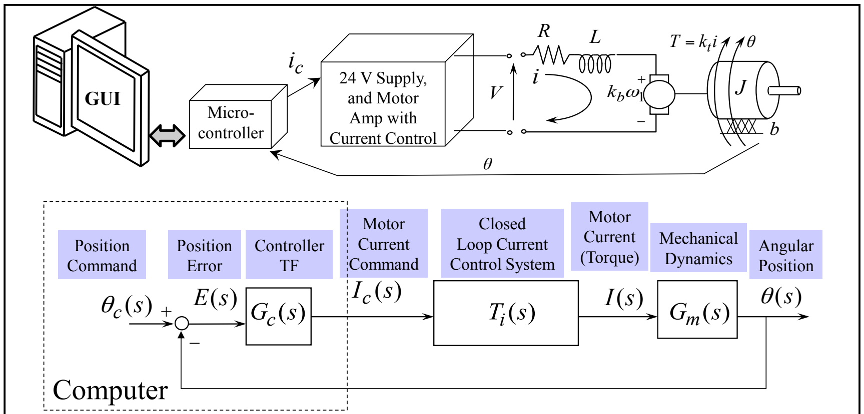
Laboratory #5

In this lab you are to experiment with the position control system of the "Motorlab" apparatus. Also, you are to use a model of the closed-loop position control system to predict the response. You will compare the theoretical step response with the actual response obtained experimentally from the Motorlab. You will compare the responses for three different proportional controller gains. You should also make connections between pole locations and characteristics of the response such as the frequency of oscillation and the decay rate of the oscillations.



$G_m(s) = \dfrac{\theta(s)}{I(s)} = \dfrac{k_t k_{dr}}{Js^2 + bs}$

$G_c(s) = K_p$, proportional controller

and CLTF

$\dfrac{\theta(s)}{\theta_c(s)} = \dfrac{K_p k_t k_{dr}}{Js^2 + bs + K_p k_t k_{dr}}$

J = motor inertia (from motor lab handout)

b = viscous friction coeficient (estimated to be 3×10^{-5} N·m·s/rad)

k_t = motor torque constant (from motor lab handout)

$k_{dr} = 180^\circ/\pi\,(rad)$ = angular postion unit conversion

$T_i(s) = 1$ (amplifier assumed "fast")

K_p = proportional gain of controller

$\theta(t)$ = angular position (measured in degrees for this problem)

Work To Be Done Prior To Lab

a) Assuming the transfer function of the closed loop current control system, $T_i(s)$, is one obtain a symbolic representation of the CLTF $\theta(s)/\theta_c(s)$.

b) From a) write an equation for the closed-loop poles of the system.

c) From b) determine an equation for K_p where the response of the system becomes oscillatory (i.e. where the poles become complex rather than real).

d) Plug in the numbers and determine the value of K_p for part c).

e) Plug the numbers and the following three gains into your equation for part b) to find the oscillation frequency, and time constant for the decay rate of the oscillations, for each gain. $K_p = 0.01, 0.001, 0.0001 (units?)$

Obtaining Data From The Motorlab

In this lab you are using a position control system. Therefore you should run the Motorlab control program in position control mode. For this part of the lab you need to collect experimental data for the step response of the closed-loop system for the three different proportional gains given above. You will have to change the gains and you will have to play with the sample frequency and wave frequency to obtain appropriate data that shows the entire step response. Use the following wave magnitudes for the responses and save the data into the matrix name given. Hint: you should have at least 3 seconds of data on the positive portion of the square wave.

PAY ATTENTION TO THE ORDER!

Gain, K_p (*units?*)	Magnitude of Square Wave (degrees)	Name MATLAB workspace matrix for data.
0.01	200	data3
0.001	1000	data2
0.0001	10000	data1

Immediately after importing the data to the workspace, plot the data using the "mlposplots(data*i*)" command inside of the MATLAB command window. Check the appropriateness of your sample frequency and wave frequency. Also, use the data cursors to measure the period of oscillation for the table below.

Obtaining the required plots and data

By completing the given m-file code you should generate the required plots for this lab. You should also fill in the table below. Some of the data for this table is generated in the m-file. Other data can be found with the data cursors available in the plots generated with "mlposplots.m".

