University of Utah
Electrical & Computer Engineering Department
ECE 3510 Lab 1
Crude Servo System

A. Stolp, 1/22/06
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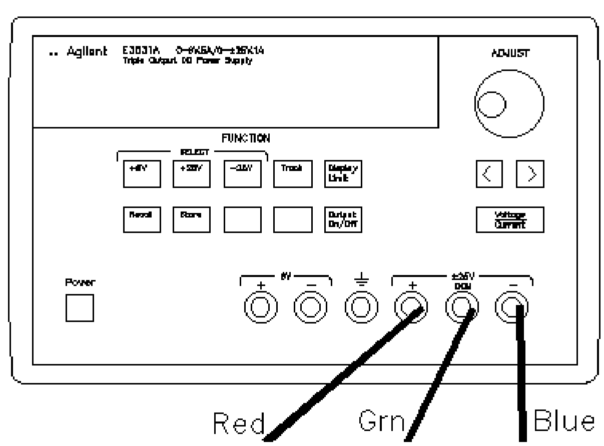
Note : Bring a book to lab that shows second-order differential equation solutions (underdamped, critically damped, and overdamped), unless you remember what they look like. If you don't recognize all of the sub circuits in the schematic (last page of the lab, before the appendix) bring your Electronics book as well.

Objectives
- To examine a crude position servo system to see how the various subsystems can be realized in simple hardware.
- To observe second-order transient system characteristics in the servo.
- To determine some simple transfer functions.
- To look for nonlinearities.

Equipment and materials from stockroom:
- ECE 2210 Servo

Experiment
Examine the servo system and find the following:
1. The power switch and the power connectors (Blue, Green and Red banana jacks).
2. The input position shaft, which is part of the input position potentiometer (pot).
3. A BNC connector which can also be used as an input.
4. The gain adjustment pot.
5. The quad-op-amp (LM 324 or TLO84) IC.
6. The power output transistors (Q1 and Q2) each mounted on a black heat sink.
7. The motor Disable jumper (P3) near the power transistors. (Removing this jumper will disconnect the motor.)
8. The DC motor and gear train.
9. The output shaft which is connected to the "Motor Position Sensor", another pot.

Power supply hookup and basic function
Turn off the power switch on the servo and hook it up to the power supply. Try hitting the **Recall** button twice to see if that will set it up to provide ± 6V. If not, adjust the power supply to provide ± 6V, and then hit the **Store** button twice to store the configuration for the next student.



Turn on the power switch on the servo. If the servo oscillates, turn down the gain. If the motor doesn't stop turning, switch the power off and get some help from your TA. Make some mention in your lab notebook of what you've done up to now.

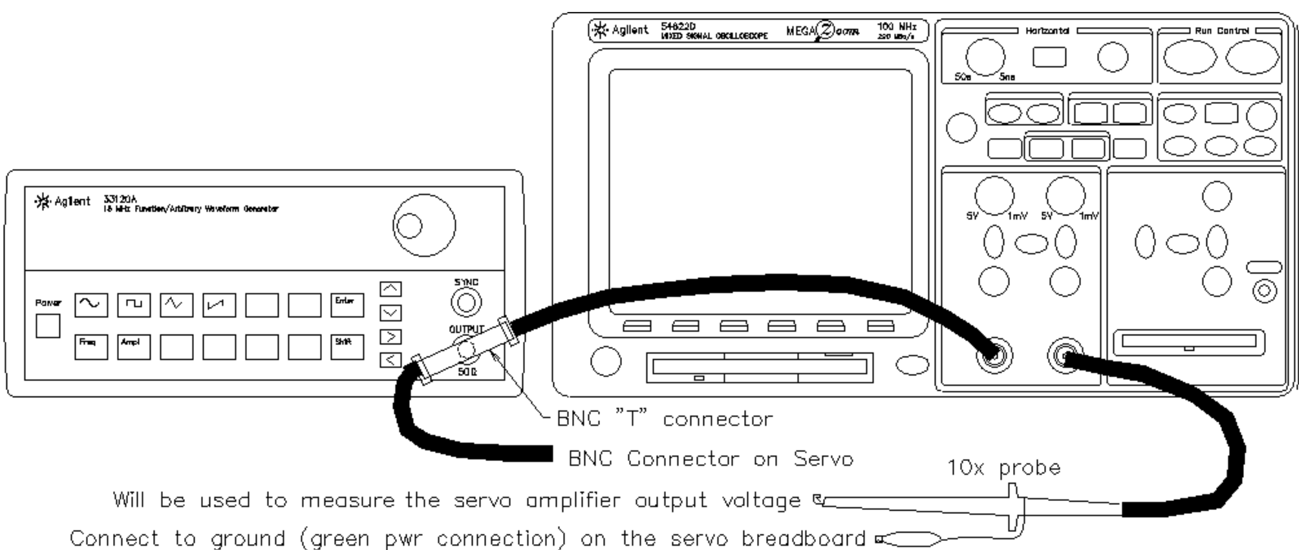
Play around with the input position shaft and watch the motor turn the output shaft to follow your input. In your lab notebook, write a short description of what the servo does. This is a very crude, slow, and weak angular position control system. In later labs we'll make a much better system using a high-quality DC motor with an attached digital position encoder and the dSPACE computer-based control system. The only reason I'm asking you to work with this inferior system now is because every part of it is visible and sort-of hanging out there for you. You're not hooking any "black boxes" together, it's all right there where you can twiddle with it.

