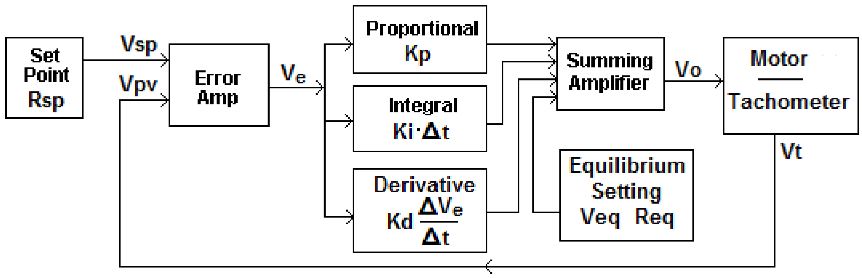
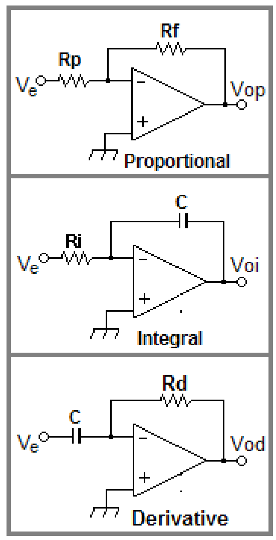
<u>Experiment 7: PID Motor Speed Control</u>

Introduction

The error output, **Ve**, of the tachometer circuit from experiment 6 will be connected to the input of a PID controller.   The output of the PID controller, **Vo**, will be connected to **Vb** of the motor drive circuit (darlington transistor, TIP120). Refer to the block diagram below.



A review of the PID control components and operational amplifier implementation is presented below.



The proportional controller's output is:

$$Vop = -K_P \cdot V_e. \qquad K_P = \frac{Rf}{Rp}$$

The integral controller's output is:

$$Voi = \frac{-1}{Ri \cdot C}\int V_e dt. \qquad \text{If } V_e \text{ is constant, } Voi = -Ki \cdot V_e \cdot \Delta t \quad \Rightarrow \quad Ki = \frac{1}{Ri \cdot C}.$$

The derivative controller's output is:

$$Vod = -Rd \cdot C\frac{dV_e}{dt}. \qquad \text{If } \frac{dV_e}{dt} \text{ is constant, } Vod = -Kd\frac{\Delta V_e}{\Delta t} \quad \Rightarrow \quad Kd = Rd \cdot C.$$

Controller's response, Vo, is given by the sum of the responses: $Vo = Vop + Voi + Vod$.

This experiment has three parts. In part one the motor's response to a change in set-point and load will be investigated using only proportional control.

In part two the motor's response to a change in set-point will be investigated using proportional plus integral control.

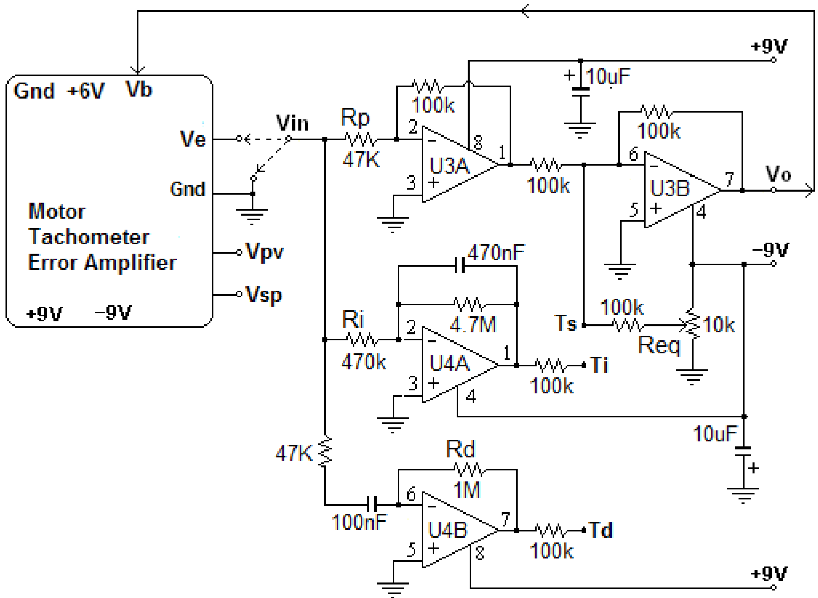
In part three the motor's response to a change in set-point will be investigated using proportional plus integral plus derivative control.

Parts and Equipment Required

Oscilloscope / Data Logger, DMM, Power Supply: 0 to 6V, 2 amps; +/- 9 volts.
ICs: LM35, two LM358, Transistor: TIP120 or equiv.
Resistors: Five 100k, 220, 820, 91k, ¼W, 5%.
Potentiometers: 10k, one turn trim pot. Capacitors: two 10µF, 10nF, 470nF.
Motor-generator-tachometer set.

Procedure Part 1: Proportional Control

1. Study the PID control system schematic diagram below. The motor-tachometer-error amplifier circuit of experiment 6 is connected to the proportional, integral, derivative, and summer op-amp circuits as shown. U3A is a proportional amplifier. U4A is an integrator, and U4B is a differentiator. U3B sums the proportional, integral, and derivative components and the equilibrium voltage.



