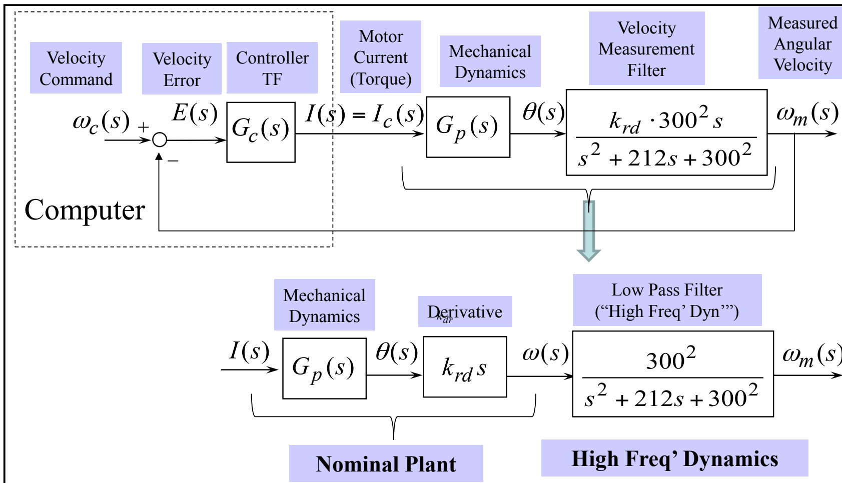
Laboratory #6

Introduction

In this lab we will use the velocity control system in the Motorlab to look at the concept of "higher frequency dyanamics." This lab should illustrate there are always some higher frequency dynamics that will affect you if you "turn up the gains" too much. We can ignore them to a point, but they are there. Often we do not have a good model for them, or even know for sure what is causing them, but they are there.

We have a rule of thumb: *We can ignore open loop poles and zeros when they are more than 10 times larger (in terms of magnitude, which is the distance from the origin of the s plane) than the closed loop poles that result from ignoring them.* You should note it refers to the effect of open loop poles on the closed loop system. This is typical in control system design. We are usually trying make predictions or calculations for the closed loop system using open loop models.



Nominal Plant

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

$$G_s(s) = \frac{\omega(s)}{I(s)} = \frac{k_t k_{dr} k_{rd}}{Js + b}$$

Controller

$$G_c(s) = K_p$$

J = motor inertia + double collar (1.29×10^{-5} kg·m^2)

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

k_t = motor torque constant (0.05 N·m/A)

$k_{dr} = 180/\pi$ deg/rad

$k_{rd} = \frac{1\ rpm}{6\ \deg/s}$ = angular velocity unit conversion

K_p = proportional gain of controller (A/rpm)

$\theta(t)$ = angular position (measured in deg by controller)

$\omega(t)$ = angular speed (measured in rpm by controller)

Collecting Data

You should collect data for at least three gains, listed in the table below. Use a sample rate of 1000 Hz for all the data. For the first two gains you should collect a step response. For the last gain we want to capture the unstable growth of the response.

Gain, K_p (units?)	Square Wave (rpm)	Name of MATLAB workspace matrix for data
0.0008	1000	data1
0.0016	1000	data2
0.008	Use Special Procedure below	data3

Table 1: Information for Acquiring Data

Special Procedure:

1.Turn off the amplifier.
2.Set the gain to 0.008.
3.Change the rpm to 50 rpm in the manual command window.
4.Turn on the amplifier. Then wait one second and save the data to the workspace.
5.Use mlspeedplots to plot the data and zoom in on the exponential growth in both speed and current plots.

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Things to Turn In

- Include the two plots the measured and calculated step response when for $K_p = 0.0008$ and $K_p = 0.0016$. These should include separate responses, one measured and the two models of the closed loop system.
- Include a documented copy of your MATLAB code (complete the comments).
- Include the narrative below with the blanks filled in with **<u>bold underlined</u>** answers. Hint: to find the open loop poles of the two systems use “damp (Gs)” and “damp (Gs*???)” in MATLAB.

The “damp” command in MATLAB prints out the poles of a TF in both Cartesian form and polar form. The Cartesian form gives the real and **<u>A</u>** parts, while the polar form gives the damping ratio and the magnitude. The angle in polar form is directly related to the **<u>B .</u>**

A.____________________
B.____________________

The nominal system model is the one without the higher frequency dynamics (i.e. without the low pass filter on speed). The nominal **<u>C</u>** TF has one pole and the nominal closed loop TF has **<u>D</u>** pole(s). With the higher frequency dynamics the open loop TF has **<u>E</u>** poles and the closed loop TF has **<u>F</u>** poles. Closing the loop **<u>G</u>** change the number of poles. It changes the **<u>H</u>** of the poles (i.e. they move in the s-plane).

C.____________________
D.____________________
E.____________________
F.____________________
G. does/does not
H.____________________

One of the open loop poles in the system with the higher frequency dynamics has the same value as the nominal open loop pole. This pole is much **<u>I</u>** in magnitude than the other two poles. The magnitude of the other open loop poles in the model with the high frequency dynamics is **<u>J</u>** rad/s, which is their natural frequency. Therefore according to our rule of thumb, when the **<u>K</u>** loop poles of the nominal system approach a magnitude of **<u>L</u>** rad/s we might expect the accuracy of the nominal model to be questionable.