Observe how the gain knob affects the response of the servo

The gain pot varies the gain of the amplifier from about 1.7 (fully CCW) to about 133 (fully CW). Operate the servo at several different gains to get an idea of how the gain affects the response. Notice that if you turn the gain all the way up, the servo will oscillate. What does that say about the poles of the system transfer function? (If it won't oscillate, read the upcoming section labeled "Setup the Servo to minimize friction" or ask your TA to check your servo for excessive friction.) Next you'll see these responses again with a more standardized input.

Setup the Function generator and Scope

Find a BNC "T" connector, look where the wires are hung in the lab or for a small red bin on one of the central tables in the lab. Connect it to the output of the function generator. Then wire the function generator, scope, and servo as shown in the next drawing with two BNC-to-BNC cables and one 10x probe. Connect the scope ground to the big green connector on the circuit board marked "Ground" (where that power supply is connected).



Turn on the function generator and set the **Ampl**itude to 50 mVpp (output will actually be 100 mVpp). Hit the **Shift** key, the **Store** key (shifted **Recall**), turn the knob 'till the display shows "STORE 1", and then hit the **Enter** key. This stores the current configuration of a 100mV, 1kHz sine wave as configuration "1". Now adjust the **Freq**uency to 500 mHz (0.5 Hz), the **Ampl**itude to 500 mVpp (output will actually be 1 Vpp), and set the waveform to a square wave. Store this as configuration "2". Make some mention of what you did in your lab notebook. NOTE: It needs to be a SQUARE WAVE !

Setup the Servo to minimize friction

In order to get the best results, you will have to make sure the servo isn't running with too much friction. Check the gears and turn them by hand (the red gear is the easiest to turn) to make sure that they are turning freely. The most common cause for binding is the rubber connector between the gear train and the motor position sensor pot. It needs to be pushed onto the pot shaft just the right distance. If it's pushed on the shaft too far, it causes the whitish-clear output gear to rub against the metal frame of the gear train. Too little and it causes the whitish-clear output gear to push the red gear against the white gear. Either way there's too much friction. When you're satisfied that the gears turn smoothly, turn on the power switch on the servo and make sure that it is functioning properly. Turn it back off for now. Make some mention of what you did in your lab notebook.

Observe again how the gain knob affects the response of the servo

Turn down the gain of the servo to minimum (fully CCW). Turn the Input Position pot to the center of its range and connect the function generator to the BNC connector.

The servo should now move back and forth in jerks, making one move every second. Observe how little the servo moves and how sluggishly it gets there at the minimum gain. Does it overshoot its intended position? Do you think it even reaches its intended position? Slowly turn up the gain. What happens to the motion? Does it get a little more snappy? Does it move further than it did before and thus get closer to its intended position? The low-gain response was slow and had a lot of position error. The response gets much better as you turn up the gain. You can actually hear it get better. Continue to turn up the gain until you start to see (or hear) some overshoot. (Just under this point is the optimal gain setting.) Turn up the gain further until you get a little ringing (more than one overshoot). In earlier classes you learned about the three types of second-order transient responses in terms of overdamped, critically damped, and underdamped. Relate those to the servo outputs you've just observed at various gains.

Determine minimum gain for oscillation

Disconnect the function generator, turn the input position knob to the center of its range, and turn up the gain all the way so that the output shaft oscillates. Turn down the gain very slowly until the oscillation stops, then turn it back up just a hair. Try to get the oscillation started again by turning the "INPUT POSITION" knob a bit. Repeat this until you are satisfied that you've found the minimum gain needed for oscillation.

Measure the circuit transfer function (gain)

Disconnect the motor by pulling it's connector from the circuit board. Note that the circuit board is marked with a + and - at that connector and hook the scope CH2 to the + side. Reconnect the function generator and recall configuration "1" (Hit **Recall**, turn the knob 'till the display reads "RECALL 1", then hit **Enter**). Observe CH2 on the scope. If it doesn't show a sine wave, manually turn the red gear and thus the "Motor Position Sensor" until you see a full unclipped sine wave. Check that the scope CH2 is set to match the scope probe (1x or 10x) and then use the scope to find the gain. You may assume the input is 0.1 V_{pp}, so the gain is just $V_{opp}/.1 = 10xV_{opp}$. Disconnect the scope and reconnect the motor.

