ME 1049

Mechatronics Lab

DC Motor Modeling

Revised April

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Mechanical Engineering Department

Lab 4: DC Motor Modeling

Figure 0: One of the many applications of DC motor modeling and control

The design and implementation of a control system almost always begins with the creation of a model of the plant that is to be controlled. This is because in industry it is rare to be able to test, tune, and characterize the performance of a controller on a plant without risk of damage or injury. This is also because, as illustrated in the example in Figure 0, a controller often needs to be designed and tuned enough for basic operation before final tuning and validation are even possible. That being said, the creation of a theoretical model of a complex system can be prohibitively difficult, resulting in the creation of various approaches to experimental modeling to characterize complex systems. The ultimate goal of modeling for control design is to be able to create a simulation of a plant and various controllers in order to gain confidence that an approach will work before implementation on hardware.

Learning Objectives

After completing this lab, you should be able to complete the following activities.

1. Create an electromechanical model of a DC motor using first principles.
2. Inspect the step response of a DC motor to characterize a transfer function.
3. Use Bode plotting to experimentally determine the model of a DC motor.

Required Tools and Technology

Platform: NI ELVIS III	✓ View the NI ELVIS III User Manual http://www.ni.com/en-us/support/model.ni-elvis-iii.html
Hardware: Quanser Controls Board	✓ View the Controls Board User Manual http://www.ni.com/en-us/support/model.quanser-controls-board-for-ni-elvis-iii.html
Software: LabVIEW Version 18.0 or Later Toolkits and Modules: • LabVIEW Real-Time Module • NI ELVIS III Toolkit • LabVIEW Control Design & Simulation	• Before downloading and installing software, refer to your professor or lab manager for information on your lab's software licenses and infrastructure • Download & Install for NI ELVIS III http://www.ni.com/academic/download • View Tutorials http://www.ni.com/academic/students/learn-labview/

Expected Deliverables

In this lab, you will collect the following deliverables:

- ✓ LabVIEW first principles model of the DC motor
- ✓ Calculated equivalent moment of inertia acting on the motor shaft
- ✓ Response of the first principles model and hardware
- ✓ Transfer function representing the first order model
- ✓ Experimental step-response of the DC motor
- ✓ Transfer function of the experimental model of the DC motor
- ✓ Response of the DC motor to different sinusoidal inputs
- ✓ Bode magnitude plot of the response
- ✓ Calculated DC gain, cutoff frequency, and time constant of the DC motor
- ✓ Experimental model of the DC motor based on the Bode plot

1 Experimental Procedure

1.1 First Principles Modeling

1. Open the project **Quanser Controls Board.lvproj**, and open **DC Motor First Principles.vi**. Browse to the block diagram, shown below:

