Mechatronics II   Laboratory Exercise 3
Motor Characteristics
Measurement of Lumped Parameters

The purpose of this exercise is to measure the parameters of a motor. The motor used in this laboratory is a permanent magnet DC motor. Comprehensive discussion on various types of electric motors can be found in any standard "electromechanical devices" texts such as:

(1) *Basic Electric Machines*, Vincent Del Toro
(2) *Electromechanical Systems*, Dietrich K. Gehmlich
(3) *Electric Machines: Steady State Theory and Dynamic Performance*, Mulukutla S. Sarma.

In this exercise, you will measure the following parameters:

(1) Motor Resistance – R (Ω)
(2) Back EMF Constant – K_e (Volts/radians/second)
(3) Viscous Drag – D_v (oz.in/radians/second)
(4) Coulomb Drag – D_c (oz.in)
(5) Mechanical Time Constant – τ_{mech} (second)
(6) Motor Torque Constant – K_t (oz.in/Ampere)
(7) Inertia of the motor – J_m (oz.in.second^2)
(8) Inertia of the load – J_l (oz.in.second^2).
(9) Electrical time constant τ_{elec} (seconds)
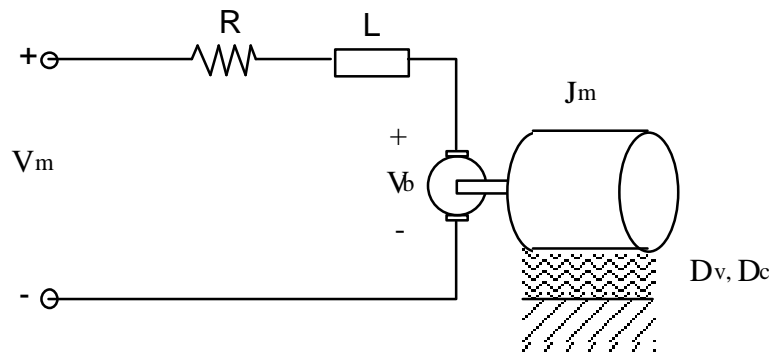(10) Inductance L (Henries)

Figure 1. A model of armature voltage controlled PM DC motors:

1) Introduction

DC motors can be modeled as shown in Figure 1. V_b is the velocity-dependent voltage (the back-EMF), which is linearly related to the motor's angular velocity ϖ by the constant K_e. Kirchhoff's voltage law around the electrical circuit gives us

$$V_m = I\ R + L\ dI/dt + K_e\ \varpi \qquad (1)$$

At steady-state conditions (as time approaches infinity), the L dI/dt term disappears. In reality, this term disappears very quickly. Thus, the electrical motor constant can be solved easily.

Assuming that the developed torque T of the motor is linearly related to the motor current I by the constant K_t, the motor can be mechanically modeled as

$$T = K_t\ I \qquad (2)$$

It can be shown from conservation of energy that K_t must be proportional to K_e:

$$K_t\ (N.m/Ampere) = K_e\ (Volt/radians/second) \qquad (3)$$
$$K_t\ (oz.in/Ampere) = 141.6\ K_e\ (Volt/radians/second) \qquad (4)$$

Figure 2 shows a diagram of the torque balance on a motor rotor that has no external disturbance torque. Summing the torques (Kirchhoff's current law) results in:

$$T = K_t\ I = J\ \alpha + D_v\ \varpi + D_c signum(\varpi) \qquad (5)$$

Note that D_c is independent of velocity and that the sign of D_c changes with ϖ. This is shown in Figure 3. Equation (5) is therefore nonlinear and requires linearization to develop a linear model for the system.

Inertia
$J\ \alpha$

Applied Torque
T

Viscous
Friction
$D_v\ \omega$
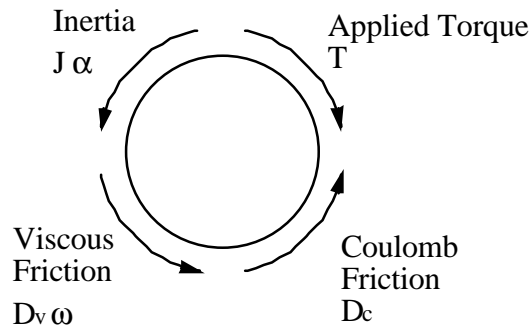
Coulomb
Friction
D_c

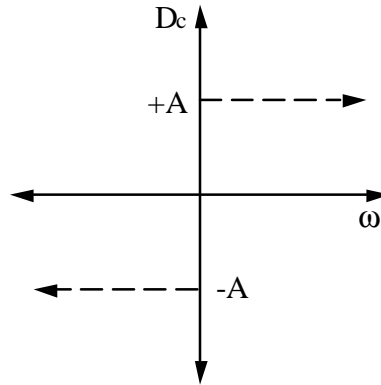Figure 2. Torque balance on motor rotor.

Figure 3. Nonlinear coulomb friction model.

At the <u>steady-state</u> for DC input, the inductance and inertial terms in equations (1) and (5) drop out, leaving us with the equations

$$V_m = I\,R + K_e\,\varpi \tag{6}$$
$$K_t\,I = D_v\,\varpi + D_c \mathrm{signum}(\varpi) \tag{7}.$$

Note that the tachometer, which is connected to the motor, affects the inertia and friction forces. The constants you obtain from this exercise will include the tachometer's parameters and not just the motor's.

