

Department of Mechanical Engineering

2.010 CONTROL SYSTEM PRINCIPLES

**Laboratory Session 3:**  
**Construction of a Proportional Velocity Controller**

**Laboratory Objectives:**

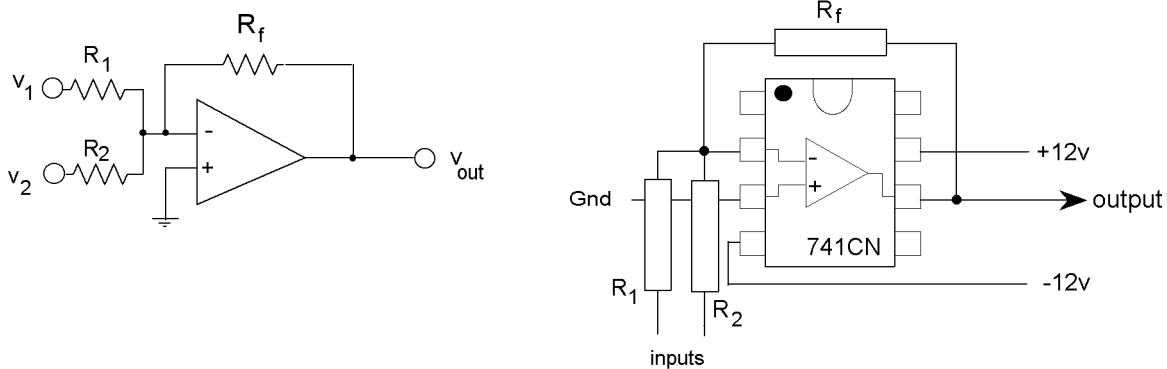
- (i) Construction and testing of an operational-amplifier summing amplifier.
- (ii) Use of the op-amp summer as a proportional velocity controller for a dc servo motor motor at a variety of controller gains.
- (iii) Measurement of the transient response characteristics and the steady-state behavior of the closed loop controller.
- (iv) Comparison of the measured performance with predictions based on the prelab exercise.

**Preparation:** You were asked to predict the transient and steady-state performance of the closed loop velocity controller before coming to the lab. Attach your prelab answers to your report.

**Wiring Guidelines:** When wiring up circuits on the circuit board, follow these guidelines:

- Make sure the power to the breadboard is turned off before wiring or rewiring a circuit. (The switch for the power supply is at the left of the power console under the computer monitor, designated “Aux 1”). When the power is on, the red light-emitting diode (LED) on the breadboard is lit.
- When building circuits, lay down wires, resistors, and capacitors at right angles and keep them flush to the surface, if possible. The circuits that you build today will serve as sub-units of larger circuits that you will build in subsequent labs. Streamlined wiring makes the circuits more durable.
- It is important that you follow our suggested component layouts. (The instructors must be able to quickly spot wiring errors in order to help you debug the circuits.) For example, the op-amp should be placed with pin 1 toward the top of the breadboard. Similarly, the op-amp feedback loop should consist of two wires going vertically from pins 2 and 6 to the same row in the circuit board above the op-amp, and should be closed by a resistor, capacitor, or whatever device is appropriate, placed across that row.
- Use the supplied pre-cut wire jumpers where possible. Note that the length of the wires is specified using the standard color code (in increments of 0.1, and 1 inch): for example a 0.3” or 3” jumper is colored orange.

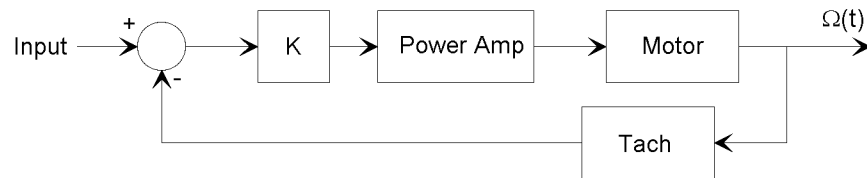
**Construction of an op-amp summing amplifier:** Refer to the class handout *Introduction to the Operational-Amplifier* (page 5) for a description of an inverting summing amplifier. Construct a summer in the lower lefthand corner of your breadboard, using the first two (left) BNC connectors as inputs, and the third BNC connector as output from the summer. (Do not connect the summer to the motor and power amplifier yet.) The circuit and layout are shown below:



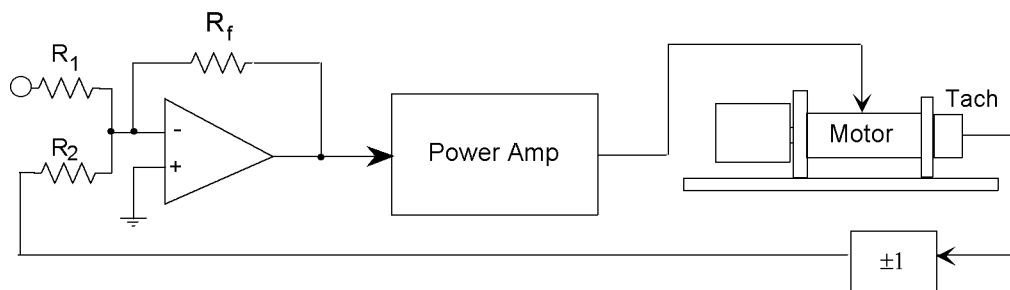
- (1) Make sure the power is off.
- (2) Place the op-amp over the central rail near the lower lefthand corner of the circuit. Leave some space below it, but make sure that its pins do not line up with gaps on the side rails that deliver power and ground.
- (3) Connect  $+V_{ss}$  (pin 7) to the +12 V input rail (orange wire) and  $-V_{ss}$  (pin 4) to the -12 V input rail (clip the proper length of green wire and bend to an L shape).
- (4) Connect the non-inverting input (pin 3) to the ground (0 v) rail. (orange wire).
- (5) Install the feedback resistor across the top of the op-amp. Use two jumpers that differ in length by 0.1" to connect the inverting input (pin 2) and the output (pin 6) to the same row above the op-amp. Close the loop using a 10 k $\Omega$  resistor (don't trim its leads yet).
- (6) Using vertical and horizontal wiring, connect each input (i.e., the first two BNC connectors) via a 10 k $\Omega$  input resistor to the inverting input (pin 2, also called the 'summing junction') as in the circuit diagram.
- (7) Connect the output (pin 6) to the third BNC connector.
- (8) Check your wiring for mistakes. When you think it's OK, turn on the power.
- (9) Write an expression for the for the output  $v_{out}$  of the amplifier. Use the function generator to supply an input voltage waveform to one of the inputs and monitor the output on the oscilloscope. Are the input and output in phase? Now apply the function generator signal to both inputs. Does the inverting summer live up to its name?

- 10 Turn off the power and the function generator and substitute a 49.9 k $\Omega$  resistor for the 10 k $\Omega$  resistor in the op-amp feedback loop. Write an expression for the for the output  $v_{out}$  of the amplifier with the new resistor. Turn on the power and supply various inputs. Describe your observations briefly in your report.

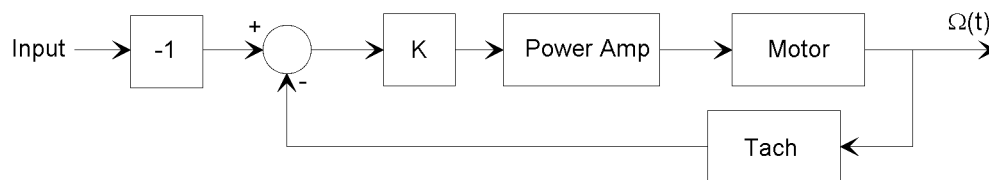
**Proportional control of the motor:**



The above figure shows the block diagram of a proportional velocity controller for the servo motor. Below a single op-amp implementation is shown. Assume  $R_1 = R_2 = R_{in}$ . The op-amp acts both as the summer and the gain block, with the controller gain  $K = R_f/R_{in}$ . Note the block with a gain of  $\pm 1$  in the feedback path. This corresponds to the switch on the tachometer terminal box that allows you to choose the sign of the feedback.



There is one minor problem with this implementation: the amplifier inversion effectively causes an inversion of the input command, so that the actual block diagram should be:



and the output angular velocity  $\Omega(t)$  will be the negative of the input command.

- (1) Turn off the power to your circuit and turn off your function generator. Make sure your servo power amplifier is off.
- (2) Replace the 49.9 k $\Omega$  feedback resistor in the feedback with 10 k $\Omega$  resistor to give a gain of -1 for the summer.

- (3) Connect the system as indicated above, and use the function generator to provide the command input. Monitor both the FG output and the tachometer on the oscilloscope.
- (5) Supply a 1 Volt 0.5 Hz square-wave input from the function generator. Turn on the circuit board power supply.
- (6) Turn on the power amplifier. What happens? Flip the switch on the tachometer. What happens now? Which setting of the tachometer switch gives positive feedback, and which gives negative feedback? Why? Note and discuss your results in your report.
- (7) Compare the input signal with the tachometer output. Note and discuss any deviation of the output velocity from the desired velocity. Are the input and output in phase with each other? If not, why not?

**Measure the Response of the Closed-loop System:** Repeat the following measurements for controller gains  $K = 1, 5, 10$  by changing the op-amp feedback resistor:

- (1) Measure and record the time constant of the circuit using a square wave input. Use the oscilloscope *rise-time* measurement. How does the measured value compare with the value predicted by the transfer function derived in the prelab exercise? Make a plot of the time constant against controller gain, and show the theoretical values on your plot. (You may want to use an Excel spreadsheet to make the plot.)
- (2) What did your prelab exercise predict for the steady state error in response to a constant (step) input? Use the math channel on the oscilloscope to display the measured error. (Do you need to add or subtract the input and response?) Is it finite? Does the static motor friction as measured in Lab Session 2 account for the measured error?
- (3) Perform a qualitative test of disturbance rejection by adding friction with your hand. Note any differences at the three amplifier gains.