University of Utah
Electrical & Computer Engineering Department
ECE 1250 Lab 5
Servo (Control System)

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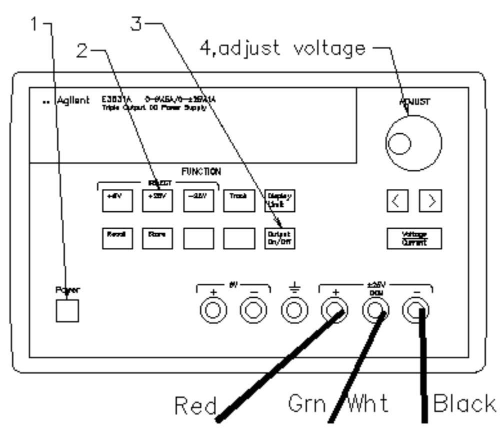
Objective
To observe a simple control system like the steering servo in the car and see how the math predicts the system behavior.

Equipment and materials from stockroom:
- R/C car
- ECE 2210 Servo

Remote-Control (R/C) car
Turn on the transmitter and the car. Operate the steering and watch the steering mechanism in the car. Find the small black box with the white wheel that operates the steering mechanism. This is the steering servo. It is not easy to get to and remove in order to examine the inner workings. For that reason we will examine a much larger version of a servo in lab today– the cheezy-looking device on the wood base.

The input to steering servo in the car is encoded information from the receiver. The input to the big servo is just a shaft that you can turn. Consider it like the steering knob on the transmitter– only we've eliminated the transmitter and receiver in between. The output shaft of the steering servo operates the steering mechanism in the car. Inside the servo there is a potentiometer which acts as a position sensor for the feedback control. The output shaft of the big servo isn't hooked to anything except a another potentiometer which also acts as a position sensor. In both servos the shaft position is compared to the desired position and the difference is amplified to control a small DC motor and gears which turns the output shaft in the right direction to eliminate the error. This is a classic feedback-loop control system.

Turn off the car and transmitter.



Experiment
Examine the big servo now and find the power switch and the power wires that are connected to that switch.

Power supply hookup
Turn on the Agilent power supply and activate the output by hitting the **Output On/Off** Button. Push the "+25V" button and then push and hold the **Track** button for a few seconds so that the - output will automatically "track" (be the same voltage value as) the + output. Adjust the + output to 6 V. Now the power supply will output $\pm$ 6 V. Turn off the power switch on the servo. Now hook up the servo as shown. (Turn the outputs off again while connecting.) Watch out, remember the HP/Agilent's **+** connection and it's **–** connection are *both* red, **–** is on the right side of ground and **+** is on the left.

Now locate the input position pot, the BNC input, the gain adjustment pot, and the motor disconnect switch. Turn on the output of the power supply and turn on the servo.

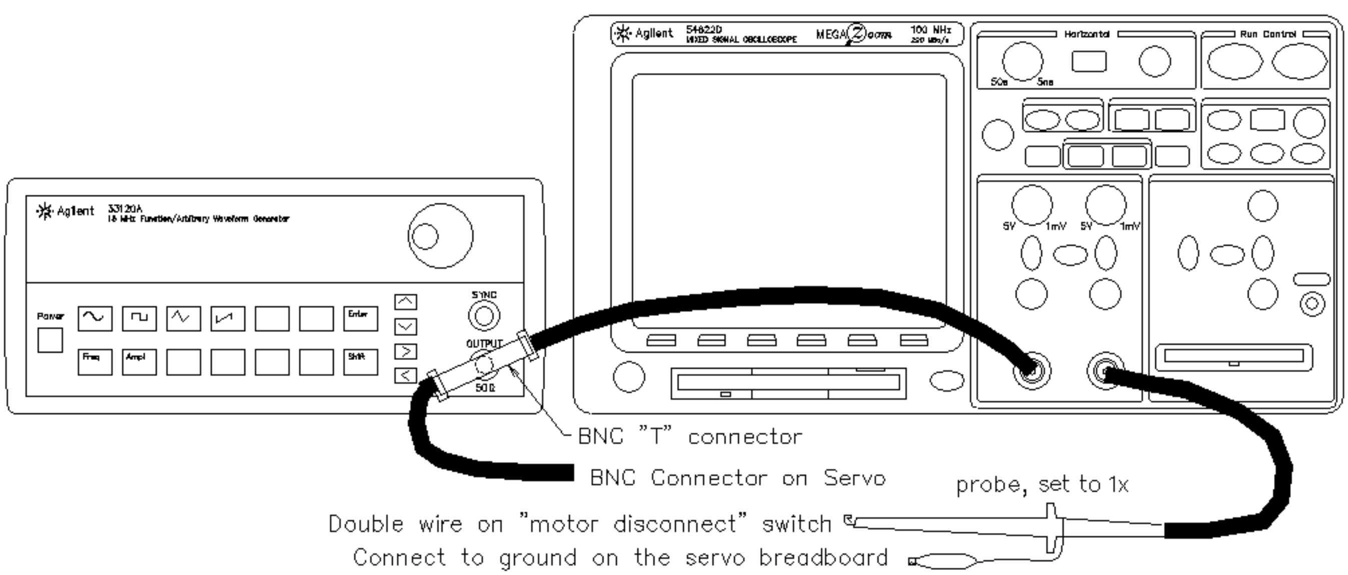
Play around with the input position shaft and watch the motor turn the output shaft to follow. (If the servo oscillates, turn down the gain.) In your lab notebook, write a short description of what the servo does. This is a very crude, slow, and weak servo, but it does illustrate how they work. Write down at least 3 uses for servos beyond the steering of the R/C car.