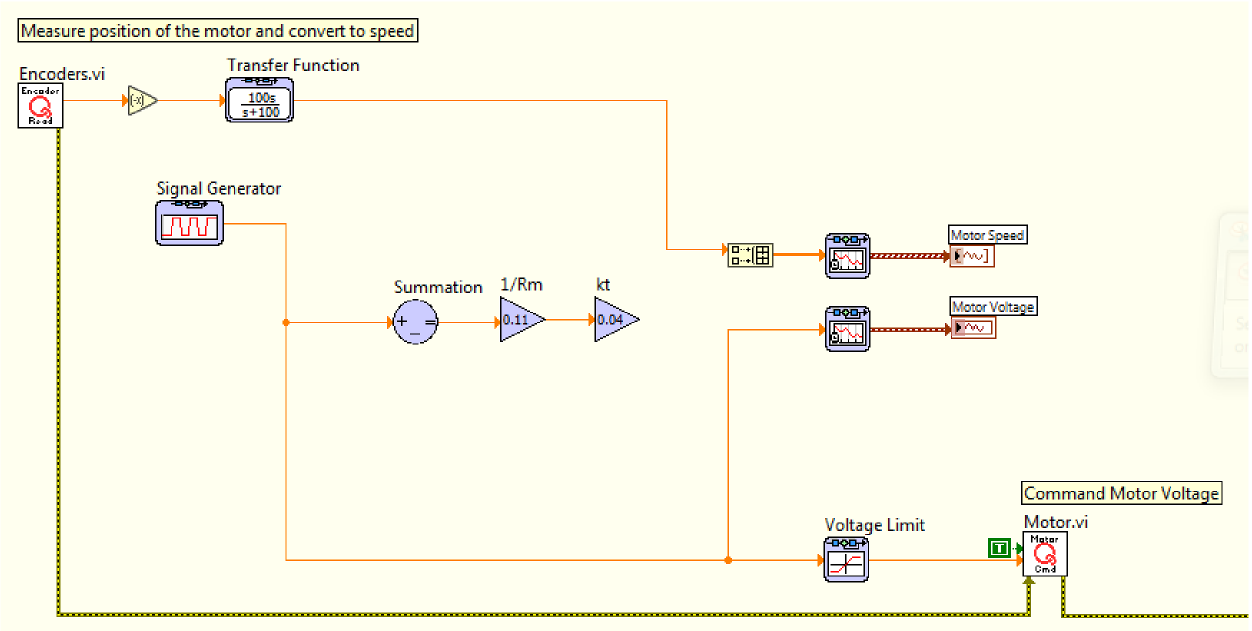

Figure 2: Incomplete block diagram representing the DC motor model

2. The motor shaft of the Quanser Controls Board is attached to a load hub and a disk load. Based on the parameters given in Table 1, calculate the equivalent moment of inertia that is acting on the motor shaft.

Equation 1

$$J = \frac{1}{2} m r^2$$

$$J_{eq} = J_m + J_h + J_d$$

Table 1: Quanser Controls Board system parameters

Symbol	Description	Value
DC Motor		
R_m	Terminal resistance	8.4 Ω
K_t	Torque constant	0.042 N·m/A
K_m	Motor back-emf constant	0.042 V/(rad/s)
J_m	Rotor inertia	4.0×10^{-6} kg·m^2
L_m	Rotor inductance	1.16 mH
Load Hub		
m_h	Load hub mass	0.0106 kg
r_h	Load hub radius	0.0111 m
Disk Load		
m_d	Load disk mass	0.053 kg
r_d	Load disk radius	0.0248 m

3. Using the Equation 2, assemble a simple block diagram to model the system. You will need a few Gain nodes, a Subtract node, and an Integrator node (to go from acceleration to speed). Part of the solution is shown in Figure 2. Save a screen capture of your model.

