The University of Jordan
School of Engineering
Electrical Engineering Department

EE 449
Instrumentation and Control Lab

EXPERIMENT 8
PID CONTROLLER

Prepared by: Prof. Mohammed Hawa

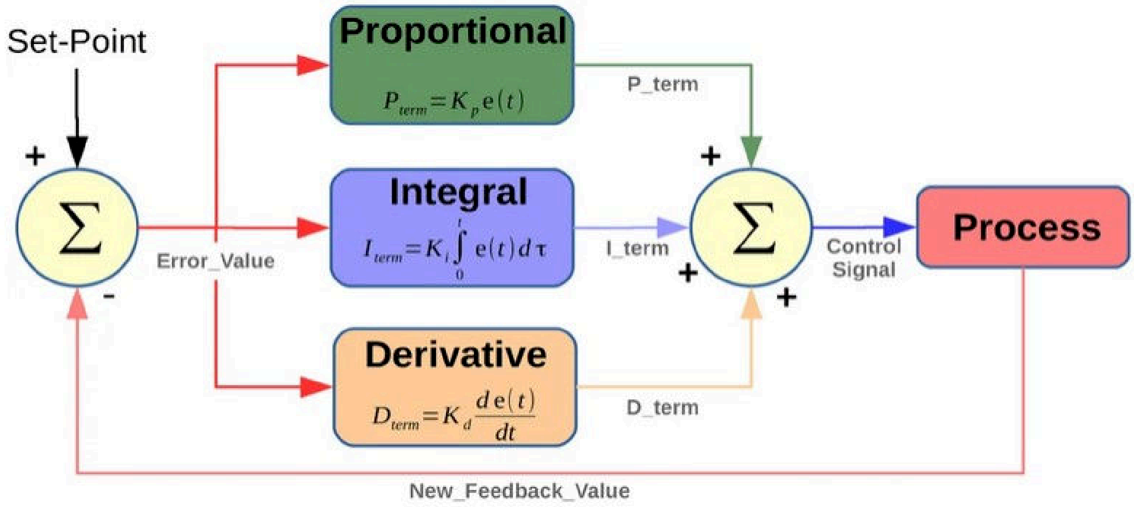
EXPERIMENT 8
PID CONTROLLER

OBJECTIVES

1. To understand the basic principles behind PID controller.
2. To recognize the effects of the gain parameter for each term in the PID controller.
3. To design a PID controller using trial-and-error method to control DC servo motor position.

DISCUSSION

A proportional-integral-derivative (PID) controller is a form of feedback controller that is popular in industrial control systems. The PID controller compares the desired target value (called *setpoint*) with the actual *output value* of the *system* (also known as *process* or *plant*). The difference between the setpoint and output value is the *error value*, and is denoted by $e(t)$ below. Three terms are generated from this error value: proportional, integral and derivative terms as shown in the figure. The sum of these three terms is used to control the system to force the output value to be the same value as the setpoint.



The proportional (P) component is the *current* error value multiplied by gain K_p. This provides correction based on how far the system is from the desired setpoint, *speeding up* the system response. The integral (I) component represents the *cumulative sum* of past errors, which helps eliminate any *residual steady-state error* that persists over time. Finally, the derivative (D) component predicts future error by using the *rate of change* of the error. This helps *reduce overshoot* and enhance system stability, especially when the system goes through rapid changes.

Hence, the control signal, $u(t)$, is written mathematically as the sum of the above three terms:

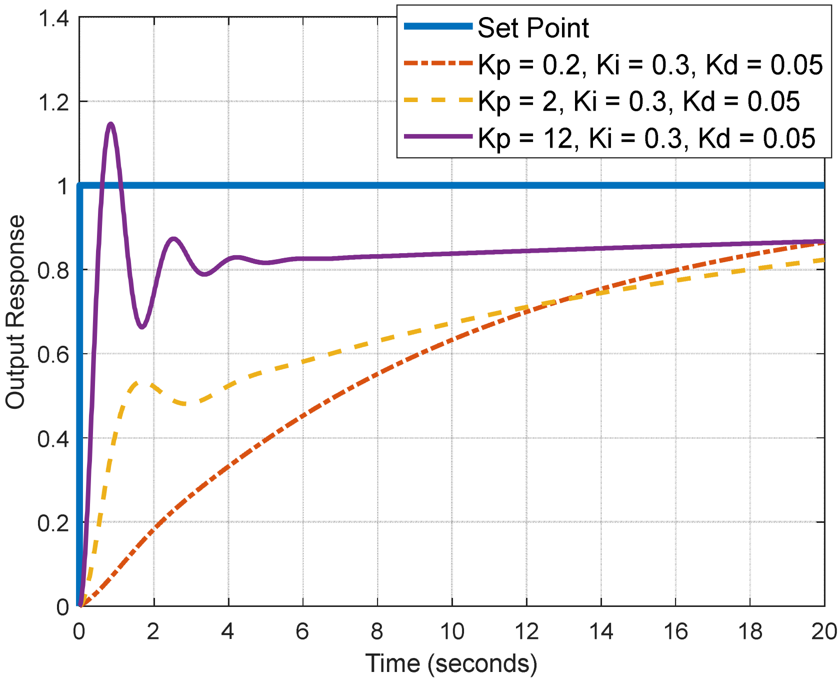
$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau + K_d \frac{de(t)}{dt}$$

