MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.007 – Electromagnetic Energy: From Motors to Lasers
Spring 2011

Lab 1: DC Motors

Tuesday, Feb 8 / Wednesday, Feb 9

Introduction

- Do the pre-lab *before* you come to the lab.
- Read the oscilloscope tutorial *before* you come to the lab.
- Turn in this handout with the data sections filled out and a report answering the questions at the end along with the pre-lab questions on **Friday, Feb 11, 2011**.

This is an introductory lab designed to introduce you to the oscilloscope and MATLAB. You are encouraged to ask for help often! Before leaving the lab, you should get checked off by the TA. At the end of the lab, you should feel comfortable using an oscilloscope and plotting data in MATLAB. Work in your preassigned teams. Each person should turn in his/her own lab report, but your experimental apparatus and data can be shared.

There are three discrete parts to this lab. In the first part, you will measure the angular velocity of your home-built motor. The second part is qualitative and should take little time. You will use a geared DC motor to observe that current programs torque and voltage programs speed. In the third part you will characterize a specially built DC motor by measuring its *motor constant* (more on this in the theory section). Through an additional set of measurements, you will be able to tune this motor constant so that the motor runs optimally.

1 Lab Part I: Measuring the Speed of the home-built DC-Motor

Throughout the lab it will be important to know the speed of the motors' shaft. This section describes how to measure the speed using an oscilloscope.

We will measure the speed of the motor by looking for a piece of tape to interrupt the laser beam incident on a photoresistor (suggested setup for the home-built DC motor is sketched in Figure 1).

The photoresistor acts as a switch that allows current to pass only when there is light shining on it. The resistance of the photoresistor drops from 10 KOhm to nearly 1 KOhm when the laser shines on it. The actual resistances are not so important but what is important is the change in the value when light shines on the photoresistor. You should set up the laser and photoresistor so that the laser beam is shining on the photoresistor. When the motor spins, the piece of tape that you've attached will intercept the beam and the photoresistor will switch off. You will be able to observe this on the oscilloscope connected in series with the 1 KOhm resistor and parallel with the photoresistor (circuit diagram shown below (Figure 2)). When the photoresistor is "on", most of the voltage will drop across the oscilloscope and it will read a "high" voltage (over 1V). When the photoresistor is "off," only some of the voltage will drop across the photoresistor and the oscilloscope will read a low voltage (less than 1V). As the motor spins, you will observe the voltage drop from "high" to "low" voltages with the same periodicity of the motor speed.

1.1 Procedures

1. Connect the oscilloscope, voltage supply, and photoresistor together as shown in Figure 2 using alligator clips.

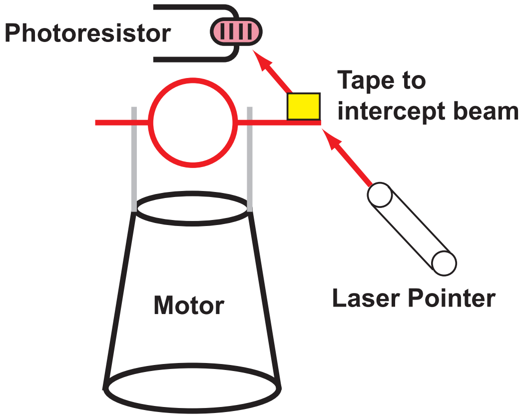

Figure 1: Speed Measurement Setup.

2. Now turn on the laser pointer and position the spot onto the photoresistor — you should see the oscilloscope output drop to a “low” voltage.
3. Position the motor that you built between the photoresistor and the laser and attach a piece of tape to the coil. Ensure that the laser is interrupted by the paper as the coil spins. (Figure 1)
4. On the oscilloscope, measure the frequency that your motor runs at. You can use **run/stop** button on the oscilloscope to freeze the screen and the **cursor** button to measure the period of your signal.

