

Experiment 2: Motor Control

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LEARNING OUTCOMES

- Implement closed-loop control of motor speed and position
- Investigate transient response and steady-state response
- Study the effects of both feedforward gain and load on the closed-loop system output

HARDWARE

DC Motor & Controller, DMM, Oscilloscope & Function Generator

Part 1: Experiment Set Up

On the motor experiment kit, you will find the Op Amp Unit as shown in Figure 1.1(a). The circuit diagram of the Op Amp Unit is shown in Figure 1.1(b).

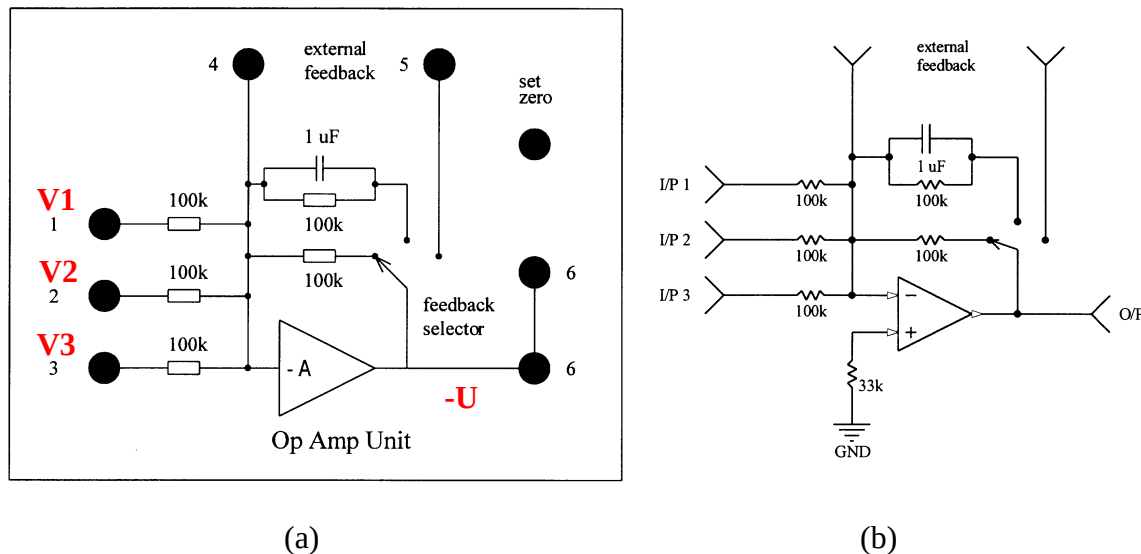


Figure 1.1.

For the circuit shown in Figure 1.1:

$$U = V1 + V2 + V3$$

Implementation of a Comparator

- Connect the devices as shown in Figure 1.2.