Equivalently, the transfer function of the PID controller in the Laplace domain is:

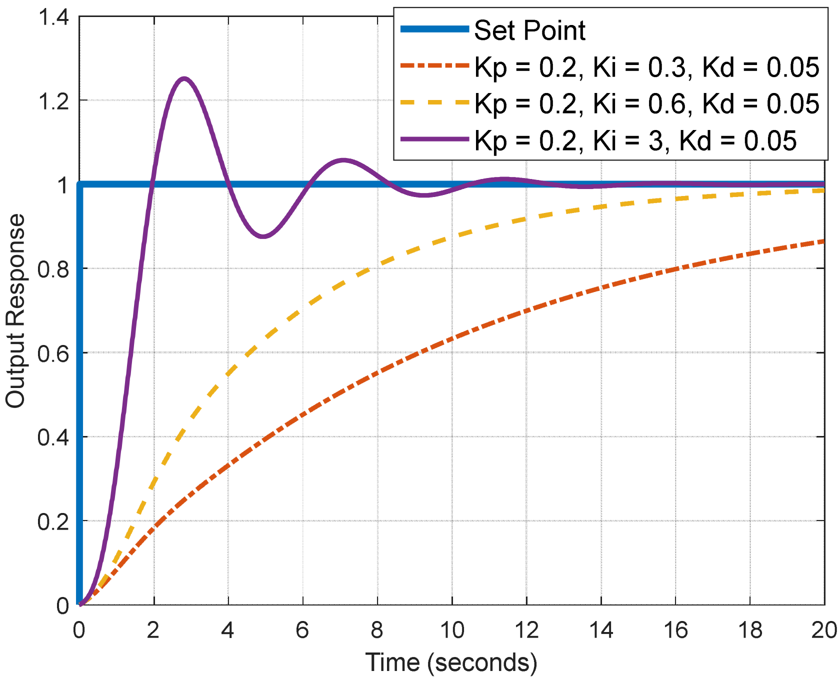
$$L(s) = K_p + \frac{K_i}{s} + K_d\, s$$

Tunning a PID controller refers to the process of balancing the effects of the three terms (P, I and D) by selecting proper gain constants: K_p, K_i and K_d. The desired controller behavior is to force the output value to reach a new setpoint with minimal delay (i.e., small settling time) and minimal overshoot. There are various suggested empirical techniques for setting the gain parameters, such as the Ziegler–Nichols technique, the Åström-Hägglund technique, etc. Such techniques are suitable in certain situations, but not all scenarios. Here, you will attempt to perform manual tuning, where you will go through an iterative trial-and-error procedure to set the different gain parameters. Usually, this process is time consuming, but can be expedited if you have enough experience.

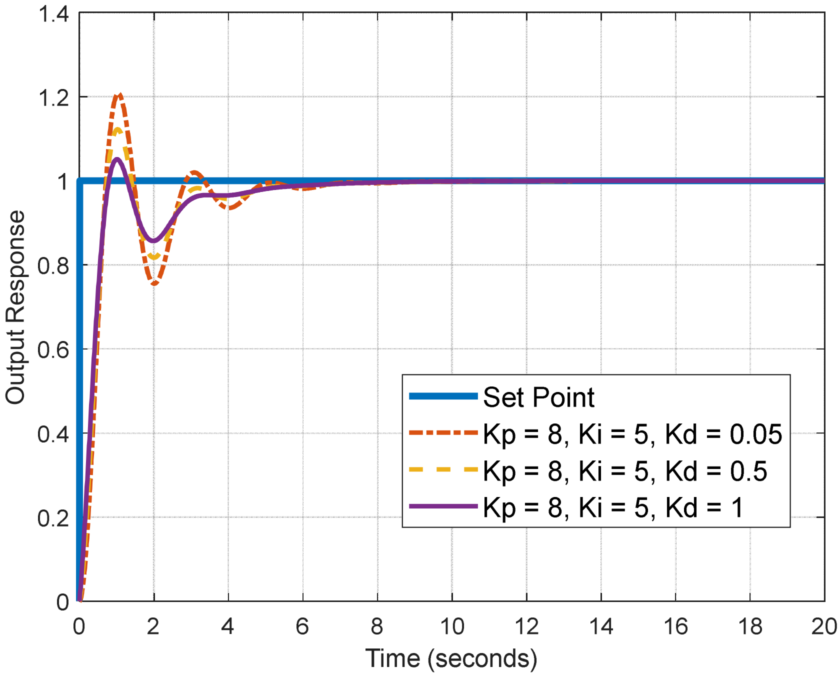
The figure below shows the effect of the proportional gain K_p. As the proportional gain is increased, we get an increasingly aggressive controller, where the response of the control loop becomes faster and faster. After increasing K_p beyond a certain value, the control loop starts oscillating and becomes unstable. A good setting is when there is a noticeable overshoot, but that overshoot quickly subsides.