Gain, K_p (*units?*)	Theoretical CLTF poles, $-\varsigma\omega_n \pm j\omega_d$ (rad/s)	Theoretical Period of Oscillations, $2\pi/\omega_d$ (seconds)	Measured Period of Oscillations, T (seconds)	Theoretical Time Constant of Envelope, $1/\varsigma\omega_n$ (seconds)	Measured Time Constant of Envelope, τ (estimate one for all three gains) (seconds)
0.01					
0.001					
0.0001					

Things to turn in

- You should have three different plots (with axis labels including units, titles, and legends): 1) simulated unit step response for all three gains, 2) experimental normalized step responses for all three gains, and 3) simulated and experimental response for Kp=0.01.
- The completed table.
- Hand development of parts a) thru e).
- The answers to the fill in the blanks below (bold and underlined).

Fill in the blanks (Turn in by end of lab)

1. In the theoretical model, as the proportional gain is increased beyond the value where the closed loop response becomes oscillatory, the damped frequency of oscillation ________ and the time constant for the envelope of the oscillations ____________. This captures the behavior of the actual system pretty well, although the envelope does change a little. This might be explained by the nonlinear friction and saturations.

2. As we increase the proportional controller gain beyond 0.001 some aspects of the controller get better while others get much worse. If we try to turn the shaft with our fingers the higher gain system deflects much _________ than the lower gain (try it). This indicates _________ disturbance rejection. However, the damping of oscillations in the step response becomes much ________. This indicates the system is nearly unstable. This is one reason we often add "dynamics" to the controller rather than just the proportional gain which has no integrals or __________.

3. If we keep turning the proportional gain up the system actually becomes ________ (try it). The theoretical model we used doesn't predict this. There are always more dynamics out there at higher frequency that we haven't modeled (we'll look at some in the next lab). For example, by assuming the current controller in the amplifier had a TF of 1, we assumed that it responds _________ fast.

4. Using mlposplots to plot the data in the "data1" matrix we see in the fourth plot, which compares the _______ with the ________ command, that early in the response the current does not actually track the commanded current. As we simulated in the previous lab real systems sometimes have saturations that can affect the response. Looking at the other plots we can see in plot number _________ that the _________ seems to saturate during this period, as can be seen by it reaching a high value and staying constant at that value for a short period. We asked our instructor (do this ☺) and they explained that this is actually due to the limited voltage of the power supply and the _________ constant of the motor. The motor actually generates a voltage as it spins that is proportional to the _________.

Starting m-file code

```
% lab5.m file
% Requires that the square-wave-response data files
% have been imported into data1, data2, and data3.

kt = ???;  % N-m/A
J=???;     % kg-m^2 or N-m-s^2/rad
b= ???;    % N-m-s/rad
kdr=???;   % deg/rad

Gm=tf(???);

kp=0.0001;
Gol=kp*Gm;
T1=feedback(Gol,1);
[th1,t1]=step(T1);
[p1,z1]=pzmap(T1)

kp=0.001;
Gol=kp*Gm;
T2=feedback(Gol,1);
[th2,t2]=step(T2);
[p2,z2]=pzmap(T2)

kp=0.01;
Gol=kp*Gm;
T3=feedback(Gol,1);
[th3,t3]=step(T3);
[p3,z3]=pzmap(T3)

dt1=data1(:,1);    %extract the time column of the data matrix
dth1=data1(:,3);   %extract the first angle column of the data matrix
dth1=dth1/10000;   %scale the response to a unit step response

dt2=data2(:,1);    %extract the time column of the data matrix
dth2=data2(:,3);   %extract the first angle column of the data matrix
dth2=dth2/2000;    %scale the response to a unit step response

dt3=data3(:,1);    %extract the time column of the data matrix
dth3=data3(:,3);   %extract the first angle column of the data matrix
dth3=dth3/200;     %scale the response to a unit step response

figure(1);               %Theoretical for all three gains
plot(???)

figure(2)                %Experimental for all three gains
plot(???)

figure(3)                %Experimental and Theoretical for Kp=0.01
plot(???)
```