University of Utah
Electrical & Computer Engineering Department
ECE 3510 Lab 3
Second-Order System
(DC Motor Position Controller)

M. Bodson, A. Stolp, 1/31/06
rev,

Note : Bring the dSpace Tutorial you used in lab 1.

Objectives
- Build a position servo system using the dSpace system.
- Observe second-order transient step responses for a critically damped and an underdamped system.
- Compare measurements to calculations.
- Observe the steady-state sinusoidal responses at many frequencies in order to create a frequency-response curve.
- Observe the transient response to a sinusoidal input.

Equipment and materials from stockroom:
- Wire kit
- DC Brush Motor
- Dual Power Amp
- DSpace kit

Experiment
Hook up the computer, dSpace box, power amp, and motor as you did in the first lab. Refer to "Hardware Setup" in the dSpace Tutorial. Leave the power amp off for now. For the software, look in the MyDocuments\ECE3510_Lab_Files\Kp_Control_DC_Motor folder on the computer. These files will implement a higher quality servo system similar to the crude one you used last week. Continue through the dSpace Tutorial to setup the software and data saving. Do not try to save data in MyDocuments\ECE3510_Lab_Files\ or its sub-folders. They are write-protected and the dSpace program will not warn you when it is not actually saving data.

Look at the appendix to this lab to see a block diagram of the control loop implemented by this lab setup. Also find the development of the overall transfer function. Copy these items into your lab notebook by hand and confirm the math to yourself.

Look over the control screen of this new experiment and find the following: (If your control screen isn't as described below, try again to load the right files. If it still isn't right, get help from your TA to locate the files.)
1. The position display. It shows the angular position of the motor shaft in degrees. Check for yourself by manually turning to motor shaft ½ revolution and see how much the reading changes.
2. The velocity display. It shows the angular velocity of the motor shaft in degrees/second. Check for yourself by manually turning to motor shaft ½ revolution in about 1 second and try to see about how much it reads. You should be able to tell if

it's in the order of 180°/sec or 3 rad/sec.

3. The Experiment Reset button. You will have to click this before each run of the transient experiments.
4. The Input Signal Type section. Make sure that "Step Response" is selected.
5. A section titled "System Parameters" which only includes one parameter marked "Proportional Gain", k_p. Set this value to 2.66 and hit <Enter>. (If you forget to hit <Enter> it will go back to 0. All the data entry boxes are that way.) This "Proportional Gain" is what we simply called "Gain" in the last lab. There it was controlled by a potentiometer and here by this number.
6. A section with three data entry boxes that control the input signal to the control loop. Think of it as the function generator that you hooked to the servo last week. Here the input signal is called the "reference" (Ref). When the Signal Type is set to "Step response" the step signal that has a magnitude set by "Ref. Magnitude (Degrees)" and is relative to the zero encoder position. That's why you will have to "Reset" the experiment between each run to zero the position sensor. Set it to 90 (degrees). The other two boxes are for the "Sinusoidal Response" only.
7. Two output graphs. The top one is the most important. It shows the reference and actual positions (in radians) vs time.
8. The experiment Run and Stop buttons in the upper, left corner.

Turn on the power amp. The motor should not start running on its own. If it does, first try using DACH 2 or DACH 3 on the dSpace I/O breakout box instead of DACH 1, otherwise consult your TA, you may have to move to another bench.

Reset the experiment, start data capturing, and run the experiment. The motor should turn 90° and stop. The graphs should run for ½ second and the top graph should show the position change. Check to make sure that a data file was created. Stop the data capturing. Stop, reset, and run the experiment a number of times to "loosen up" the motor. This will warm up the bearings to reduce the friction. (You can do this more effectively if you manually turn the motor shaft a turn or two when the experiment is stopped and then don't reset before you run it again.)

Step Responses

Recall from the last lab how the gain affected the damping of the step response. In this lab you will use two gain (k_p) settings; 2.66 for critical damping and 13.3 for under damping. (Yes, you can never actually set the gain to the exact number needed for critical damping, but it will be close enough for us.)

Obtain the step response for the critically-damped case for a reference input equal to 90 degrees. Remember to start the data capturing, reset before you run, and check to see that a data file was created.

Set the gain (k_p) to 13.3 and repeat the step response for the under-damped case. Make sure that the data graph shows ringing. Look in the appendix to see what the theoretical curves look like. Move your data into Matlab®. The rest of this section may be done after lab if you are short on time.

Next you will calculate and plot the theoretical step response of the system for k_p = 2.66.

You may want to use the Matlab® Control Toolbox “step” function. You should check the help files for the functions “step()” and “tf()” to get the correct syntax. My appendix shows similar calculations and plots done in MathCAD and may help you. Now add your measured data on the same plot. Print this plot. Determine from the plot the values of the 10-90% rise time for both curves. Add the plot to your notebook and compare them. Compare the rise times. (If you write both numbers on the plot, that will constitute a visual comparison.)