For the integral gain K_i, increasing this value allows the system to reach the desired set point and avoids steady-state errors. However, a large integral gain can lead to unwanted oscillations or even instability. You want a value between small gain for more robust control and large gain to allow for very small steady-state errors.

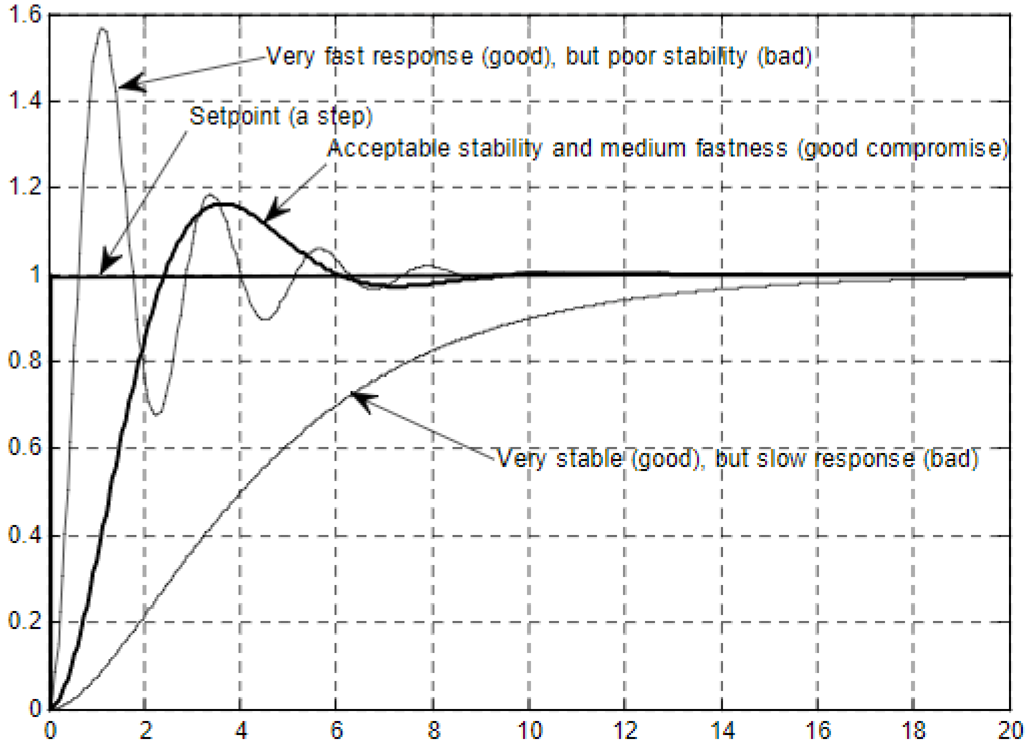


The differential gain K_d can be kept small for many practical applications. However, increasing the differential gain slightly can sometimes lead to more satisfactory performance by decreasing the resulting oscillations, while reducing the settling time. Typically, a larger differential gain K_d can also allow higher values of proportional gain K_p to be selected without the system starting to oscillate.



It is important to note that a PID controller is always a linear controller that can only be adjusted well for one operating point in a nonlinear world. Its response can change dramatically for other operating points depending on the nonlinearity of the process being controlled. Hence, a previously well-tuned PID controller can suddenly start to oscillate at a different operating point (say, when applying a partial load on the system instead of a full load).

To avoid such problems, the PID controller in real life is typically tuned so it can operate robustly under different operating points. In general, there is always a tradeoff between performance and robustness. Many engineers choose the gain parameters to provide a slower (more stable) operation, so that the controller stays stable under changing operating conditions. The figure below shows the desired response from a well-tuned PID controller.

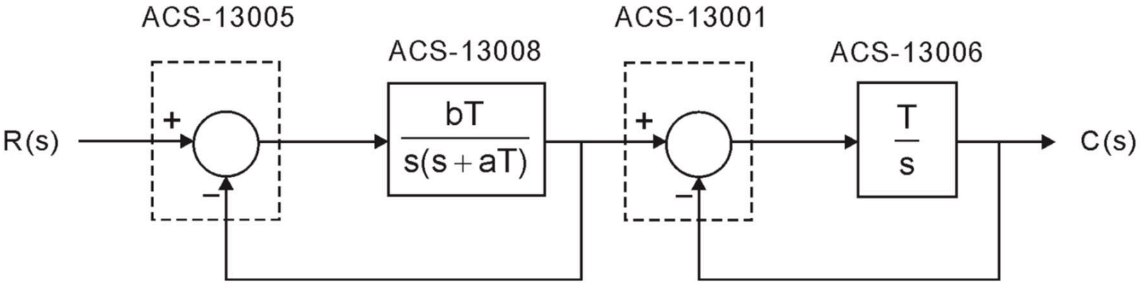


PROCEDURE A – CONTROLLING A HIGH-ORDER SYSTEM

1. You want to build and control the following plant:

$$\frac{800}{(s+10)(s^2+20\,s+80)}$$

2. You can build this plant using the following system block diagram:



3. Show below the mathematical calculations which illustrate that the ACS-13001 and ACS-13006 blocks combined produce the transfer function:

$$\frac{T}{s+T}$$

. . . .