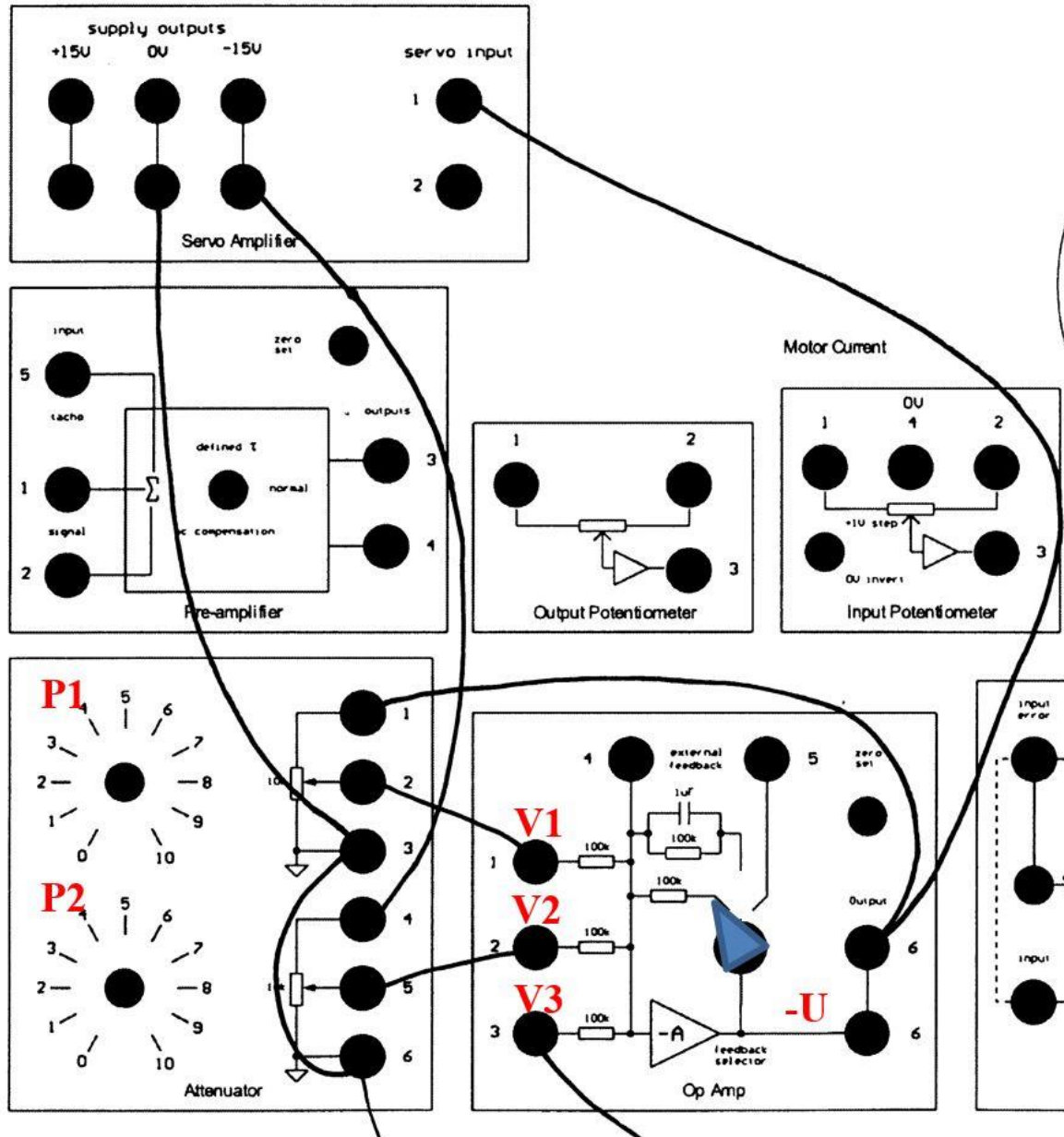


Figure 1.2

In Figure 1.2:

- Verify that V_i can be expressed as a function of the potentiometer setting P_2 :

$$V_i = 1.5 P_2$$

Similarly, verify that

$$V_1 = -\frac{P_1}{10} U$$

In Figure 1.3 (the attenuator unit):

- The reference input voltage is:

$$V_i = -V_2$$

- From $V_1 + V_2 + V_3 = U$ where $V_1 = -\frac{P_1}{10} U$ and $V_2 = -V_i$, verify that

$$U = \frac{V_3 - V_i}{1 + P_1/10}$$

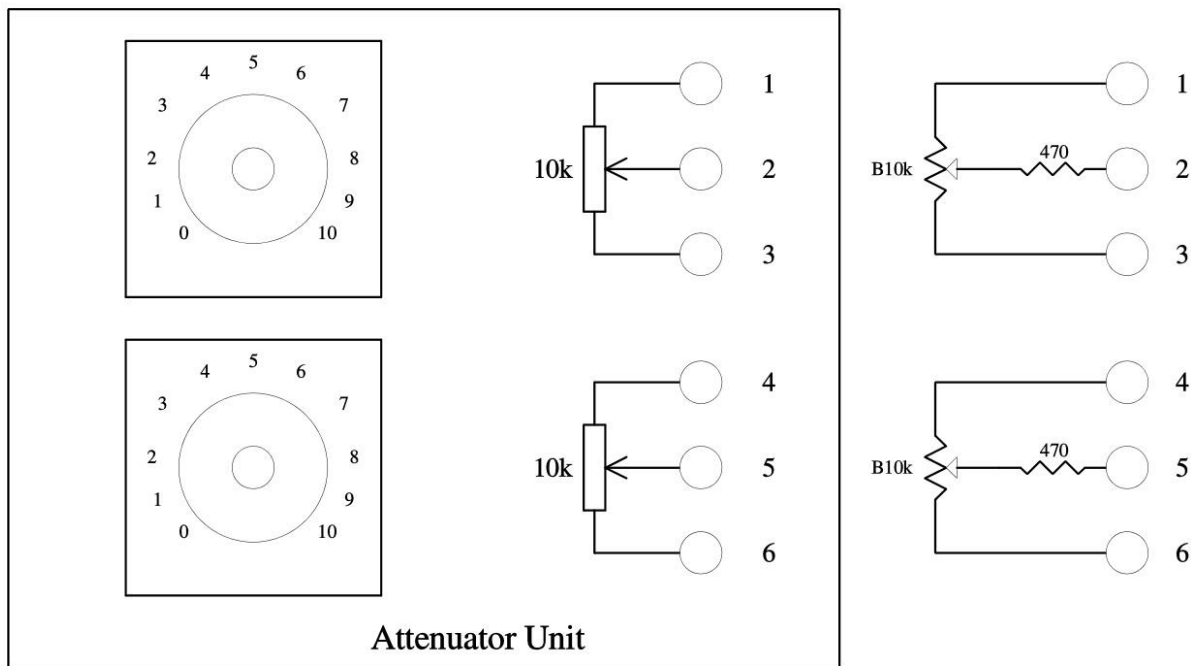


Figure 1.3

Part 2: Simple Speed Control

The transfer function $G(s)$ of a DC motor is given by

$$G_1(s) = \frac{\dot{\Theta}(s)}{U(s)} = \frac{K_m}{((R + Ls)(Js + b) + K_m^2)}$$