Equation 2

$$i_m(t) = \frac{v_m(t) - k_m \omega_m(t)}{R_m}$$

$$\tau_m(t) = k_t i_m(t)$$

$$J_{eq}\dot{\omega}_m(t) = \tau_m(t)$$

4. Run the VI with your model. The waveform chart response should be similar to Figure 3.

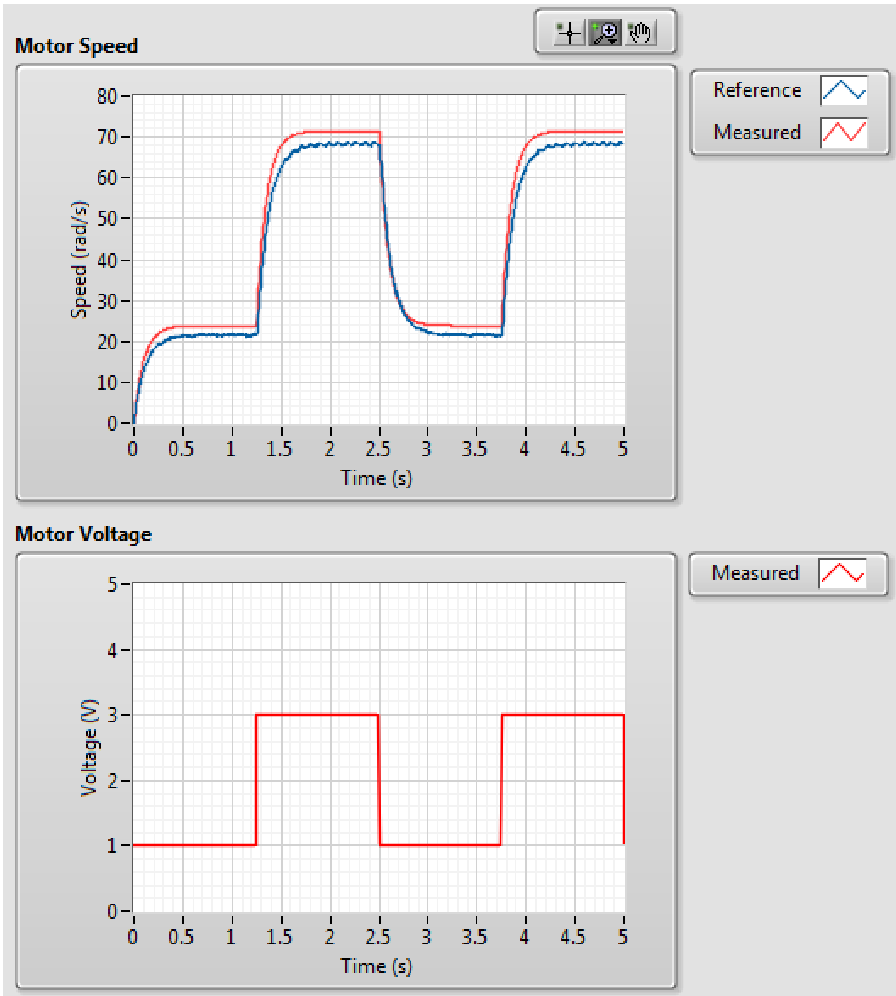

Figure 3: Measured and simulated response of the Quanser Controls Board DC motor

5. Save a screen capture of your waveform charts.
6. Click on the **Stop** button to stop the VI.

1.2 Experimental Modeling

1. Open the project **Quanser Controls Board.lvproj**, and open **DC Motor Experimental.vi**.

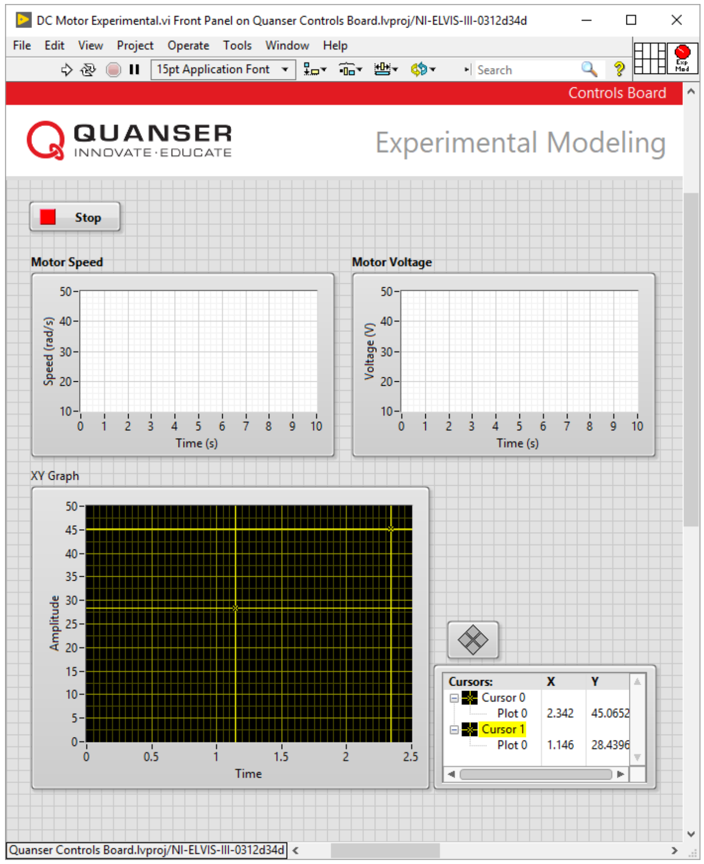

Figure 4: Application for experimental modeling of the Quanser Controls Board DC Motor

