

ME 104
Sensors and Actuators

Laboratory 6b
Closed Loop Analog Control
Of DC Motor Velocity

Department of Mechanical Engineering
University of California, Santa Barbara

Introduction

In this laboratory, you will continue investigating closed-loop feedback control of a DC motor. Your ultimate goal is to control the DC motor such that the velocity (voltage) output \mathbf{V}_{OUT} is equal to a (desired) reference (voltage) input \mathbf{r} . In Lab 6a, you built analog proportional (P) and integral (I) control circuits. Now, you will combine these circuits into a proportional-integral (P-I) control circuit.

Background Reading

Please read the following material prior to this lab:

1. Hystand and Alciatore, **Introduction to Mechatronics**, Sections **5.1-5.8** and Sections **5.10-5.11**.
2. **DC Motor Control Module User Manual, Pages 3-7 and 14-16**, LJ Technical Systems Inc.

Experiment 1b: Proportional-Integral (PI) Control of DC Motor

Velocity

In this experiment, you will use a LabVIEW VI and a proportional-integral (PI) feedback control circuit to control a DC motor. Mathematically, the PI controller can be described in the time domain as

$$u_{PI}(t) = u_P(t) + u_I(t) = K_P e(t) + K_I \int_0^t e(\eta) d\eta$$

where K_P and K_I are constant gains.

1. Use op-amps 1 and 2 on the LMC6484 op-amp on the **RIGHT** on the breadboard to build the circuit shown in Figure 1. Provide the inputs (\mathbf{u}_P and \mathbf{u}_I) to this circuit from the circuits you built in Experiment #2a and #3a of Lab 6a. Choose the resistors such that $R = 10 \text{ k}\Omega$. Then, K_P and K_I will remain unchanged from Experiment #2a and #3a.

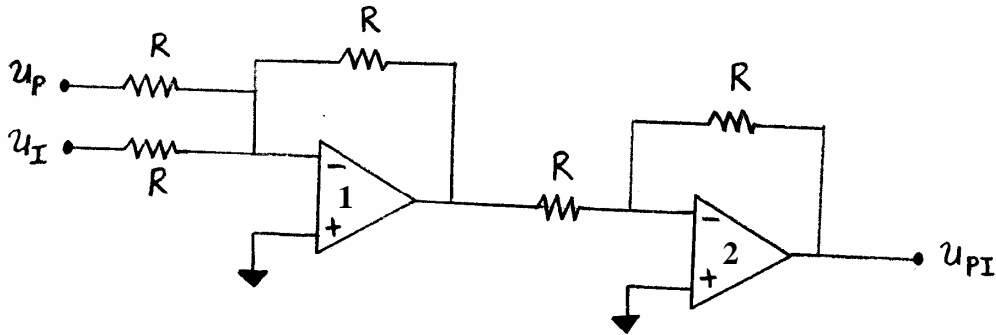


Figure 1. A portion of the PI control circuit. This portion consists of a summer (that sums the proportional and integral control signals) followed by an inverting amplifier with unity gain. (Note that power supply connections are not shown for clarity).

2. To drive the motor using the PI control signal u_{PI} from the feedback control circuit, connect your motor control module and feedback circuit to the CB-68LP connector block as shown in Table 1.

Table 1. CB-68LP connector block pin assignments for PI control of DC motor velocity.

DC motor module & Control circuit	Connect to:
r – reference signal to P-control circuit	A00
V_{IN} socket (Analog voltage) on MOTOR DRIVE INPUT panel	PI feedback circuit output (u_{PI} connection).
V_{OUT} socket (Analog voltage) on TACHOGENERATOR OUTPUT panel	AI0 and PI feedback circuit input (y connection).
Ground on DC power supply*	AIGND
Ground on DC power supply*	AOGND

*The connector block can also be grounded to the breadboard if the breadboard is grounded to the DC power supply.

3. Connect your DC motor control module to your oscilloscope such that the reference r (A00) is viewed on Channel 1 and the velocity feedback V_{OUT} (Tachogenerator output) is viewed on Channel 2.
4. Make sure the **Eddy Current Brake** is disengaged. That is, make sure it is in the 0 position.
5. Open and run `yourname_MotorDrive_AcquireVoltage.vi` by clicking the **Run Continuously** button. Increment your Motor Drive Input Control by 1 V from -5.00 V and $+5.00$ V, inclusive, and observe the voltage signals on Channels 1 and 2 of your oscilloscope. Make a sketch of the transient behavior and

write down the steady state values of \mathbf{r} and \mathbf{V}_{OUT} as displayed by the digital indicators on your VI front panel.

6. Set the **Eddy Current Brake** to the 1 position and repeat Step 5.
7. Set your Motor Drive Input Control to 0.00 and stop running the VI by clicking the **Abort Execution** (stop) button.

Your plant $P(s)$ should show zero steady state error for all reference values and your system should show little or no transient oscillations. In other words, not only will the velocity signal \mathbf{V}_{OUT} equal the reference value \mathbf{r} at steady state, but also, the velocity will achieve its intended target with little or no overshoot.

Saving Files

Before you leave, remember to save all of your files to your ECI account (for later use and backup purposes).

Laboratory Report

1. Add the data you collected with the **Eddy Current Brake** in the 0 position to last week's data. Provide a graph of steady-state velocity (voltage) output \mathbf{y} versus reference (voltage) signal \mathbf{r}^1 for the following control methods: (a) open loop, (b) proportional, (c) integral, and (d) proportional-integral. For comparison, all four control methods should be plotted on the same graph. Clearly indicate which plot corresponds to which control method and compare the steady-state performance of the different control methods.
2. Repeat Question 1 for data you collected with the **Eddy Current Brake** in the 1 position. Is there a notable difference between your plots in Question 2 and 3? Explain.
3. Draw a complete diagram of the analog PI control circuit you built in Experiment #1b. The inputs² to your circuit diagram should be \mathbf{y} and \mathbf{r} , while the control output should be \mathbf{u}_{PI} . Clearly label the error \mathbf{e} and the proportional control \mathbf{u}_{P} and integral control \mathbf{u}_{I} .
4. In Experiment #1b, the PI control circuit you built used 6 op-amps (two LMC6484 chips). Design and draw a circuit diagram in which the same PI controller is implemented using only 4 op-amps (one LMC6484 chip). Retain the same difference amplifier (error calculating op-amp) as before. (Hint: One of your remaining three op-amps must be an integrator.) The inputs to your circuit diagram should still be \mathbf{y} and \mathbf{r} , while the control output should be \mathbf{u}_{PI} . Clearly label the error \mathbf{e} . Explain how your new circuit design works.

¹ Your x-axis should consist of the values $\mathbf{r} = [-4, -3, -2, -1, 0, 1, 2, 3, 4]$, with units in volts.

² Naturally, the ground and power connections should also be shown.