- **Find out if you managed to make the fastest spinning motor in your lab.**

1.2 Questions to answer

1. What is the voltage measured when the photoresistor is in the Off state? ______ V.
2. What is the voltage measured when the photoresistor is in the On state? ______ V.
3. What is the frequency of the motor you have built? ______ Hz.

2 Lab Part II: Current Programs Torque, Voltage Programs Speed

Call the TA over to do this section. If the TA is not available at the moment, you can start with Section 3 and come back to this part later when the TA is available.

2.1 Materials needed

- Geared DC motor
- Current supply at 2 A with voltmeter
- Voltage supply at 10 V with ammeter
- Alligator clips

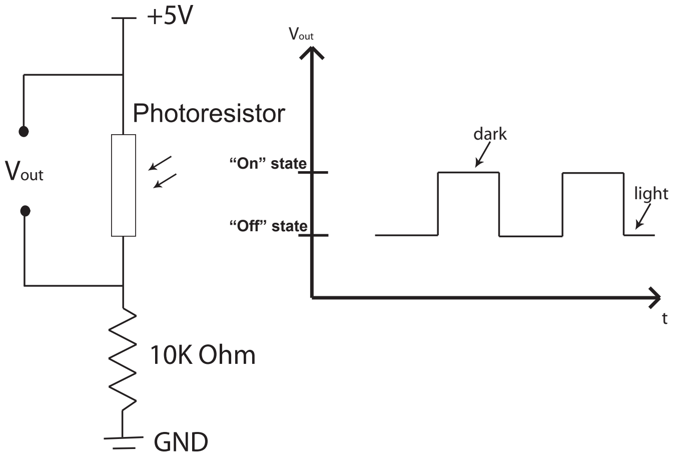

Figure 2: Speed Measurement Circuit.

2.2 Procedures

1. Connect the motor to the voltage supply biased at 10 V. Try to stop it with your hand. You should find it nearly impossible to arrest its motion. Observe what happens to the current as you apply more resistance.
2. Connect the motor to the current supply set at 2 A. Try to stop it with your hand. Observe what happens to the voltage.

2.3 Questions to answer

1. What happened when you tried to stop the motor when it was powered by a voltage supply/current supply? Explain why this happens.
2. Which constant are you changing as you increase the load on the motor in each situation. Is it increasing or decreasing?
3. Use Eqns 1 and 2 from the Pre-Lab to explain your observations. Which statement do your observations support: that $K^2 \gg R\beta$, that $K^2 \sim R\beta$, or that $K^2 \ll R\beta$?

3 Lab Part III: Characterizing a DC Motor

In this part of the lab, we will observe the optimality position ($K = \sqrt{R\beta}$) for a specially built motor. The TAs will help you with the measurement setup. It is your job to analyze the data to determine the motor constants.

3.1 The Motor Setup

The motor of interest has a solenoid style stator, meaning the stator's magnetic field is generated from a pair of solenoids rather than a pair of permanent magnets. The advantage is that we can control I_{stator}, which in turn affects K. The additional feature of our setup is that the motor's shaft is connected to a second motor. This allows us to externally drive the motor shaft and collect data about the back EMF.

Just to confuse you, the external drive motor is a permanent magnet motor. For our experiment, it is used only as a means of driving the first motor's shaft. We will distinguish between the two with the labels "wound-field (WF) motor" for the motor with the solenoids and "permanent magnet (PM) motor" for the motor with the permanent magnets. If you keep it in mind the only reason we have the PM motor attached is to be able to externally drive the WF motor, and that we are only interested in the properties of the WF motor, you should find this lab straight forward.