2. Run the VI to apply a 2 V step to the servo. The response should be similar to that shown in Figure 5.

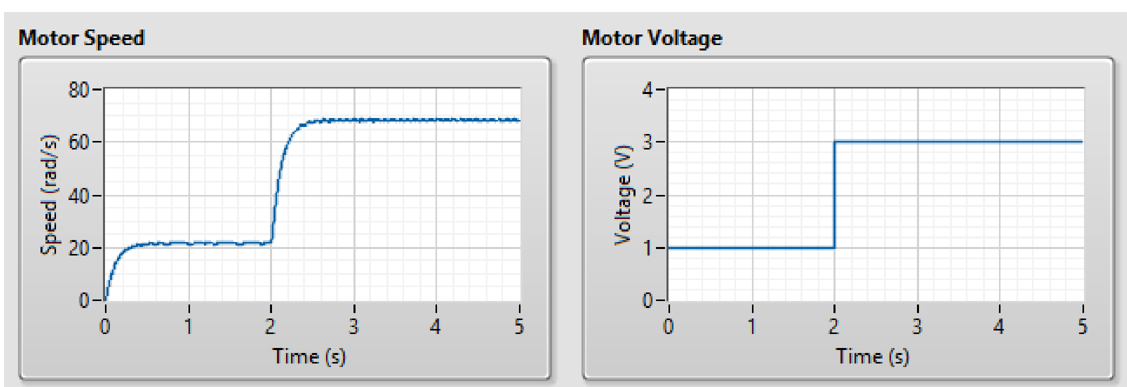

Figure 5: Quanser Controls Board DC Motor bump test response

3. Plot the motor speed response and the input voltage. For example, you can right click any of the waveform charts and select **Export >> Export Simplified Image**

to save the measured load/disk speed and motor voltage to a bitmap image file and attach that to your report.

4. Find the steady-state gain using the measured step response. Hint: Use the Cursor palette in the XY Graph to measure points off the plot.
5. Find the time constant from the obtained response.
6. Record your derived model parameters K and τ.

Equation 3

$$\frac{\Omega_m(s)}{V_m(s)} = \frac{K}{\tau s + 1}$$

7. Modify the VI by adding a *Transfer Function* block using the derived model parameters to plot the simulated and measured responses simultaneously. Run the VI. Save a figure displaying both the measured and simulated response in one plot and another showing the input voltage.
8. Click on the **Stop** button to stop the VI.