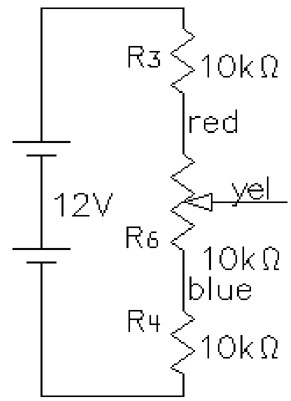
Determine minimum gain for ringing

Recall the function generator configuration “2". Turn down the gain very slowly and try to find the minimum gain needed for ringing (either direction of motion). Measure the gain as you did above.

Determine minimum gain for single overshoot

Repeat the above procedures to find the minimum gain for a single overshoot. This is closer to the actual minimum needed for ringing since overshoot is almost always really ringing.

The circuit has a range of gain from min to max of about 1.7 to 133. Confirm this with measurements if you want to.



Potentiometers as position sensors

This servo uses two potentiometers as position sensors. They translate shaft position into voltage. When the shaft is turned, the voltage on the center lead changes.

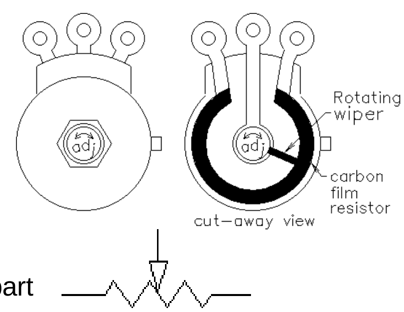
One of the pots is labeled “Input Position” and is the one you turn. Another is coupled to the output shaft of the motor and gear train. The circuit compares the positions of these two pots and amplifies the difference to run the motor in the correct direction to eliminate that difference. Attached to this lab you will find a schematic diagram of the servo. Find the Input Position pot (R6) on the diagram and notice that it is connected it is connected like the small diagram above.

Measure the voltage at the center lead of the pot with respect to ground. Record the voltage at the two limits of rotation. Assuming that the total range of rotation is 270° and that 0° is where the output is 0 V, find the transfer function for the pot in volts/degree and volts/rad.

Repeat this for the motor position pot. You will have to pull the Motor “Disable” jumper (P3) and turn the pot by hand to get the full range. The red gear is the easiest to turn. ~~Notice that the range of voltages is a little bigger for this pot. Look at the schematic and see if this is an intentional design or some aberration. Explain in your notebook. Why would you want the range of this pot to be a little bigger?~~ Turn off the servo and replace Motor “Disable” jumper (P3).

Potentiometers

A *potentiometer* is resistor with a special third connection. (The name comes from its old-time use in voltage measurements.) The third (center) connection can be made anywhere along the length of the resistor, it’s position is adjustable. All potentiometers (pots) and volume controls work in a similar manner, with a moveable slider or "wiper" that makes contact with a resistor somewhere between its two ends. A rotary potentiometer is shown here, first in its package, then as bare workings, and finally as a schematic symbol.



The resistance of a pot is the full resistance between the two outside terminals and is usually written on the part somewhere.

The resistor in a potentiometer can have a linear or an audio "taper". Audio taper potentiometers are used as volume controls in audio circuits. Your hearing does not respond linearly to changes in loudness, so the resistor in a volume control is nonlinear to compensate. The potentiometers used in the servo are all linear taper.

The DC Motor and Full Loop Transfer Functions
You've now measured the simpler transfer functions. We'll look at characterizing a DC motor in a later lab. In the meantime, examine the appendix and see how the transfer function of the DC motor is derived and then placed in the full loop to get the overall transfer function. If we neglect the motor inductance for simplicity we can eventually calculate some step responses for various gains. Look at those responses now and remember what you observed in this lab. Comment in your lab notebook.

The Electronics
Look at the schematic of the servo circuit. The left three op-amps make up a very common circuit that you should recognize. What is it called, and why is it a good choice here? Just in case you've made it this far in Electrical Engineering without encountering this circuit, ask your TA what it is and look it up in your Electronics book.

The two transistors also comprise a very common circuit which you should recognize. What is it called and why it is used here? If you don't recognize it or can't figure out why it's there, look up class B amplifiers in your Electronics book.

What is the purpose of diodes D1 and D2? Remember that motors have windings and thus inductance, plus the moment of inertia of the armature and gears reflects back thought the motor as even more inductance. Ask yourself what happens when you try to stop the current flow in an inductor very quickly (like when the transistors switch off).

Nonlinearities
Look over the servo and find at least two nonlinearities. Hint 1: look at the power supply as you make the servo move quickly. Hint 2: switch down the Motor Disconnect Switch and carefully watch the Motor Position Pot shaft as you turn the red gear back and forth. Describe these nonlinearities in your lab notebook.

Conclusion
Call your lab instructor over to check you off. Usually you do this before you tear down your final setup. Be prepared to discuss your measurements, calculations, and conclusions and to show off your notebook.

Write a conclusion in your notebook. Touch on each of the subjects in your objectives. Mention any problems that you encountered in this lab and how you overcame them.

This sort of check-off and conclusion will be required at the end of each lab, even if it's not specifically asked for in the lab handout. Before leaving, make sure everything is turned off and return what you checked out.