. . . .

. . . .

. . . .

4. Calculate the transfer function produced by the blocks ACS-13005 and ACS-13008 combined:

. . . .

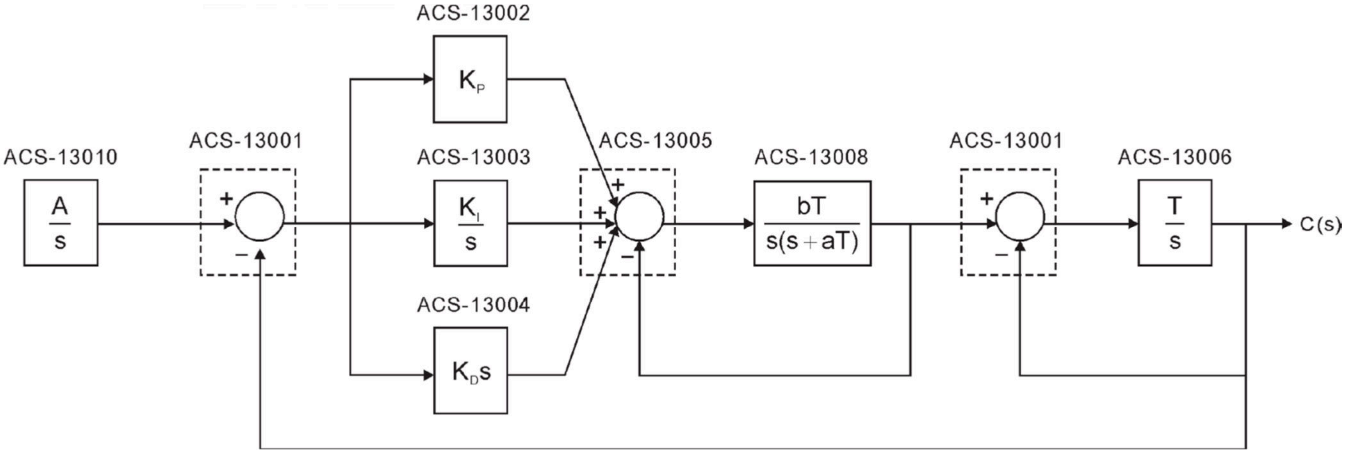
. . . .

. . . .

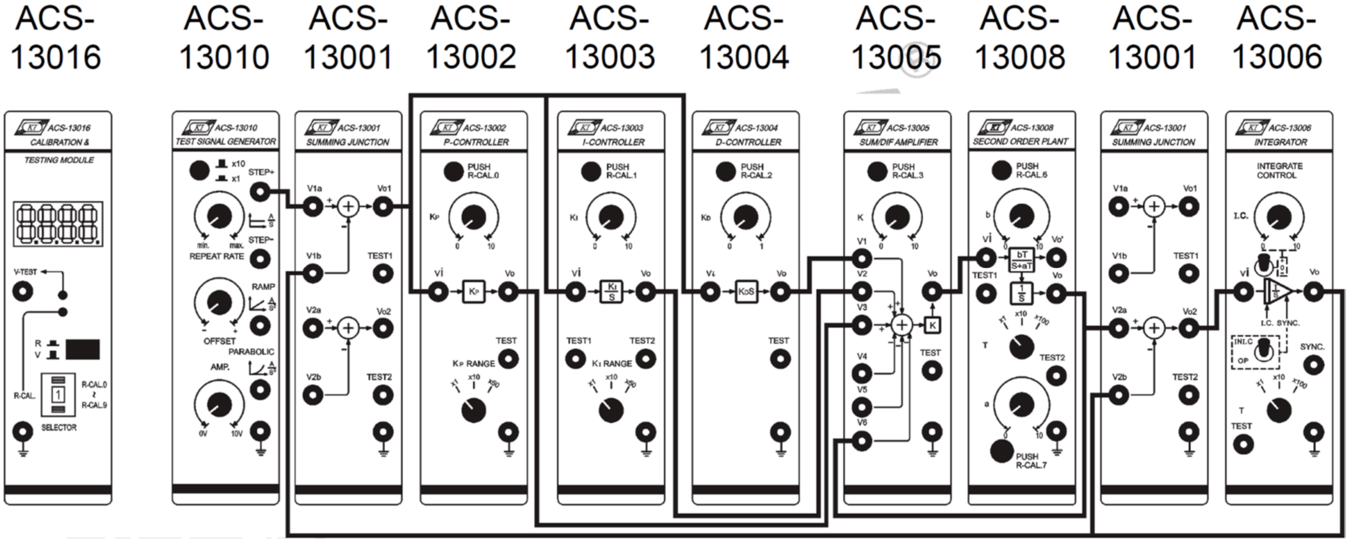
. . . .

