Lab #1 Commissioning the Servo Motor Control System

Objectives

The objectives of this experiment are:

- To become familiar with the servo motor and associated components needed for its control
- To wire up the servo motor tachometer and encoder to the hardware interface and DAQ
- To create a SIMULINK model that tests the communication link between the servomotor and computer

Completion of a pre-lab[1] is required to be submitted at the beginning of Lab #2. Instructions are provided at the end of this lab.

Background

Servomotors are used when tracking a specific trajectory is required, such as articulation of a robot arm, automated assembly (for example, spot-welding, or positioning tooling tables), positioning radar and satellite dishes, etc. In all cases either rotation or translational motion along one, two or even three axes is necessary.

The basic component of the servomotor system is typically a high precision DC motor. Since DC motors typically operate efficiently at high speeds, the rotational motion must be geared down when used in a positioning control system. Furthermore the rotational motion can be converted into translational motion through a use of rack and pinion or lead-screw mechanisms. The computation of an appropriate input trajectory for the system, as well as implementation of a control algorithm to ensure trajectory tracking, is typically performed by a computer. This will become clear as you work through this and subsequent ELEX 7720 labs.

The servo motor that we will be using is a laboratory scaled system containing a high efficiency Faulhaber DC Motor[2] model 2338S006, geared down between the motor and load, represented by an external load disk, as shown in Figure 1.

[1] Pre-lab is worth 25% of the total mark for Lab #2.

[2] Complete motor and load specifications are found in Appendix A

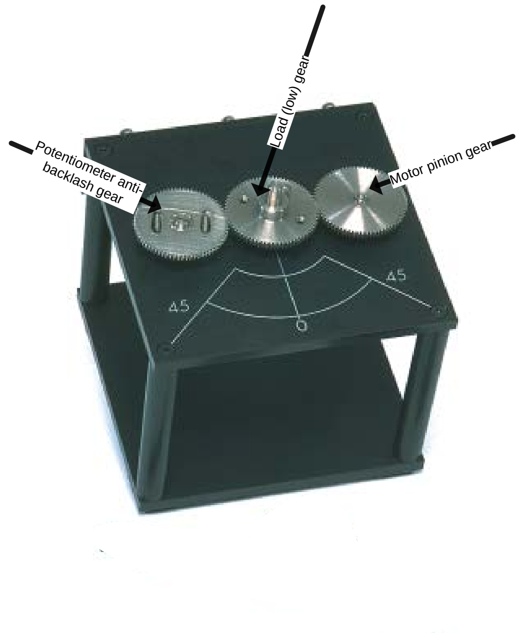


Figure 1: Servo Motor Components

The system is equipped with a US digital S1 single-ended optical shaft encoder that provides 4096 counts (1024 lines) per revolution when in quadrature mode. It is also equipped with a tachometer that is directly attached to the motor and provides a voltage signal that is proportional to the motor speed.

An in-house built Servo Motor Interface, shown in Figure 2, provides the connection between the motor and tachometer connectors on the servo motor and the National Instruments USB 6215 DAQ for the computer[3]. The encoder is connected from the motor directly to the DAQ breakout box interface.

Figure 2: Servo Motor Interface

[3] A potentiometer is also available to provide shaft position measurement. However, it is much noisier than the encoder, and so is no longer used.

Communication to the motor is implemented using QuaRC and SIMULINK to support hardware-in-the-loop. With the USB DAQ, fixed rate sampling is used for data acquisition fast enough to ignore the digital nature of the system for the purpose of this analog control course.

Procedure

1. Connect the DAQ to the computer using the cable provided.

2. The servo motor interface has connections for the tachometer and the armature voltage, so wire these up first:
   a. Connect the tachometer from the servo motor connector to the servo motor interface using the cable provided. Use an **unfiltered** analog input channel to make connection between the DAQ and the servo motor interface.
   b. Connect the armature voltage using the connector labelled Motor on the servo motor and interface with the cable provided. Connect the amplifier input to a DAQ analog output channel.

   Plug in and power on the servo motor interface.