I.____________________
J.____________________
K.____________________
L.____________________

At a gain of Kp=0.0008 **<u>M</u>** the magnitude of the closed loop pole of the nominal model is **<u>N</u>** rad/s and is close to the pole at **<u>O</u>** rad/s in the closed loop model with the higher frequency dynamics. At this gain we are very close to our rule of thumb, and although there are slight differences, the step responses from the two models and from the actual system all look very similar. The other two closed loop poles in the model with the filter have complex values of **<u>P</u>** rad/s, which have a magnitude of **<u>Q</u>** rad/s. This magnitude is much larger than the magnitude of the real pole and therefore these poles **<u>R</u>** affect the response much.

M. (units)
N.____________________
O.____________________
P. ________ +/- ________ j
Q.____________________
R. do/do not

At a gain of 0.0016 **<u>S</u>** the magnitude of the closed loop pole of the nominal model is **<u>T</u>** rad/s, so it is **<u>U</u>** than the magnitude predicted by our rule of thumb where we will start to see significant differences between the two models. At this gain the real closed loop pole of the higher order model has a value of **<u>-68.8</u>** rad/s, so we might expect similar behavior from the two models. However, the other two closed loop poles in the model with the filter have complex values of **<u>V</u>** rad/s, which have a magnitude of **<u>W</u>** rad/s. At this gain the magnitude of the real pole and the complex poles are closer together than for the lower gain and we begin to see the effects of the complex poles with some **<u>X</u>** in the responses of the higher order model and in the actual system.

S. (units)
T. ____________________
U. larger/smaller
V. ________ +/- ________ j
W.____________________
X.____________________

At a gain of 0.008 **<u>Y</u>** the closed loop pole of the nominal model is at **<u>Z</u>** rad/s, which predicts a fast, first order, stable response. However the higher order model and the actual system are **<u>AA</u>**, as predicted by the positive real parts of the two closed loop poles at **<u>BB</u>** rad/s. Although the oscillations in the actual response from the Motorlab do not grow to infinity, they do begin grow and then reach a **<u>CC</u>** cycle after a few oscillations. It can be seen in plot of the motor current that it saturates at **<u>DD</u>** Amps.

Y. (units)
Z.____________________
AA.____________________
BB. ________ +/- ________ j
CC.____________________
DD.____________________

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```
% High Frequency Dynamics Lab

kt   = 0.05;     % N-m/A
J    = 1.29e-5;  % kg-m^2 or N-m-s^2/rad
b    = 3e-5;     % N-m-s/rad
kdr  = 180/pi;   % deg/rad
krd  = 1/6;      % rpm/(deg/s)

Gs   = tf([kt*kdr*krd],[J b]);

wn  = ;        % Low pass filter in velocity measurement
zwn = ;
Ghf = tf(wn^2,[1 2*zwn wn^2]);

% WHEREEVER YOU SEE ????? IN THE COMMENTS YOU NEED TO COMPLETE
kp=[ 0.0008 0.0016 0.008];                % array of kp gains used
for i=1:length(kp)                        % cycle through the gains
    Tnominal(i) = feedback(kp(i)*Gs,1);   % ????? TF for nominal model
    Thf(i) = feedback(kp(i)*Ghf*Gs,1);    % CL TF for higher order model
    display(kp(i));                       % display the current kp value
    damp(Tnominal(i))                     % show the poles in polar form
    damp(Thf(i))                          %     ""
    [p1,z1]=pzmap(Tnominal(i));   % CL loop poles and zeros of ????? model
    [p2,z2]=pzmap(Thf(i));        % CL loop poles and zeros of ????? model
    p1= sort(p1);                         % order the poles small to ?????
    p2 = sort(p2);                        %   ""
    pnominal(:,i) = p1;                   % add poles for this gain to list
    phf(:,i) = p2;                        %   ""
end

figure(1);              % Plot the closed loop poles for each of the gains
hold on;
for i=1:length(kp)
    plot(real(pnominal(:,i)),imag(pnominal(:,i)), '+'); % Nominal model
    plot(real(phf(:,i)),imag(phf(:,i)), 'x');           % Higher order model
end
hold off;
axis equal;
s=sprintf('Poles of nominal CL system, + \n');
s=[s sprintf('and higher order CL system, x \n')];
s=[s sprintf('for three gains \n')];
title(s);
axis equal;

tfinal = .3;
[speedN,timeN]=step(1000*Tnominal(1), tfinal); % step response of nominal model
[speedHF,timeHF]=step(1000*Thf(1), tfinal);    %     ""   of higher order model
speed= data1(:,5);     %extract the first speed column of the data matrix
time=data1(:,1);       %extract the time column of the data matrix

figure(2);
plot(timeN,speedN,timeHF,speedHF,time,speed);   % step response plot kp=0.0008
title('Plot of CL step response for Kp=0.0008');
legend('model with nominal dynamics','model with hi freq dynamics','actual');
xlabel('time (sec)'); ylabel('speed (rpm)');

tfinal = .15;
[speedN,timeN]=step(1000*Tnominal(2), tfinal); % step response of nominal model
[speedHF,timeHF]=step(1000*Thf(2), tfinal);    %     ""   of higher order model
speed= data2(:,5);     %extract the first speed column of the data matrix
time=data2(:,1);       %extract the time column of the data matrix

figure(3);
plot(timeN,speedN,timeHF,speedHF,time,speed);   % step response plot kp=0.0016
title('Plot of CL step response for Kp=0.0016');
legend('model with nominal dynamics','model with hi freq dynamics','actual');
xlabel('time (sec)'); ylabel('speed (rpm)');
```