. . . .

5. The block diagram below shows the PID controller (ACS-13001, ACS-13002, ACS-13003, ACS-13004, ACS-13005) added to the system, along with the ACS-13010 TEST SIGNAL GENERATOR.



6. Build the above system using the Analog Control Kit by completing the connections shown in the following wiring diagram.



7. On ACS-13005, set **K = 1**. You can do that by first setting the SELECTOR switch to R-CAL.3 on ACS-13016 and setting the R/V switch to R position. Now the kit displays the **K** value on the 7-segment display of ACS-13016. Then on ACS-13005, press R-CAL.3 pushbutton switch, and simultaneously turn the **K** control knob until the ACS-13016 displays 10 *times* your desired value (i.e., **displayed value of 10**).

8. On ACS-13008, set **a = 2**, **b = 8**, and **T = 10**. Notice that you can change **a** and **b** parameters in the range 0~10, while the **T** parameter can only be set to one of three possible values: 1, 10, 100. Set **T = 10** using the selector switch in the middle of ACS-13008 module.

9. On ACS-13006 INTEGRATE module, place **T** selector switch in the **x10 position** (i.e., set **T = 10**), and set SYNC switch to OP mode (to synchronize integrator to output).

10. In order to show the **b** parameter on the 7-segment display of ACS-13016, set the SELECTOR switch to R-CAL.6. On the other hand, to show the **a** parameter, set the SELECTOR switch to R-CAL.7. The ACS-13016 displays 10 *times* your desired value. Hence the **displayed** values will be **20** for **a** and **80** for **b**.

11. Use an oscilloscope to display the setpoint and output values. Use CH1 of the oscilloscope to display the signal at ACS-13010 STEP+ output terminal (setpoint) and CH2 to display the ACS-13006 Vo signal (output value). Set both CH1 and CH2 vertical scales to **500 mV/DIV** and set both channels to **DC coupling**. Set trigger type to **Edge**, trigger mode to **Auto** and trigger source to **CH1**. Set the horizontal time scale to **1 sec/DIV**. At this scale, the oscilloscope runs in the roll mode, which means you need to be patient as the oscilloscope takes some time to draw the slowly varying traces. Once you see the result you want to record, press the STOP button to freeze the trace and then you can draw it. Afterwards, press the same button again to let the oscilloscope resume tracing the output. You can also offset the traces by two division downward for better visual clarity. **Do not use** the MEASURE feature of the oscilloscope as it does not work in the roll mode. Also **avoid** using the Auto SET feature.

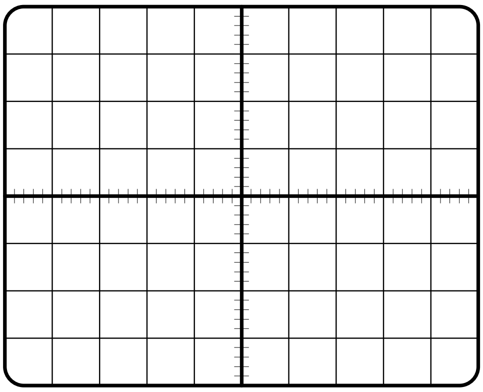
12. On ACS-13010, generate a **0.05 Hz**, **2Vpp square** wave at STEP+ output terminal (i.e., one cycle every 20 seconds or half cycle every 10 seconds). You can adjust the AMP control knob to change the output signal amplitude, and adjust the REPEAT RATE control knob to set the output frequency. Set the x1/x10 switch to **x1 position** to obtain 0.05 Hz. Set the OFFSET knob so that the low level = **0V** and high level = **2V**. Be careful that changing the AMP might affect the OFFSET and vice versa, so double check the signal on the oscilloscope as you make your modifications. Read the divisions on the oscilloscope screen, and do not rely on the MEASURE feature

13. Set ACS-13002 **K_P = 5.18**. To do that, set the SELECTOR switch to R-CAL.0 on ACS-13016 and set the R/V switch to R position. Then on ACS-13002, press R-CAL.0 pushbutton switch, and simultaneously turn the K_P control knob until the ACS-13016 displays 10 *times* your desired value (i.e., **displayed value of 51.8**). Also make sure the selector switch for **K_P** is set to **x1 position**.