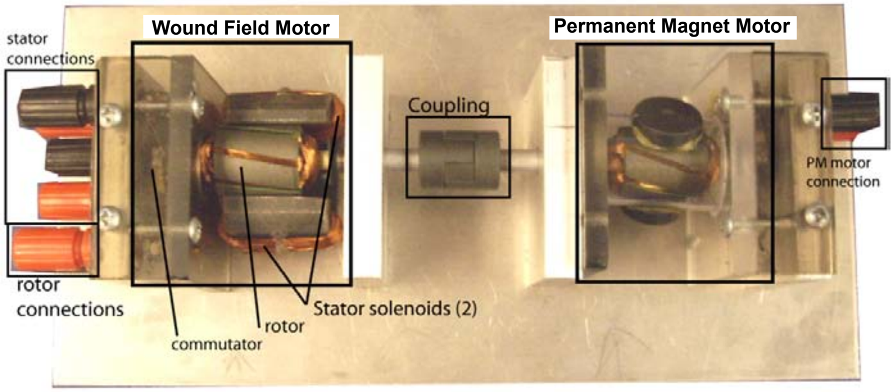

Figure 3: Setup for DC motor characterization. We will find motor constants for the left motor. The right motor is only used to externally drive the left one.

The setup is shown in Figure 3. The WF motor has three pairs of connections. Two of the connections run current through the pair of stator solenoids. The third connection connects to the rotor through the commutator. The motor will not turn unless the stator is producing a magnetic field. Hence it is necessary not only to drive the rotor with a voltage source, but also to pass current through the stator solenoids. We will always use a current source with stator solenoids and a voltage source with the rotor.

The right motor in Figure 3 allows us to use the WF motor as a generator by externally turning the shaft. We can then measure the back EMF and find K, as will become apparent later. The right motor is a permanent magnet design and has a single connection to the rotor. When this PM motor is driven with a DC current, the shaft will turn with ω_{ss} proportional to the current running through the PM rotor. The spinning shaft will induce the back EMF (V_{Bemf}) across the rotor terminals of the WF motor. Hence, V_{Bemf} on the WF motor is equal to its V_{a} if the WF rotor terminals are left open circuit. (What would happen if it is not an open circuit? Is V_{Bemf} still equal to V_{a}?).

3.1.1 Let's make sure the WF motor works

- On the WF motor, connect the two solenoids in series so the magnetic fields inside the motor add.
- Connect the current meter in series with the solenoids when you connect them to the power supply so you can measure the current while adjusting the voltage of the power supply. **You will be using a multimeter so make sure the setting is on current reading (10A) and nothing else!**
- Connect the WF motor to the power supply. Set $V_{\mathrm{rotor}} = 5$ V and $I_{\mathrm{stator}} = 0.5$ A and make sure that your WF motor works. You will want to use the constant voltage supply for the 5 V and the variable voltage supply to power the solenoids.

3.2 Finding an Optimal K

In this section we will explore the functional dependence of ω_{ss} on the current through the stator of the WF motor, I_{stator}, and observe an optimal K for the WF motor.

We know that $V_{\text{Bemf}} = K\omega$. First, we will find the K of the PM motor (K_{PM}) by driving the shaft with the WF motor and measuring the V_{Bemf} of the PM motor and ω_{ss}. Knowing K_{PM} allows us to figure out ω_{ss} of the shaft the next time we drive it with WF motor just by measuring the V_{Bemf} of the PM rotor. We then repeat a similar experiment to find the K of the WF motor (K_{WF}) and its dependence on I_{stator}.

We know from the theory section that K depends linearly on the strength of the magnetic field, B. As we increase I_{stator} of the WF motor, B and K_{WF} will also increase. The B-field on the axis of a solenoid is linearly dependent on the current through the solenoid; we should observe that $K_{\text{WF}} = cI_{\text{stator}}$, where c is the constant we're going to measure.

Knowing the relationship between I_{stator} and K_{WF}, it will be possible to set the drive voltage across the rotor and vary K_{WF}. We will observe a peak in the speed of the motor where $K = \sqrt{\beta R}$. Although we will have taken measurements of I_{stator} and ω, knowing c we can convert these measurements to K_{WF} and ω and find the value of βR.

3.2.1 Finding K_{PM} and K_{WF}

We will start with measuring K_{PM}. If we can turn the motor shaft at a known speed ω, then we should be able to measure the back EMF across the PM motor's rotor terminals. The ratio between ω and V_{Bemf} of the PM motor is K_{PM}.