Procedure

2. Build and connect the PID controller circuit as shown in the diagram above, but do not turn on the power supplies.

3. Connect **Vin** to ground (not to **Ve**). Connect oscilloscope channel 1 to **Vsp** and channel 2 to **Vpv**. Set both channels to DC input, 0.5 volt per division.

   Set the zero reference for both channels to the bottom of the screen so that you can measure zero to four volts with both channels.

   Set the time base to 100µSec per division and the trigger to AUTO and external input.

4. Turn on the power supplies. Motor speed jumper, **Jsp**, should be connected. Measure the set point voltage, **Vsp**, (ch. 1) and the set point motor speed in rpm.

   Vsp: ____________________ RPM: ____________________

5. Adjust equilibrium (offset) potentiometer, **Req**, so that **Vpv** (on channel 2 of the oscilloscope) is equal to **Vsp**.

6. Disconnect **Vin** from ground. Connect **Vin** to **Ve**. This enables the proportional control mode. Check that the motor speed, **Vpv**, remains at the set point speed. The motor is now running under proportional control with a proportional gain of about 2.

7. Set time base to 1 second per division. Set trigger mode to "auto" and the trigger point to the left edge of the screen. Each scan will be for a duration of 10 seconds.

8. The objective of the following procedure is to capture the motor speed response to a change in set point, **Vs**, and to a change in load. The set point will be changed by pulling out the jumper, **Jsp**.

   Use waveform capture software, such as "Tek OpenChoice", to capture the motor's response. The lab instructor may have additional information.

   a) Begin with the motor running at the equilibrium speed (about 2800 rpm – **Jsp** is connected). Start the acquisition when the trace is on the left side of the screen.

   b) After about 4 seconds (4 horizontal divisions) change the set point by pulling out jumper, **Jsp**. Stop the capture when the trace reaches the right side of the screen.

   c) Save the result to a word processor file named Exp 7. Label the response type as "Kp = 2, set point change".

   d) Repeat step (a). After about 4 seconds (4 horizontal divisions) connect a 47 ohm load resistor to the generator. The resistor should be able to be connected to the generator by inserting one wire into the protoboard. Stop the capture when the trace reaches the right side of the screen. Remove the 47 ohm resistor.

   e) Save the result to the word processor file named Exp 7. Label the response type as "Kp = 2, load change".

   f) Replace Rp with a 4.7k resistor to change the proportional gain to 10. Repeat steps (a) and (b).

   g) Save the result to the word processor file named Exp 7. Label the response type as "Kp = 10, set point change".

   h) Repeat step (a). After about 4 seconds (4 horizontal divisions) connect a 47 ohm load resistor to the generator. Stop the capture when the trace reaches the right side of the screen. Remove the 47 ohm resistor.

i) Save the result to the word processor file named Exp 7. Label the response type as “Kp = 10, load change”. Reconnect **Jsp**.

Procedure Part 2: Proportional + Integral Control

1. Change the proportional gain back to 2 by replacing Rp with a 47k ohm resistor. Check that the motor is running at the equilibrium speed (about 2800 rpm).

2. Connect circuit node **Ti** to circuit node **Ts**. This adds an integral gain of about 4.5.

   a) Begin with the motor running at the equilibrium speed (about 2800 rpm – **Jsp** is connected). Start the acquisition when the trace is on the left side of the screen.

   b) After 4 seconds (4 horizontal divisions) change set point by pulling out jumper, **Jsp**. Stop the capture when the trace reaches the right side of the screen.

   c) Save result to the file named Exp 7. Label the response type as “Kp = 2, Ki = 4.5, set point change”.

   d) Change the integral gain to 9.7 by replacing Ri with a 220k ohm resistor. Repeat steps (a) and (b). Save the result to the word processor file named Exp 7. Label the response type as “Kp = 2, Ki = 9.7 set point change”.

Procedure Part 3: Proportional + Integral + Derivative Control

1. Check that the motor is running at the equilibrium speed (about 2800 rpm).

2. Connect circuit node **Td** to circuit node **Ts**. This adds a derivative gain of about 0.1.

   a) Begin with the motor running at the equilibrium speed (about 2800 rpm – **Jsp** is connected). Start the acquisition when the trace is on the left side of the screen.

   b) After 4 seconds (4 horizontal divisions) change set point by pulling out jumper, **Jsp**. Stop the capture when the trace reaches the right side of the screen.

   c) Save result to the file named Exp 7. Label the response type as “Kp = 2, Ki = 4.5, Kd = 0.1”.

   d) Increase the derivative gain by replacing the 100nF capacitor with a 470nF.

   e) Repeat steps (a) through (c).

3. Optional: Based on the results of all three parts of this experiment, vary the proportional, integral, and derivative gains to optimize the motor’s response to a change of set point.

Analysis

Write an analysis for each screen capture that includes:

1. Steady state error.
2. Rise and fall times.
3. Over-shoot and under-shoot.
4. Settling time.
5. Oscillation frequency if under damped.
6. Optional part, part 3 step 3: present the results of optimizing the motor's response.

Write a summary or conclusion at the end of the report. Divide the report into three sections: proportional only, proportional plus integral, and proportional plus integral plus derivative.

Divide the proportional section into set point change results and load change results.

Each group may collaborate on the report and turn it in as a group project.