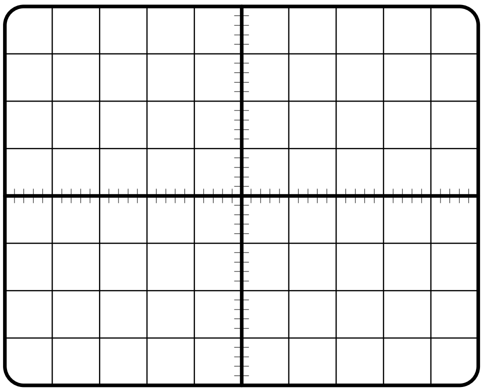
14. Set ACS-13003 **K_I = 0.09**. To do that, set the SELECTOR switch to R-CAL.1 on ACS-13016 and set the R/V switch to R position. Then on ACS-13003, press R-CAL.1 pushbutton switch, and simultaneously turn the K_I control knob until the ACS-13016 displays 10 *times* your desired value (i.e., **displayed value of 0.9**). Also make sure the selector switch for **K_I** is set to **x1 position**.

15. Set ACS-13004 **K_D = 0.037**. To do that, set the SELECTOR switch to R-CAL.2 on ACS-13016 and set the R/V switch to R position. Then on ACS-13004, press R-CAL.2 pushbutton switch, and simultaneously turn the K_D control knob until the ACS-13016 displays 100 *times* your desired value (i.e., **displayed value of 3.7**).

16. Measure and record below the signals at ACS-13010 STEP+ output and ACS-13006 Vo output terminals. Only show the **10 seconds** when the input signal goes from low voltage (**0 V**) to high voltage (**2 V**). Wait for a minute or so for the system to settle before recording the output.



17. Adjust ACS-13002 **$K_P = 6.84$** (i.e., **displayed value of 68.4 and x1 position**), ACS-13003 **$K_I = 0.66$** (i.e., **displayed value of 6.6 and x1 position**), and ACS-13004 **$K_D = 0.628$** (i.e., **displayed value of 62.8**). Measure and record below the signals at ACS-13010 STEP+ output and ACS-13006 Vo output terminals. Only show the **10 seconds** when the input signal goes from low voltage to high voltage. Wait for a minute or so for the system to settle before recording the output.



18. Explain the effect of increasing the proportional gain K_P on your results:

. . . .

. . . .

. . . .

. . . .

19. Explain the effect of increasing the integral gain K_I on your results:

. . . .

. . . .

. . . .

. . . .

20. Explain the effect of increasing the derivative gain K_D on your results:

. . . .

. . . .

. . . .

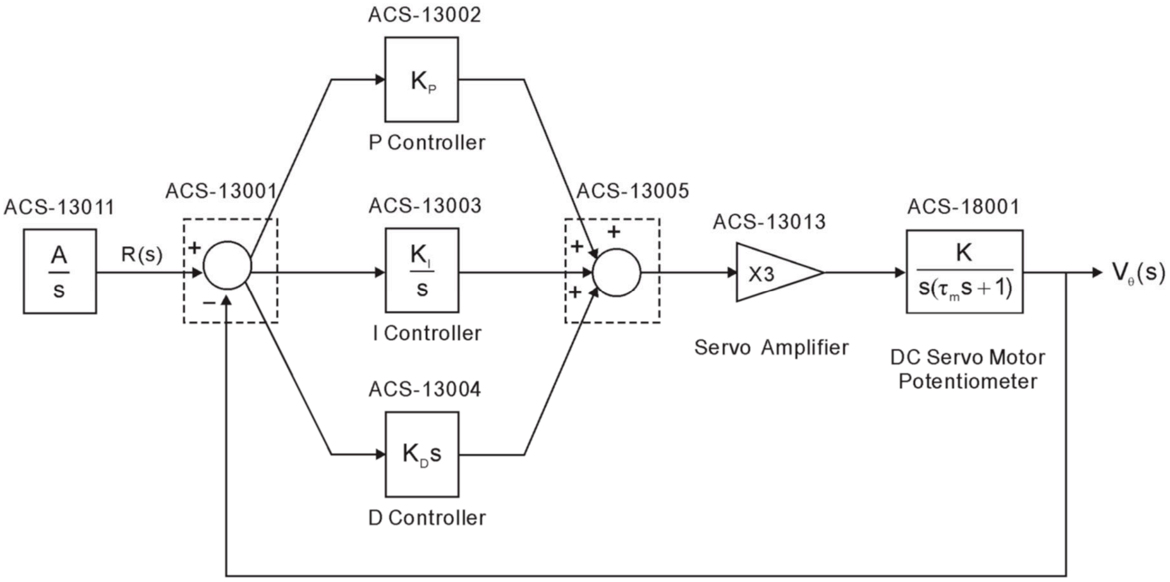
. . . .