where $V_i(t)$ is the input voltage in Volt and $\dot{\Theta}(t)$ is the rotational speed output in rad/s, as shown in Figure 2.1, with motor parameters $K_m = K_1$ (in Figure 2.1) and R, L, J, b (not shown).

From Figure 2.1, for open-loop with $V_t = 0$ one has $U = -K_1 V_i$.

Recall that $U = \frac{V_3 - V_i}{1 + P1/10}$, which gives $U = \frac{-V_i}{1 + P1/10}$.

Now, the above these two equations yields

$$K_1 = \frac{1}{1 + P1/10}$$

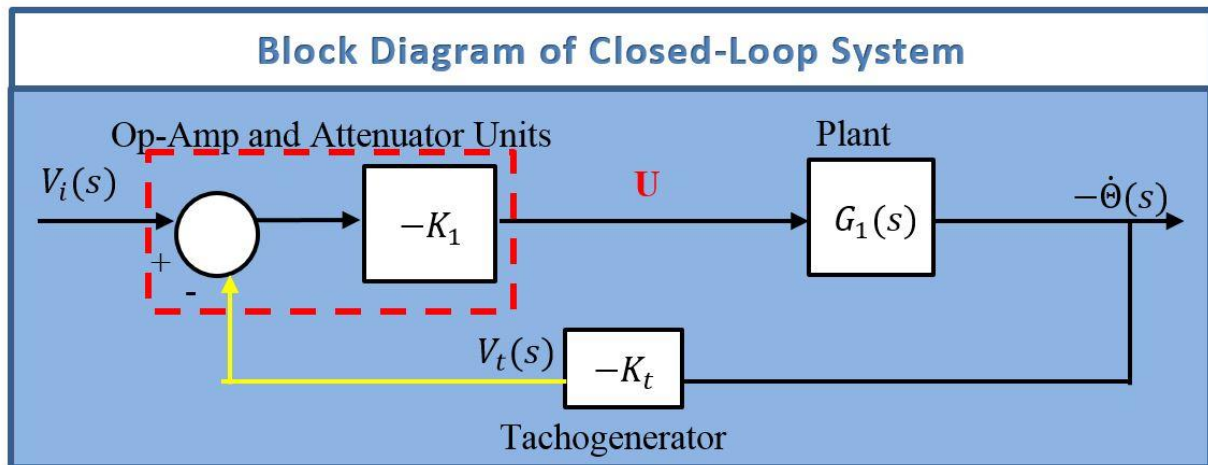


Figure 2.1

- **Shift the phase of the tachogenerator by 180°** (by tuning the switch at the low-right corner in Figure 2.2).

Tachogenerator measures the angular velocity $\dot{\Theta}$, producing a proportional voltage V_t :

$$V_t = K_t \dot{\Theta}$$

where K_t is the tachogenerator gain constant.

Task 2.1 Open-Loop Control of Motor Speed

- Connect the devices as shown in Figure 2.2, except the feedback from the tachometer highlighted in yellow (thus, $V_t = 0$), which is the open-loop setting.
- When P1 and P2 are 0, the motor speed should be 0. If not, adjust the “zero set” of Op Amp unit the motor stops.