1.3 Frequency Response Modeling

1. Open the project **Quanser Controls Board.lvproj**, and open **DC Motor Frequency Response.vi**.

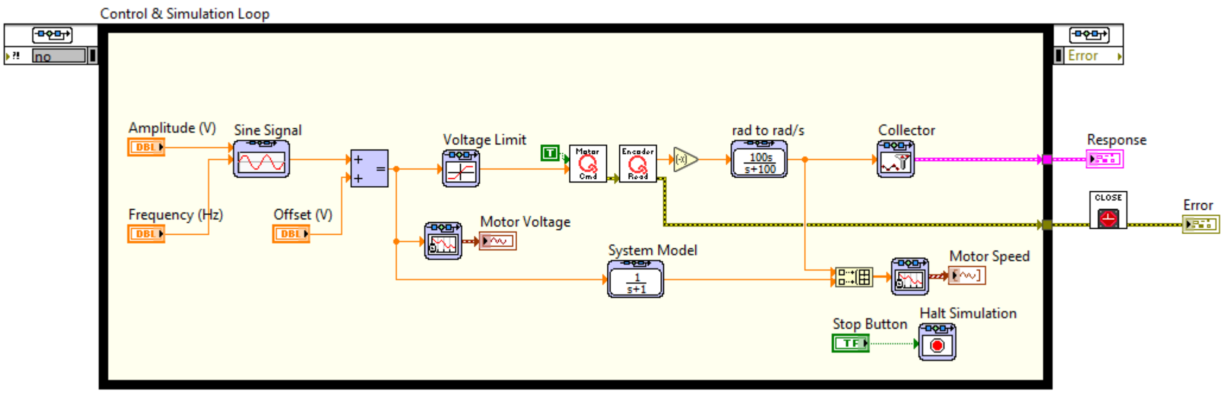

Figure 6: VI that applies a sinusoidal voltage and measures the corresponding servo speed

2. The VI applies a sinusoidal input to the DC motor and measures the load disc velocity using the encoder as shown in Figure 6.
3. Initially, you need to find the peak (steady-state) velocity of the load disc when a constant input voltage is applied to the DC motor (f = 0 Hz). To create a 2 V constant input voltage, set the following parameters from the front panel:
   a. **Amplitude:** 0 V
   b. **Frequency:** 0 Hz
   c. **Offset:** 2 V

4. Run the VI.
5. The load disc should begin rotating in one direction and stop after 3 seconds. Your results should be similar to Figure 7, which shows the input motor voltage as well as the actual response of the plant. Take a screenshot of your results. Alternatively, you can right-click on any of the LabVIEW graphs and select **Export >> Export Simplified Image** to save the presented data to a bitmap image file.
6. Using the **Response** XY Graph, measure the peak velocity of the load disc and enter the measurement in Table 2 under the f = 0 Hz row. *Hint:* Use the *Cursor* palette in the XY Graph to measure points off the plot.
7. Proceed to measure the peak velocities of the DC motor for different input frequencies, starting from 0.5 Hz up to 3 Hz in 0.5 Hz increments. Start by setting the following parameters in the front panel:
    a. Amplitude: 2.0 V
    b. Frequency: 0.5 Hz
    c. Offset: 0 V
8. Re-run the VI. Typical response is shown in Figure 8. Take a screenshot of your results and record the peak velocity in Table 2.

