linear path). Gravity is not included in this simulation.
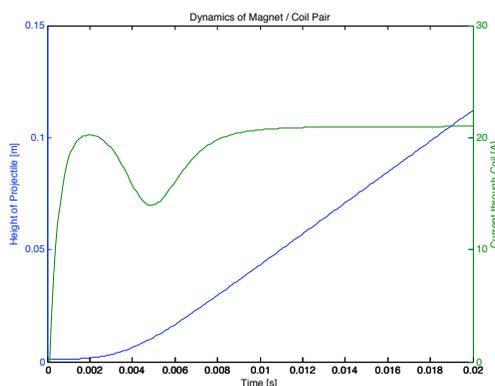

Figure 3: Simulated waveform for $i(t)$.

We will measure the current directly with the current probe. Put your magnet in your coil gun and practice shooting (**Note: You should put 2 magnets together and use them as a single magnet**). When you're ready, bring your magnet to the magnet launcher setup (The set-up will be ready in the lab for measurement when you come in).

- Connect the current probe to your coil and fire the launcher without the magnet. Observe the current and estimate the average.

- Now observe the current as you shoot the magnet. Estimate the average current i_{avg}. Note that most of the error in this experiment comes from an inaccurate measurement of i. **Your data can be saved as a *csv* file on floppy disk, but in the interest of time, your TA will provide you with a copy of this data**. Also record how high the magnet was launched. Repeat the launch 5 times to get reproducible data. You may use the table below to record the height.

Trial	Height [m]
1	
2	
3	
4	
5	
6	

1.3 Predict h

You now have the necessary data to estimate the height h. Use MATLAB to numerically evaluate:

$$mgh = \int_0^d f(y) \cdot dy = \int_0^d (i_{\text{avg}}) \left(\frac{d\lambda}{dy} \right) dy \tag{4}$$

Use 9.8 m/s^2 as your g in the potential energy expression. Mass of the magnet is 3.0 g per pellet of magnet. Your value for a is less then 9.8 not because of a local variation in the Earth's gravity, but rather because of the friction in the tube! That friction is not present (as much) in the launch setup.

- How high will your magnet fly? **Predicted height:** _____.

- How well does your predicted height agree with the measured height?
  Observation:

6.007 Electromagnetic Energy: From Motors to Lasers
Spring 2011