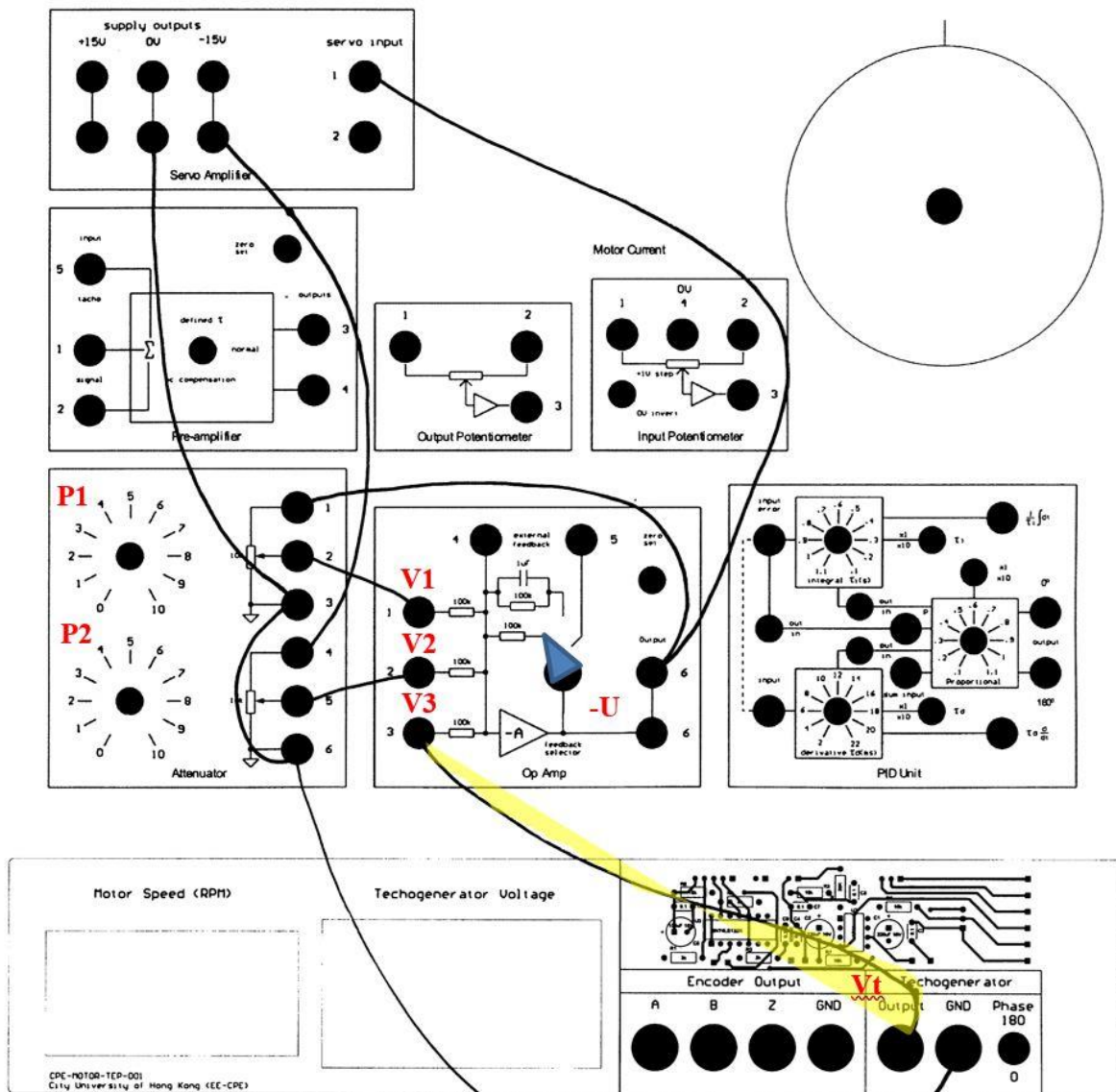


Figure 2.2

- Now, change P1 and P2 according to Table 2.1, and measure V_2 and the output of the tachogenerator (V_t) using DMM.

Table 2.1: Output of the tachogenerator with open-loop control

P1	P2	K_1 (Calculated)	V_i (-V2, Measured)	V_t (Volt) (Measured)
0	1			
5	1			
10	1			
0	2			
5	2			
10	2			

- Fill out Table 2.1
- How is V_t influenced by V_i and K_1 ?

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Task 2.2 Closed-Loop Control of Motor Speed

- Connect the output and the ground of the tachogenerator, as shown by the yellow-highlighted wire, in Figure 2.2, so $V_3 = V_t$
- Change P1 and P2 according to Table 2.2 and measure the output of the tachogenerator (V_t) using DMM.

Table 2.2: Output of tachogenerator under closed-loop control

P1	P2	K_1 (Calculated)	V_i (-V2, Measured)	V_t (Volt) (Measured)
0	0			
0	1			
5	1			
10	1			
0	2			
5	2			
10	2			

- Fill out Table 2.2.

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Task 2.3 Effects of Load

- Keep $P1 = 2$ and $P2 = 2$. Measure V_i

$V_i = \underline{\hspace{2cm}}$

- Measure V_t of the open-loop and the closed-loop systems, with and without loads, using DMM. (The load is implemented by pulling down the magnetic fork to the rotating disk.)

Table 2.3: Effects of load on system output

		V_t (Volt)
Open-loop	With Load	
	Without Load	
Closed-loop	With Load	
	Without Load	

- Fill out Table 2.3.
- How does the load affect the steady-state response of the open-loop and the closed-loop systems, respectively?