3. To access the servomotor position, you will need to use the digital input[4] channels 0 and 1 from the DAQ. The encoder connects the between the motor encoder socket using a stereo cable to +5, DGND, encoder channel A, and encoder channel B, as shown in Table 1.

Encoder Signal	Stereo Cable Wire Colour
DGND	Brown
Index	White
A	Red
+5	Yellow
B	Black

Table 1: Encoder Connections

4. Start Matlab, and then Simulink. Create a Simulink model, and pull from the Quanser HIL menu (search for 'HIL') HIL Initialize, HIL Read Analog, HIL Read Encoder, and HIL Write Analog – there are several different I/O blocks so make sure you get the correct ones!). Initialize the hardware to NI usb 6215 DAQ, encoder channel 0 with 4 x quadrature, analog input channel (the one that you chose – make sure it is unfiltered), and the analog output channel that you chose.

5. Configure HIL Initialize for the NI 6215 usb daq, the analog input and output channel that you have chosen, and analog input/outputs to have range of +/- 10 volts, if this hasn't been set by default. Configure HIL Read Encoder for channel 0. Configure the HIL Write Analog for the channel that you selected. Configure the HIL Read Analog for the channel that you selected.

6. Choose a fixed-time step solver for the Simulink integration routine, i.e., from the simulation -> configuration parameters menu, and select a sampling time of 0.002 seconds.

[4] I am suspicious that the digital inputs/outputs were swapped in some of the usb box construction. You may have to open the box and switch them around if so.

7. In the toolbar at the top of the model, set the Simulation Stop Time to *inf*, and set the Simulation Mode to *External*. Then, from the Quarc menu, build the model. You will get several warnings about things not being connected, but it should build error-free.

8. If the model builds correctly, pull in a constant source block to test that 1 volt applied to the armature will start the motor spinning in one direction, and a negative voltage will cause it to spin in the other direction. Rebuild the model and chose connect to target. The constant voltage can be changed without having to stop/restart.

9. Use sink display blocks connected to the tachometer and encoder inputs to check that motor speed and position is displayed. Don't worry about the actual values at this point.

10. Once you are certain that communication between the motor and the computer is working, save your Simulink model as a starting point for Lab #2.

Prelab for Lab #2

The servomotor system is shown schematically in Figure 3. The output signals from the system are the angular position and velocity of the motor shaft measured on the load side of the gear, i.e. $\theta(t), \omega(t)$ respectively. The input to the system is the armature voltage $v_a(t)$. When connecting to the motor, please note that the BCIT interface module has a power amplifier connection to the armature voltage.