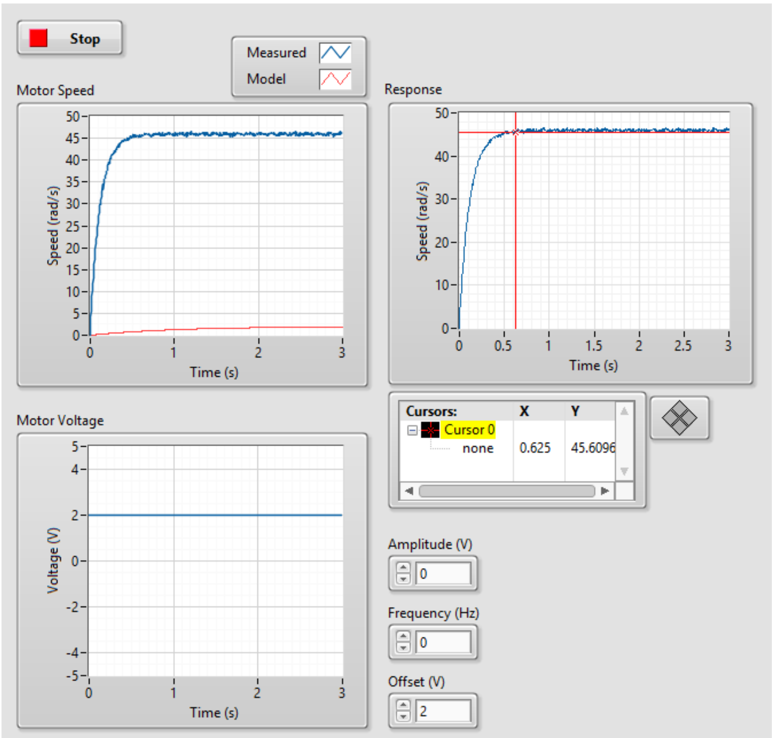

Figure 7: DC motor response to a constant input voltage

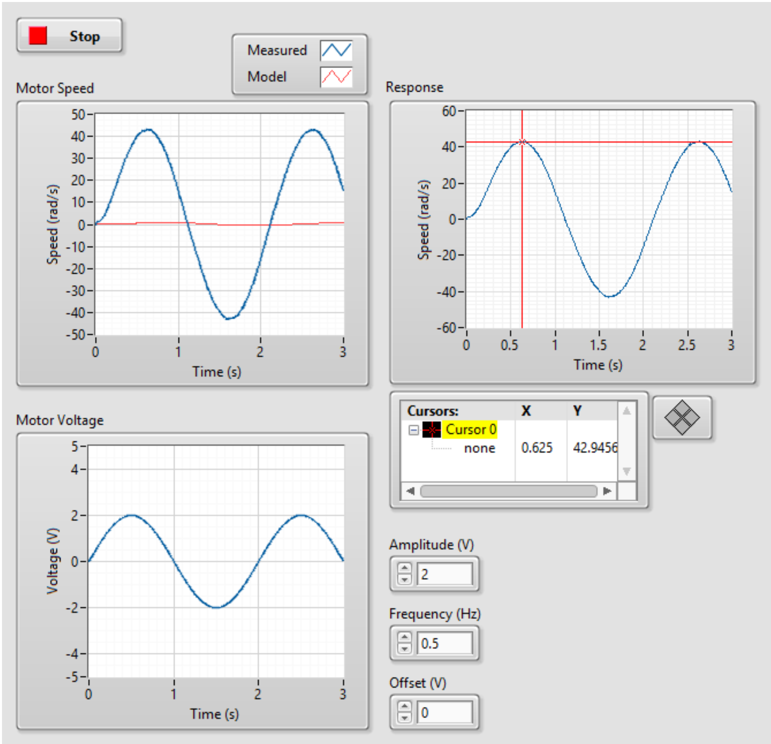

Figure 8: DC motor response to a 0.5 Hz sinusoidal input

9. While keeping the amplitude at 2 V and offset at 0 V, increase the input frequency in increments of 0.5 Hz and run your VI. Record the resulting peak velocities in Table 2.

Table 2: Collected frequency response data

f (Hz)	Peak Velocity (rad/s)
0	
0.5	
1.0	
1.5	
2.0	
2.5	

3.0	

10. From the Project Explorer open **Bode Plot.vi**. Using this VI and the data collected in Table 2, generate a Bode magnitude plot similar to the one shown in Figure 9. In this example, the Y-axis represents magnitude in decibels and the X-axis represents frequency in hertz using a logarithmic scale.

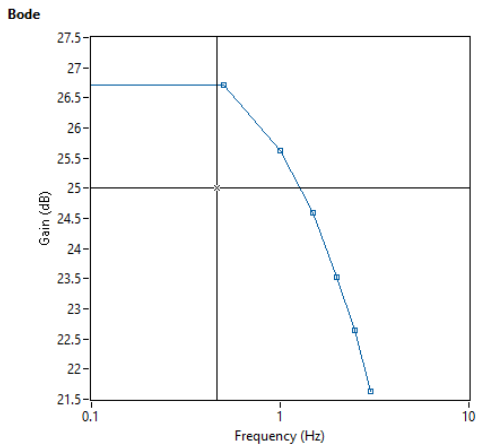

Figure 9: Sample Bode plot

11. From the VI front panel, enter the recorded peak velocities from Table 2 in the **Vel (rad/s)** column.
12. Run the VI.
13. The VI will automatically calculate gains in rad/s/V and in dB. Take a screenshot of your Bode plot.
14. Referring to Equation 4 and using the Bode plot, determine the cutoff frequency (ω_c), time constant ($\tau_{e,f}$) and DC gain ($K_{e,f}$). Record your findings in Table 3. *Hint:* Note that magnitude in the Bode plot is given in dB. To convert gain from rad/s/V to dB use the following expression $|G|_{dB} = 20\log_{10} K_{e,f}$