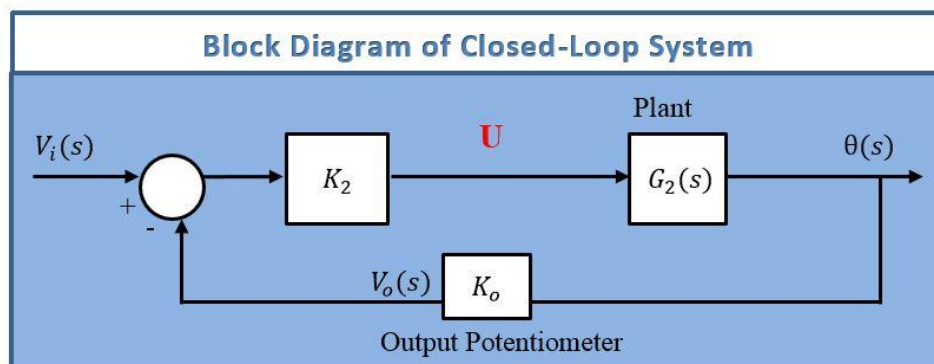
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Part 3: Simple Position Control

The transfer function $G_2(s)$ of a DC motor is given by

$$G_2(s) = \frac{\theta(s)}{U(s)} = \frac{K_m}{s((R + Ls)(Js + b) + K_m^2)}$$

where V_i is the input voltage (in Volt) and $\theta(t)$ is the rotational position output in rad, as shown in Figure 3.1.

**Figure 3.1**

- Connect the devices as shown in Figure 3.2. The input potentiometer is set by the dial in the top right corner. The output potentiometer is utilized as sensor for motor positions.

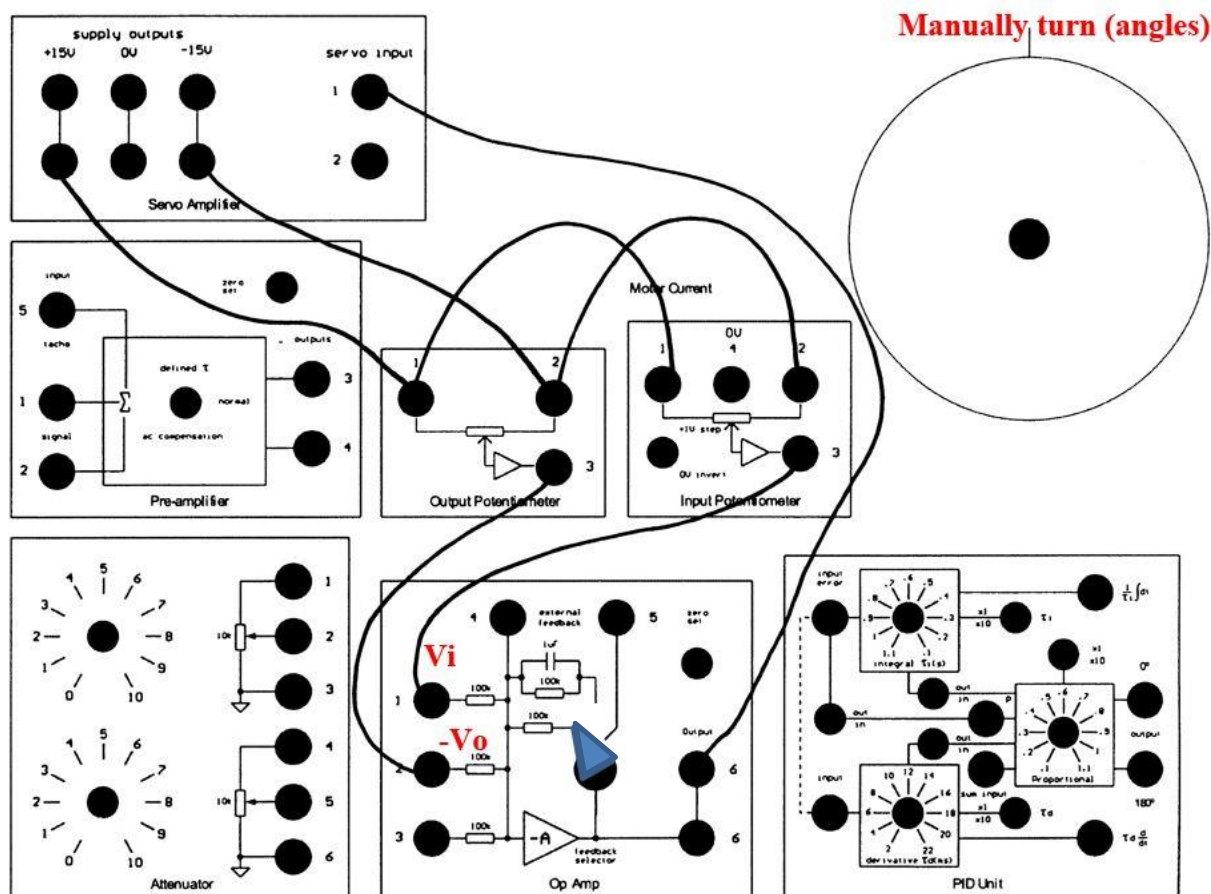


Figure 3.2

- Rotate the dial following the degrees shown in Table 3.1. Using DMM to measure the Op Amp output U , the input voltage V_i at terminal 3 of the input potentiometer and the output voltage V_o at terminal 3 of the output potentiometer.