Setup the Servo to minimize friction

In order to get some decent comparisons between measurements and calculations you will need to eliminate any possible extra friction in the mechanical section of the servo. Turn off the power switch on the servo. Turn the servo gears 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.

Setup the Function generator and Scope

Find a BNC "T" connector, usually they are in 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 scope probe (set to 1x). The "Double wire" referred to at the "motor disconnect" switch is the bottom connection that has two wires rather than one. Trace one of the wires down to the breadboard on the servo, push in an extra wire there and connect CH2 of the scope to that wire. This is the output of the servo circuitry, normally hooked directly to the motor. There's a green wire to the left of that connection that runs from the top of the breadboard to the bottom. That is ground. Connect the scope ground where that wire is connected.



Turn on the function generator and set the **Ampl**itude to 50 mVpp (output will actually be 100 mVpp because of an Agilent weirdness). 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 !

Observe how the gain knob affects the response of the servo

Turn down the gain of the servo to minimum (fully CCW). Turn on the servo. It should move back and forth in jerks, making one move every second. Slowly turn the gain knob through its entire range to get an idea of the different types of motion that the servo can make. Return the gain to minimum and observe how little the servo moves and how sluggishly it gets there. 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 the appendix to this lab you will find a number of calculated plots of output position verses time for a step input, each for a different gain setting. Relate these to the servo outputs you've observed at various gains.

Disconnect the function generator, turn up the gain all the way, and turn the input position knob near the center of its range. What is the servo doing now? Does it relate to the last plot in the appendix?

Measure the circuit gain at important points

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. Switch down the motor disconnect switch, 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 (hit Autoscale as neccessary). Check that both scope channels are set to use 1x probes and then use the scope find the gain. You may assume the input is 0.1 V_{pp}, so the gain is just $V_{opp}/.1 = 10xV_{opp}$.

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). Recall the function generator configuration "1", switch down the motor disconnect switch, turn the red gear if necessary to get a CH2 sine wave, and measure the gain.

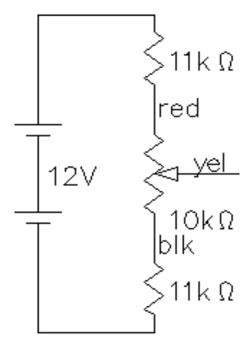
Repeat this to find the minimum gain for overshoot. This is closer to the actual minimum needed for ringing since overshoot is almost always really ringing.

The gain should range from about 1.7 to 65. Confirm this with measurements if you'd like.

Look at the calculations in the appendix. Do they correspond reasonably well with the cases that you have seen and the gains that you have measured? Notice that although the last one shows oscillation, the frequency is almost 5 Hz. Does your servo oscillate that fast? Does the oscillation continue to grow? The main reason for the discrepancies is that I've linearized and simplified the models. The theoretical response is much too fast because I've disregarded nonlinearities in the system, particularly power supply limits and amplifier clipping. There simply isn't enough power to really move that fast. The limits also keep the oscillations from growing without bounds. Additionally, I've simply modeled the time delays in the system by using an artificially high motor inductance value. Comment in your notebook.

Find the system block diagram in the appendix. You now have some experience with the gain box of this system and how it affects the system response. The comparing and gain functions of this block diagram are both performed by an instrumentation amplifier. You've already learned about an instrumentation amplifier in this class. You've also seen the power amplifier and will learn how the transistors work in ECE 2280. The motor and gears transfer function is beyond the scope of this class, although you may well be able to follow its derivation if you've had dynamics. You can learn more about these sorts of transfer functions in ECE 3510. The remaining transfer functions are the position sensors. You will find that transfer function next.

Find Kp, the transfer function of the potentiometers used as position sensors
The "INPUT POSITION" potentiometer translates shaft position into voltage. When the shaft is turned, the voltage on the center lead changes. Hook a voltmeter up to this center lead and circuit ground. The function generator should be disconnected.



Measure the voltage at the two extremes of the potentiometer rotation. The potentiometer rotates about 270°. K_p is the change in volts per change in angle. Determine K_p as volts/deg and as volts/rad.

Conclusion
Check off and conclude as always. Make sure everything is off.