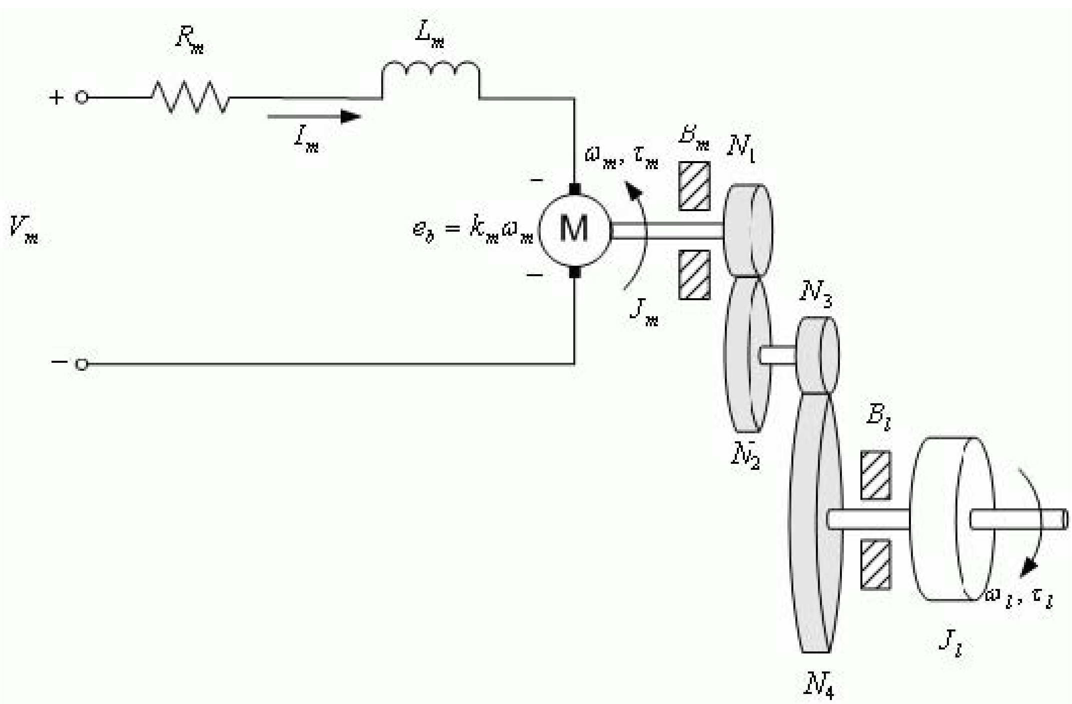


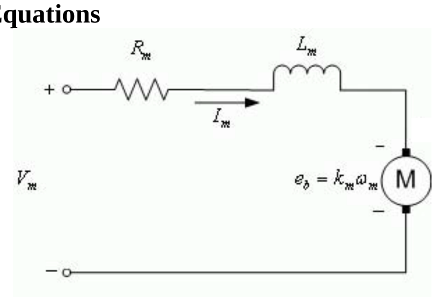
Figure 3: Schematic Diagram of the Armature Controlled DC Motor

R_m and L_m represent the resistance and inductance of the armature winding, while k_m and e_b represent the back emf motor constant, and the back emf developed opposing the armature current flow, respectively. The speed of the motor shaft is denoted by ω_m, while τ_m is the torque developed by the motor. J_m and B_m represent the motor shaft moment of inertia and the viscous friction acting on the motor shaft. Similarly, ω_l, τ_l, J_l and B_l represent the same quantities on the load and load shaft.

Our motor is connected to gears, including an internal gearbox as well as the motor and load gears. The ratio N_2/N_1 represents the internal gear box ratio. The motor gear is represented by N_3 and is directly meshed with load gear represented by N_4.

Based on the derivation of the motor equations, summarized in Table 1, below, a block diagram[5] of the process can be constructed, and is shown in Figure 4.

<table>
<tr>
<td colspan="2">Electrical Equations



</td>
<td>Armature winding:

$$v_m - e_b = R_m i_m + L_m \frac{di_m}{dt}$$

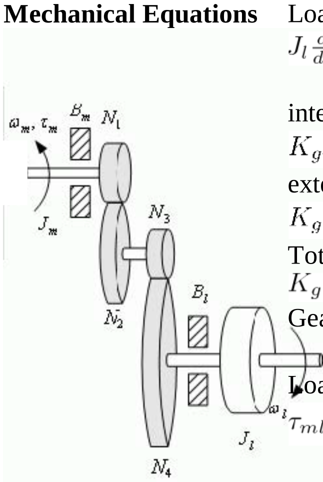
counter-electromotive (CEMF) force:

$$e_b = k_m \omega_m$$

Energy conversion:

$\tau_m(t) = \eta_m k_t I_m(t)$

with η_m, k_t motor efficiency and torque constant</td>
</tr>
<tr>
<td>Mechanical Equations



</td>
<td>Load equation of motion

$J_l \frac{d}{dt}\omega_l(t) + B_l \omega_l(t) = \tau_l(t)$

internal motor gear ratio:

$K_{gi} = \frac{N_2}{N_1}$

external motor/load gear ratio:

$K_{ge} = \frac{N_4}{N_3}$

Total gear ratio:

$K_g = K_{gi} K_{ge}$

Gearbox efficiency: η_g

Load torque reflected on motor side:

$\tau_{ml}(t) = \frac{\tau_l(t)}{\eta_g K_g}$</td>
<td>Motor shaft equation of motion

$J_m \frac{d}{dt}\omega_m(t) + B_m \omega_m(t) + \tau_{ml}(t) = \tau_l(t)$

Equivalent moment of inertia and viscous damping, reflected on motor side $J_{eq} = \frac{J_l}{\eta_g K_g^2} + J_m$

$B_{eq} = \frac{B_l}{\eta_g K_g^2} + B_m$

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

Motor/load shaft speed/position relationship

$\omega_m(t) = K_g \omega_l(t), \theta_m(t) = K_g \theta_l(t)$</td>
</tr>
</table>

Table 1: Basic Equations for the DC Motor and Load

[5] Confirm that you understand how the block diagram results from the equations.