Repeat this for the underdamped case (k_p = 13.3). In addition to the rise times, find the 98% settling times. Also determine the percent overshoot and the frequency of oscillation of both curves. To obtain the frequency of oscillation, you may estimate the half-period as the time between the first peak (overshoot) and the second peak (undershoot). Report both frequencies in both Hz and rad/sec.

Compare the frequency of oscillation of the calculated curve to the imaginary part of the pole (b in the appendix). What is the imaginary part of the pole of the actual system?

On your plot, make your best attempt at drawing a exponential curve which passes through the origin and then through each undershoot peak of the measured ringing. (You may want to add such a curve to the Matlab® plot and experiment with the value of the time constant.) Estimate the time constant from this curve (or report what value worked the best in Matlab®). How does $1/\tau$ compare to the real part of the calculated pole (a)? What is the real part of the pole of the actual system? Find the damping factor (ζ) of the actual system and compare it to the calculated damping factor.

You probably found that the measured overshoot and the frequency of oscillation are somewhat higher than calculated. That’s because the calculations are based on a simplified version of the motor model which neglects the motor inductance, among other things.

Sinusoidal Responses

For the remainder of this lab leave the gain (k_p) at 13.3 for under damping. The experiments in this section of the lab have a tendency to overheat the power amp. If you overheat the amp IC, that channel will shut down for quite a while. Occasionally feel the heat sink for the channel you are using to make sure the IC is not getting too hot. If one channel does shut down, move to the other channel and be more careful.

Change the Signal Type to "Sinusoidal Response" to get a sine wave reference input to the control loop. The amplitude is set by "Ref. Magnitude (Degrees)", set it to 10 (degrees). The frequency is set by "Ref. Frequency (Hz)" and it should increment by 2 Hz each time you click on the up-arrow. (If it does not, right-click on it, select properties .. NumericInput and change the Increment to 2 Hz / step.) In the data capture section, change the length to 16 seconds.

Now the next part is a bit tricky. What you want to do is run the motor at 0, 2, 4, 6, 8, 10, 12, 14, ... 30 Hz each for about 1 second. To do this, you first set the frequency to 0 Hz, then you click Run, quickly move the mouse to the up-arrow button next to the frequency and hit it once every second (or as close as you can get). In the meantime you can watch the frequency response curve appear on the output graph. You may have to try this more than once to get good data. Be sure to stop the motor as soon as you're finished taking data or the power amp may overheat. Look at the frequency response curves in the appendix to see if your data looks right.

I want you to use my plots and add your data (amplitudes) by hand on my plots. If you can get amplitudes within $\pm$10% from the little graph on the dSpace screen, that's cool with me (try messing with the zoom features). To get the frequency, just start from the left and count the steps. When you can no longer make out the individual steps, go directly to the last one, plot it on my plot, and then connect the dots with a smooth curve. If you'd rather move the data to Matlab® and plot it there, be my guest. You can even make your own theoretical frequency plot if you want. (The Matlab® function "freqs()" may be used for that purpose. With "freqs()", you will need to enter the frequencies in rad/s, but be sure to label your plot in Hz.)

OK, now you should have a crude plot over the top of my (or your own) theoretical plot. Compare the peaks of the two plots, compare the frequency and magnitude above 10°. You should find that the frequency and magnitude of peaking are both somewhat higher than expected.

What is the frequency of peaking? How does this value compare to the ringing frequency of under-damped step response? Do your results make sense?

Zoom in on your plot near the frequency of peaking, and look at both the input and output signals on the same graph. Estimate the phase lag of the frequency response. When I look at my theoretical phase plot, I see about 58° of phase lag at the frequency of peaking. How does your measurement compare?

Sinusoidal Transient

In this final experiment you'll look at the transient responses to abruptly starting cosine inputs. You may have already noticed these type of transients in the frequency response data when the frequency was changed from one value to another.

Set the "Ref. Magnitude (Degrees)" to 50 (degrees), the "Ref. Frequency" to 50 Hz, and the "Ref. Phase" to 0. In the data capture section, change the length back to 0.5 seconds and stop the data capture. You don't need to create and data files.

Hit Reset, Run, and Stop. Observe that there is a transient at the beginning of the waveform and about how big that transient is. Remember in class that I said that a cosine wave makes a significant step at t = 0 whereas a sine wave does not, so you would expect a smaller transient if you started with a Ref phase of $\pm$90 (degrees). Try that now. Be sure to hit Reset before you hit Run or it will start differently every time. Is the transient smaller now? Try again at at least two more phases to see if you can find the phase that produces the smallest transient.

Conclusion

Check - off and conclude as always.