2) Procedure to experimentally determine R, K_e, K_t, D_v and D_c.
In this experiment the computer controls the speed of the motor via the power amplifier found on the lab benches.

Step 1. Measure the gain of the power amplifier.

Locate the power amplifier's input (V_{ref}), which has a BNC connection. The output of the amplifier is the white and yellow plugs below the word POWER. Use the 5 volts power-supply and the potentiometer on the experiment-bench to measure the gain of the amplifier. This value will be used in the experiment to follow.

Step 2. Connect the motor to the computer through the power-amplifier.

First, connect the power amplifier to the computer. Attach one end of a BNC cable to the V_{ref} connection on the power amplifier. Using a BNC-to-banana plug adapter, connect the other end of the BNC cable to AO_CH1 (blue plug) and ground on the A/D board. Make sure you reference the grounds between the bench power supply and the A/D board. Next, connect the power amplifier to the motor. Connect the motor leads to the "POWER" amplifier output plugs (white and yellow plugs).

Step 3. Connect the Tachometer to the computer.

Connect the positive lead (red plug) of the tachometer to AI_CH2 (red plug) and the negative lead (blue plug) of the tachometer to AI_GND (green plug).

Step 4. Connect the current sensor to the Computer.

Underneath the monitor shelf, behind the POWER connection near the black power amplifier box, there is a banana plug connected to a current sensor on the amplifier. This measures the current sent to the motor and outputs a voltage proportional to the current. Connect the "Current Sense" wire to AI_CH1.

Step 5. Check your connections and if unsure, have your TA look over your setup before you turn on the power.

Step 6. Run CVI Lab Windows. Open the motor project in C:\CVI\PROGRAMS\LABS\MOTOR\MOTOR.PRJ.
The CVI MOTOR CHARACTERISTIC LAB user interface will appear with two plots and a column of different values.

Step 7. In the gain field, check to make sure that the gain you measured for the amplifier is the same as the gain listed. In addition, make sure that the correct input channels are selected for the sensors.

Step 8. Turn on the power supply and click on the start button at the lower, center region of the window. The motor should run in increments of 0.1 volts from –5 to 5. After this process two plots will be generated.

Step 9. Save the data by clicking the **SAVE** button. The data is saved in three different columns corresponding to speed in rad/s, volts, and current in amps. Keep a copy of the data.

3) Measuring the Rotary Inertia, J

The mechanical time constant can be measured by giving the motor a step input. Assuming that the mechanical time constant is slower than the electrical time constant, the inertia can be calculated by ignoring the inductance effects (L=0) the

$$J = \frac{\tau_{mech}(R\,D + K_e K_t)}{R}$$

(8).

Here τ_{mech} is the mechanical time constant, which is defined as the time taken by the motor to go from rest to 63% of the final angular speed.

Step 1. Open CVI and run the project C:\CVI\PROGRAMS\LABS\MOTORS\3IN1OUT.PRJ.

Step 2. Set the output voltage on the right side of the window so a step input of 10 volts is given to the motor. Note that the amplifier scales the input sent from the computer. The final voltage applied to the motor must be 10 Volts.

Step 3. Set channel 2 for display and make sure the other channels are not selected.

Step 4. Choose different values for (a) the sampling rate and (b) the number of samples and collect data (angular speed of the motor) for these different settings by clicking on the start button until the step response of the motor can be seen.

Step 5. Make sure that your data does not have aliasing effects.

Step 6. Record the sampling rate and number of samples you have in the data.

Step 7. Save the data. Note: the mechanical time constant time constant is defined as the time it takes the motor to reach 63% of the final value.

4) Measurement of the Rotor Inductance, L

Step 1. Lock the shaft of the motor so that it will not turn. The back emf is zero in this condition.

Step 2. Apply a step input (voltage to the motor) and measure the current going into the motor as a function of time. This is done by using the same program as in section (3) -- this time measuring the current going into the motor from the power amplifier by selecting channel 1 to be read. Keep in mind to set the appropriate sampling rate to avoid aliasing. Run the program as before, only take one lead from the POWER source, then quickly replace it after pressing START.

Step 3. Record the sampling rate and number of samples

Step 4. Save the data.

Step 5. Determine the electrical time constant τ_{elec} from the data. Electrical time constant is defined as the time taken by the current in the motor to go from rest to 63% of the final steady-state current. The motor inductance can then be calculated by knowing the electrical time constant, τ_e and the motor resistance R by the following equation.

$$L = R\ \tau_{elec} \tag{9.}$$

5) In-Lab Report

Show your T.A. how the parameters you derived compare to those supplied by the manufacturer.

- $J = 7.0 \times 10^{-7}$ kg-m
- $R = 4.84\ \Omega$
- $L = 5.324 \times 10^{-3}$ H
- $K_t = 1.159 \times 10^{-1}$ N-m/A
- $K_e = 1.159 \times 10^{-1}$ V/rad/s
- $D_v = 5.0 \times 10^{-5}$ N-m/rad/s
- $D_c = 1.39 \times 10^{-2}$ signum(w) N-m
- $D = 2.0 \times 10^{-3}$ N-m/rad/s