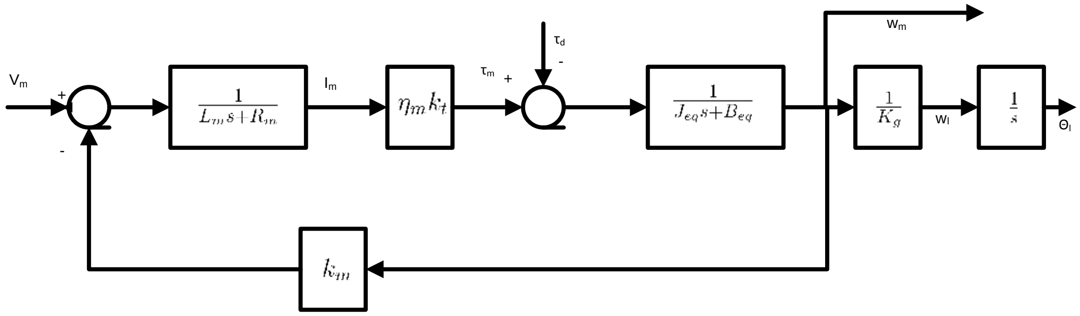


Figure 4: Block Diagram of the DC Motor

Show that the DC motor transfer function between armature voltage and shaft speed, $G_{m,2nd}(s)$, is arrived at by collapsing the block diagram of Figure 4 so that

$$G_{m,2nd}(s) = \frac{K}{s^2+2\zeta\omega_n s+\omega_n^2}$$

with second order parameters defined as

$$K = \frac{\eta_m k_t}{L_m J_{eq}},\ \ 2\zeta\omega_n = \frac{B_{eq}L_m+J_{eq}R_m}{L_m J_{eq}}, \text{ and } \omega_n^2 = \frac{R_m B_{eq}+\eta_m k_t k_m}{L_m J_{eq}}$$

Under the assumption that the motor inductance is much smaller than the resistance, i.e, $L_m << R_m$, show that the 2nd order model can be simplified as follows:

$$G_m(s) \approx \frac{K}{\tau_s+1}$$

with K the motor gain constant and τ the motor time constant defined as

$$K = \frac{\eta_m k_t}{R_m B_{eq}+\eta_m k_t k_m}, \tau = \frac{R_m J_{eq}}{R_m B_{eq}+\eta_m k_t k_m}$$

Finally, the transfer function from armature voltage to load shaft position is given by:

$$\frac{\theta(s)}{V_a(s)} = G_m(s)\cdot\frac{1}{K_g}\cdot\frac{1}{s}$$

Next, the block diagram in Figure 5 describes the connection of the servomotor with the computer.

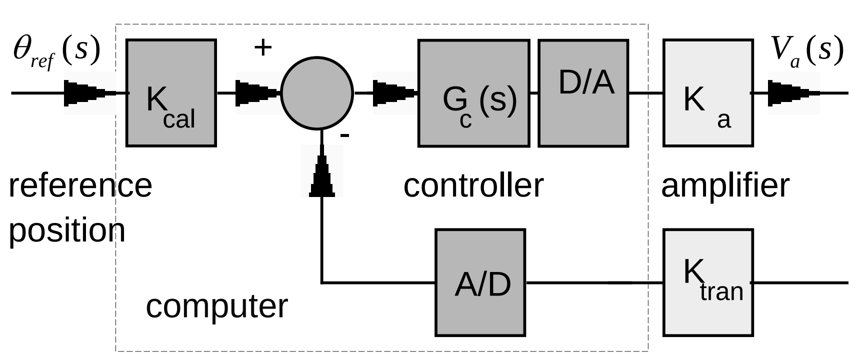


Figure 5: Block Diagram of the Servomotor and Computer

Finally, using the rules of block diagram reduction, the input command calibration gain, K_{cal} , gains of D/A and A/D converters, as well as the potentiometer gain, K_{tran} , can be eliminated yielding the following unity feedback block diagram shown in Figure 6 to represent the complete system.