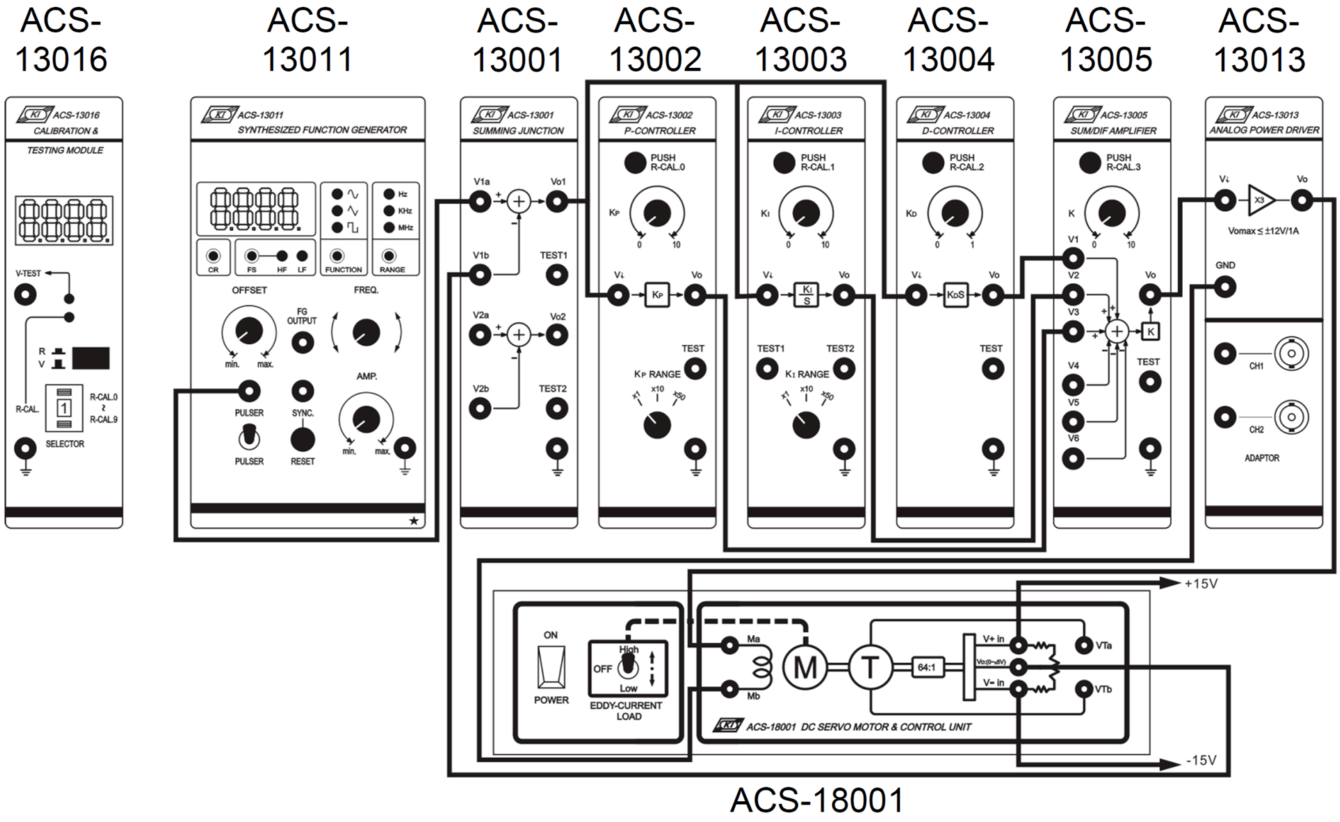
PROCEDURE B – CONTROLLING MOTOR POSITION

1. Complete the connections for the DC servo motor position control system using a PID controller by referring to the block and wiring diagrams shown below. Remember to use the ACS-13013 Analog Power Driver, and read the position of the motor as your feedback.

2. Use an external dual-output DC supply, and set it to operate in the SERIES mode in order to provide the +15V and -15V to the potentiometer reading the motor position. Check the voltages using a multimeter and show your connections to the lab supervisor before turning the DC supply ON.

3. Turn the Eddy current breaks on the motor ON, and set it to the **LOW load** setting.



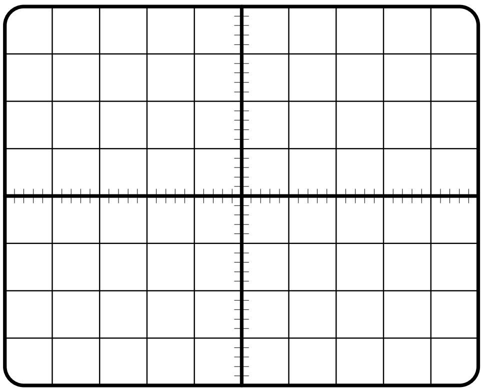


4. On ACS-13011, pull the OFFSET control knob, adjust both the OFFSET and AMP control knobs to generate a 4Vpp pulse (low level = -2V and high level = 2V) at PULSER output terminal. Watch the signal on the oscilloscope as you push the PULSER knob. Set both CH1 and CH2 vertical scales to **1 V/DIV** and set both channels to **DC coupling**. Set the horizontal time scale to **5 sec/DIV**. Be careful that changing the AMP might affect the OFFSET and vice versa, so double check the signal on the oscilloscope as you make your modifications. Read the divisions on the oscilloscope screen, and do not rely on the MEASURE feature. It might be helpful here to bring the oscilloscope traces back to the middle of the oscilloscope screen.