Here's an idea for measuring K_{PM}. Drive the WF motor at a known speed (use the speed setup used to measure your motor) and measure the back EMF across the PM rotor to find K_{PM} for 0.5 A WF stator current.

- On the WF motor, connect the two solenoids in series so the magnetic fields inside the motor add.
- Set I_{stator} of the WF motor to 0.5 A.
- By applying a range of voltage across the rotor of the WF motor vary the shaft driving speed between 20 and 50 Hz. Record the V_{Bemf} measured across the PM rotor terminals. You will need to apply about 4 V on the rotor of the WF motor to achieve a speed of 20 Hz.

$V_{\text{rotor,WF}}[V]$	f_{ss} [Hz]	ω_{ss} [rad/sec]	$V_{\text{Bemf,PM}}[V]$
4			
5			
6			
7			

- Plot V_{Bemf} of the PM motor as function ω. Determine K_{PM} from the slope of the line. You can do the plotting/calculations at home but it will be good to check now that you have a reasonable data that forms a straight line. Make sure to attach the graph and indicate K_{PM} in the report you turn in.

We will now repeat a similar experiment to find the constant c that relates K_{WF} and I_{stator} of the WF motor. This time, we will drive the PM motor with a set voltage across its rotor and measure V_{Bemf} on the WF rotor while varying I_{stator} of the WF motor.

- Apply 5V to the PM motor and measure the driving speed of the shaft.
- Vary I_{stator} of the WF motor between 0.3A and 0.9A and measure V_{Bemf} across the rotor terminals of the WF motor. Note: ω_{ss} may change when you change I_{stator} (Voltage applied on the PM motor changes) so make sure you measure the speed every time.
- Calculate K_{WF} from the V_{Bemf} measured and plot K_{WF} as a function of I_{stator}. Determine c from the slope of the line. You can do the plotting/calculations at home but it will be good to check now that you have a reasonable data that forms a straight line. Make sure to attach the graph and indicate c in the report you turn in.

f_{ss} [Hz]	ω_{ss} [rads/sec]	I_{stator} [A]	$V_{\mathrm{Bemf,WF}}[V]$
		0.3	
		0.5	
		0.7	
		0.9	

3.2.2 Finding optimal K_{WF}

Now we will find the K_{WF} that gives maximum ω_{ss}. We do so by varying I_{stator} of the WF motor while applying a fixed voltage to the rotor of the WF motor. We will measure V_{Bemf} of the PM motor from which we can calculate ω_{ss}.

- Apply 5 V to the rotor of the WF motor.
- Vary I_{stator} of the WF motor between 0.3 and 1.0 A and measure V_{Bemf} of the PM motor. You should observe a peak in the speed around 0.6 A. You want enough data points to trace a curve.

I_{stator} [A]	V_{Bemf} [V]	K_{WF}	f_{ss} [Hz]	ω_{ss} [rads/sec]
0.3				
0.4				
0.5				
0.6				
0.7				
0.8				
0.9				
1.0				

- Convert I_{stator} to K_{WF} and V_{Bemf} to ω_{ss}.

3.2.3 Questions to answer

1. Graph your data (ω_{ss} versus K_{WF}) from Section 3.2.2 in MATLAB and compare it to Figure 4 in the Pre-Lab. How well does the theoretical curve fit your data?
2. What is the optimal K_{WF}? Let us define ω_{max} to be the optimal ω_{ss}. What is ω_{max}?
3. Suppose we were to grease the rotor such that β becomes $\beta/2$. What would be the new ω'_{max}, in terms of the old ω_{max}? Intuitively, less power should be needed now to obtain the same speed as the old ω_{max}. Show that this is true.
4. Explain why ω_{ss} increases and then decreases as a function of K_{WF}

3.3 Lab Report

- Does not need to be in a lab notebook.
- Include all graphs and calculations asked.
- Include answers to all of the questions.
- Also turn in this lab handout with all of the data sections filled.
- Turn in the pre-lab, attached to the end of your lab report.
- The lab will be graded out of 10 points.

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