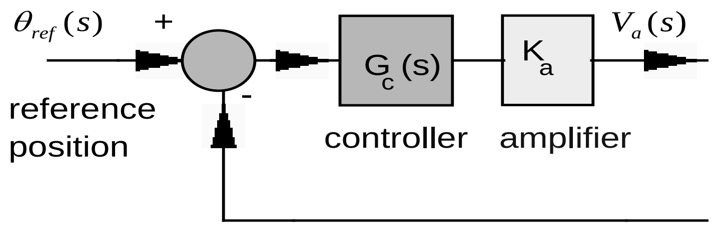


Figure 6: Equivalent Unity Feedback Block Diagram of the Servomotor System

Your task for the Prelab for Lab#2 is to calculate all nominal parameter values necessary to be able to construct parameterized linear models, $G_{m,2nd}(s)$ and $G_m(s)$, of the servo motor system.

Appendix A provides a complete set of servo motor specifications, as provided by the manufacturer.

The viscous friction coefficient for the motor, B_m, is not directly available, but can be calculated from the no-load values of torque and speed, i.e.,

$$B_m = \frac{\tau_{nl}}{\omega_{nl}}$$

Assume that the viscous load coefficient $B_l \approx 0$.

The formula to calculate the moment of inertia of a disc (i.e., assume the gears are discs) is

$$J_{disc} = \frac{mr^2}{2}$$

Prelab Table for the check required to begin Lab #2

Parameter	Numerical Value	SI Units
Motor Armature Resistance R_m		Ω
Motor Armature Inductance L_m		mH
Motor Efficiency η_m		
Motor Torque Constant k_t		$\frac{N \cdot m}{amp}$
Back EMF k_m		$\frac{V \cdot \sec}{rad}$
Motor Shaft Moment of Inertia J_m		$kg \cdot m^2$
Total Gear Inertia J_l		$kg \cdot m^2$
Motor Viscous Damping Coefficient B_m		$\frac{N \cdot m \cdot \sec}{rad}$
Internal Gear Ratio K_{gi}	14	
the external motor gear has $N_3 = 72$ teeth		
the load gear has $N_4 = 72$ teeth		
External Gear Ratio K_{ge}		
Total Gear Ratio K_g		
Gearbox Efficiency η_g		
Moment of Inertia on Motor Side J_{eq}		$kg \cdot m^2$
Viscous Damping on Motor Side B_{eq}		$\frac{N \cdot m \cdot \sec}{rad}$
Amplifier Gain K_a	1	V / V
Motor Transfer Function:	$G_{m,2nd}(s) =$ $G_{m,1st}(s) =$	

Appendix:
Servo Motor Specifications

Nominal input voltage	6.0 V
Motor Armature Resistance	2.6 Ω
Motor Armature Inductance	0.18 mH
Motor Torque Constant	7.68e-3 N-m/amp
No Load Speed	7200 RPM
No Load Current (shaft diameter is 0.12”)	0.08 amps
Motor Efficiency	0.69
Back EMF Constant	7.68e-3 N-m
Motor Shaft Moment of Inertia	3.9e-7 kg-m^2
Internal Gearbox Ratio	14
Motor Gear	72 teeth
Load Gear	72 teeth
Gearbox Efficiency	0.90
mass of the 72 tooth gear	0.03 kg
radius of the 72 tooth gear	0.019 m
tachometer sensitivity (measuring **motor** speed) [6]	1.5mV/rpm
Encoder	360 deg (counter-clockwise) /4096 counts

[6] Be careful – there is an internal motor gearbox ratio to consider.