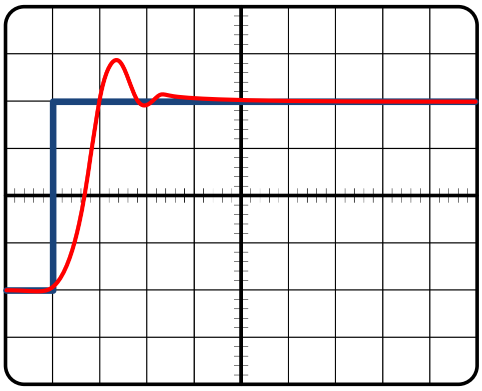
5. On ACS-13005, set **K = 1** (ACS-13016 R-CAL.3 **displayed value of 10**).

IMPORTANT: Before pressing the R-CAL pushbutton switch to read any parameters, *disconnect* the connecting wire to the motor coil terminal **Ma**.

6. Adjust ACS-13002 **K_P = 93.1** (i.e., **displayed value of 93.1 and x10 position**), ACS-13003 **K_I = 66.6** (i.e., **displayed value of 66.6 and x10 position**), and ACS-13004 **K_D = 0.913** (i.e., **displayed value of 91.3**). Measure and record below the signals at PULSER output V1a (on CH1 of the oscilloscope), and the motor position potentiometer reading V1b (on CH2 of the oscilloscope). Only show the part when the input signal goes from low voltage to high voltage. However, make sure you keep pressing the PULSER switch until you see the motor position reach steady state.



7. Use the trial-and-error method to adjust **K_P** (for ACS-13002), **K_I** (for ACS-13003) and **K_D** (for ACS-13004) to let the DC servo motor position control system produce the output response shown below (which in this case has some overshoot to reduce response time). The figure shows both the PULSER output V1a (on CH1 of the oscilloscope), and the motor position potentiometer reading V1b (on CH2 of the oscilloscope).



8. You can use the following trial-and-error method, typically employed by experienced engineers. Notice you do not need to display the actual values on ACS-13016 until you finish the whole process.

(a) Set $\mathbf{K_I}$ and $\mathbf{K_D}$ to 0, then tune $\mathbf{K_P}$ to achieve 15% ~ 25% overshoot.
(b) Increase $\mathbf{K_D}$ to eliminate the overshoot.
(c) Repeat Steps (a) and (b) to minimize overshoot and increase $\mathbf{K_P}$ as large as possible.
(d) Increase $\mathbf{K_I}$ to reduce any steady-state error.
(e) Repeat Steps (a) to (d) until the desired response is achieved (i.e., the settling time, overshoot, etc).

IMPORTANT: Before pressing the R-CAL pushbutton switch to read any parameters, *disconnect* the connecting wire to the motor coil terminal **Ma**.

9. The controller $\mathbf{K_P}$, $\mathbf{K_I}$ and $\mathbf{K_D}$ parameters that you used to produce the above response are (state both actual values and displayed values):

. . . .

. . . .

. . . .

. . . .

10. Explain why those values managed to change the motor position response from the one in step 6:

. . . .

. . . .

. . . .

. . . .

. . . .

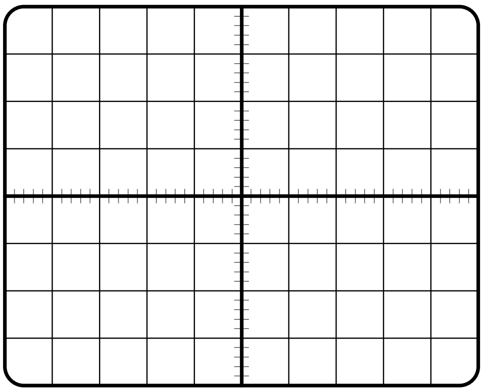
. . . .

11. Measure and record the amount of overshoot (in Volts), which is the difference between the maximum value of the response and its steady-state value:

. . . .

. . . .

12. Keep the same ACS-13002 **K_P**, ACS-13003 **K_I**, and ACS-13004 **K_D** parameters you used in step 8 above. However, set the Eddy current breaks to the **HIGH load** setting. Measure and record below the signals at PULSER output V1a (on CH1 of the oscilloscope), and the motor position potentiometer reading V1b (on CH2 of the oscilloscope). Only show the part when the input signal goes from low voltage to high voltage. Make sure you keep pressing the PULSER switch until you reach steady state.



13. Explain why the motor position response changed compared to the one in step 8 even though you maintained the same controller **K_P**, **K_I**, and **K_D** gain parameters:

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

. . . .

**** End ****