Table 3.1

Angle of Dial (Degrees)	Motor Position (Degrees)	V_i (Volt)	V_o (-V2, Measured)
- 135			
- 90			
- 45			
0			
+ 45			
+ 90			
+ 135			

Task 3.1 Simple Position Control

- Fill out Table 3.1.
- Plot V_o against the dial angle:



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Part 4: Closed-Loop Position Control

- Connect the circuit as shown in Figure 4.1.
- From Figure 3.1, one has $U = K_2(V_i - V_o)$ and from Figure 4.1, $\frac{U}{V_i - V_o} = \frac{P1}{10}$
- Combining these two equations yields $K_2 = \frac{P1}{10}$
- **Keep the setting on the pre-amplifier unit to normal (turn the switch to the middle)**
- When P1 is 0, the motor should remain stationary. Otherwise, adjust the “zero set” on the pre-amplifier unit until the motor stops.

Task 4.1 Closed-Loop Position Control

- Change the angle of the dial and the feedforward gain according to the numbers specified in Table 4.1. Measure V_i and V_o using DMM.
- Fill out Table 4.1.

Table 4.1

P1	Feedforward Gain K_2 (Calculated: $K_2 = P1/10$)	Angle of Dial (Degrees)	Motor Position (Degrees)	V_i (Volt) (Measured)	V_o (-V2, Measured)
2		- 90			
2		- 45			
2		0			
2		+ 45			
2		+ 90			

5		- 90			
5		- 45			
5		0			
5		+ 45			
5		+ 90			

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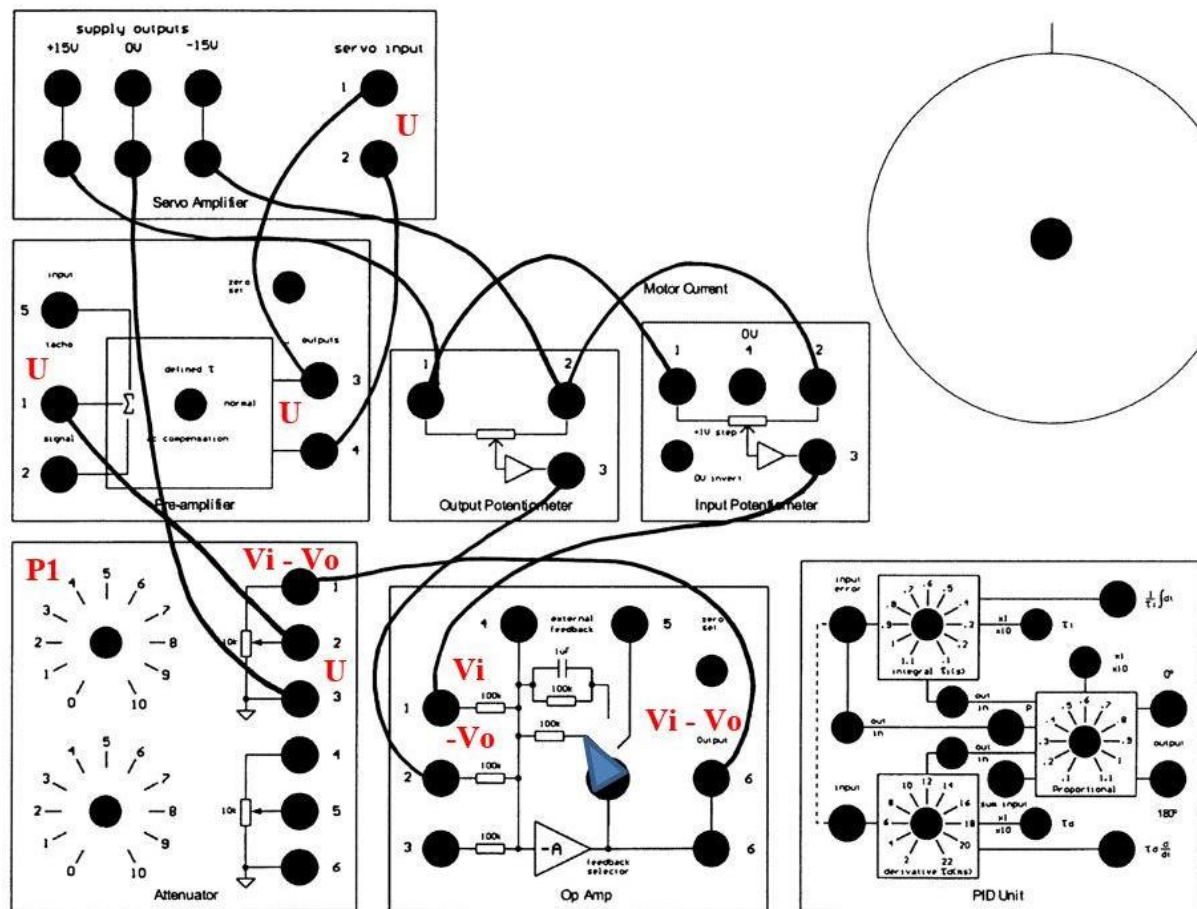