Equation 4

$$K_{e,f} = \left|G_{\omega l,v}(0)\right|$$

$$\frac{1}{\sqrt{2}}\left|G_{\omega l,v}(0)\right| = \frac{G_{\omega l,v}(0)}{\sqrt{1+\tau_{e,f}^2\omega_c^2}}$$

$$\tau_{e,f} = \frac{1}{|\omega_c|}$$

Table 3: Derived model parameters

$K_{e,f}$ (rad/s/V)	ω_c (rad/s)	$\tau_{e,f}$ (s)

15. To validate the derived model parameters, modify the **System Model** transfer function block in **DC Motor Frequency Response.vi** using the derived values of $K_{e,f}$ and $\tau_{e,f}$. Re-run your VI and observe the measured and modeled responses. How well do they match? Take a screenshot of your results. Sample results comparing the measured and modeled responses are shown in Figure 10 using the following input parameters:
    a. Amplitude: 2.0 V
    b. Frequency: 2.5 Hz
    c. Offset: 0 V

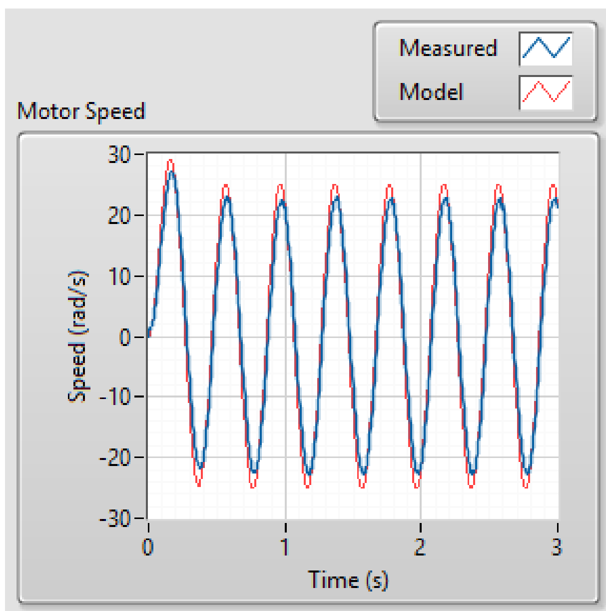

Figure 10: Sample modeled and measured responses of the DC motor

2 For the Report

The report format will be a MEMO. Be sure to include:

First Principles Modeling

1. Formulate the differential equation for ω_m using Equation 2. Compare your result with the transfer function obtained from the experimental modeling laboratory (Equation 3). Hint: Obtain the Voltage $V_m(s)$ to Speed $\Omega_m(s)$ transfer function by applying a Laplace Transform to the derived differential equation.
2. What is the equivalent moment of inertia acting on the motor shaft that you calculated in Step 2?
3. Attach the screen capture you saved in Step 3.

Experimental Modeling

1. Attach the plot that you saved in Step 3.
2. What is the steady-state gain that you found in Step 4?
3. What is the time constant that you found in Step 5?

Frequency Response Modeling

1. Present the frequency response data you recorded in Table 2.
2. Attach a screen capture of the Bode plot that you obtained in Step 13.
3. What is the cutoff frequency (ω_c), time constant ($\tau_{e,f}$) and DC gain ($K_{e,f}$) that you obtained in Step 14? Show your calculations.
4. How well did your modeled and actual responses compare? Attach a screen capture of your results.