Figure 4.1

Part 5: Step Response

Task 5.1 Transient Response

- Connect the devices as shown in Figure 5.1. The signal from the functional generator is the input. Set it as a square wave with peak-to-peak magnitude 4V at a frequency below 200 mHz.

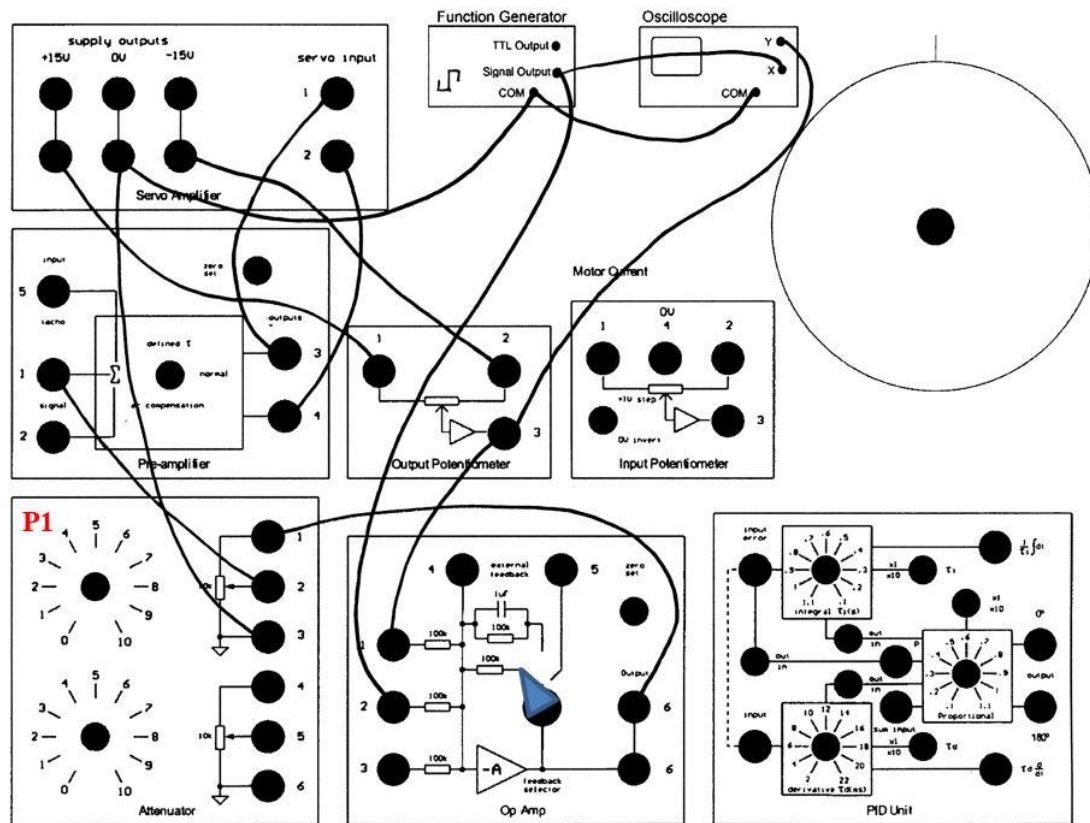


Figure 5.1

- Without load, measure the transient response characteristics at different $K_2 = P1/10$ listed in Table 5.1. Note that if the system is overdamped, the rise time is the time required for the output to reach 90% from 10% of the steady-state value (instead of 0 to 100% for the underdamped system).

Table 5.1: Measurements of transient response for the closed-loop system

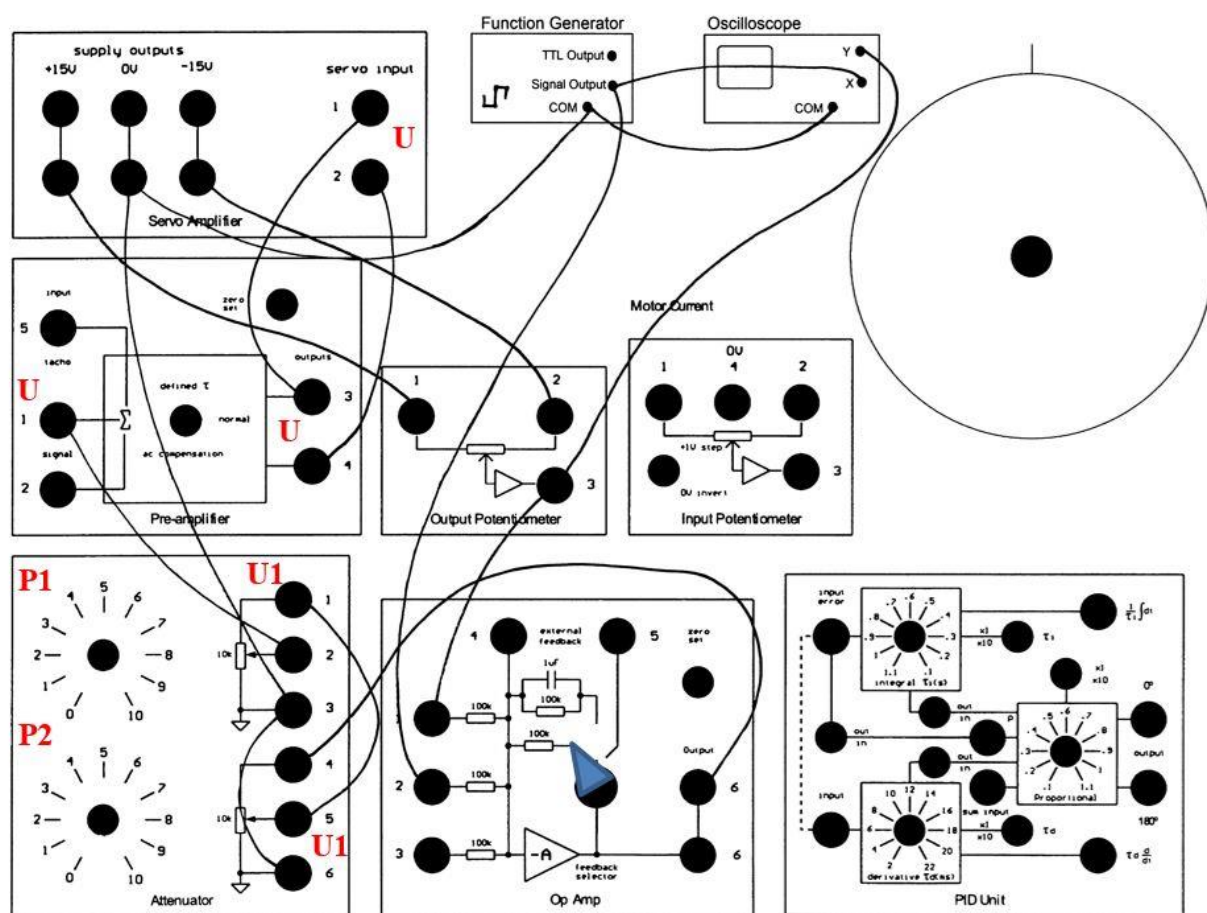
P1	$K_2 = P1/10$ (Calculated)	Rise Time (s)	Peak Time (s)	Overshoot (%)	Settling Time (within 5% error)
1					
2					
3					

- Fill out Table 5.1.
- Describe how the feedforward gain changes the transient response.

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Part 6: Ramp Response

- Connect the devices as shown in Figure 6.1.

**Figure 6.1**

- From Figure 6.1, one has $U1 = \frac{P2}{10}(V_i - V_o)$ and $U = \frac{P1}{10}U1$.
- From Figure 3.1, one has $U = K_2(V_i - V_o)$
- Combining these two equations yields

$$K_2 = \frac{P1}{10} \times \frac{P2}{10}$$

- Now, set the input as a triangle wave or sawtooth wave with peak-to-peak magnitude 4V at a frequency below 200 mHz.
- Set P2 = 3. Using the oscilloscope, measure the input signal and V_o again.

Table 6.1: Steady-state error (e_{ss}) of the ramp response

P1	2	4	6	8	10
K_2 (Calculated)					
tracking error					

- Without load, record the steady-state errors of the ramp response at different P1 values as listed in Table 6.1. Fill out Table 6.1
- Describe the effect of K_2 on the ramp response.

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