

Experiment 3: PID Controller

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LEARNING OUTCOMES

- Implement a PID controller
- Study how the different gains in a PID controller affect the output
- Investigate the frequency response of the PID controller.

HARDWARE

DC Motor & Controller, Oscilloscope & Function Generator

Background Information

Consider the closed-loop PID control system shown in Figure 1.

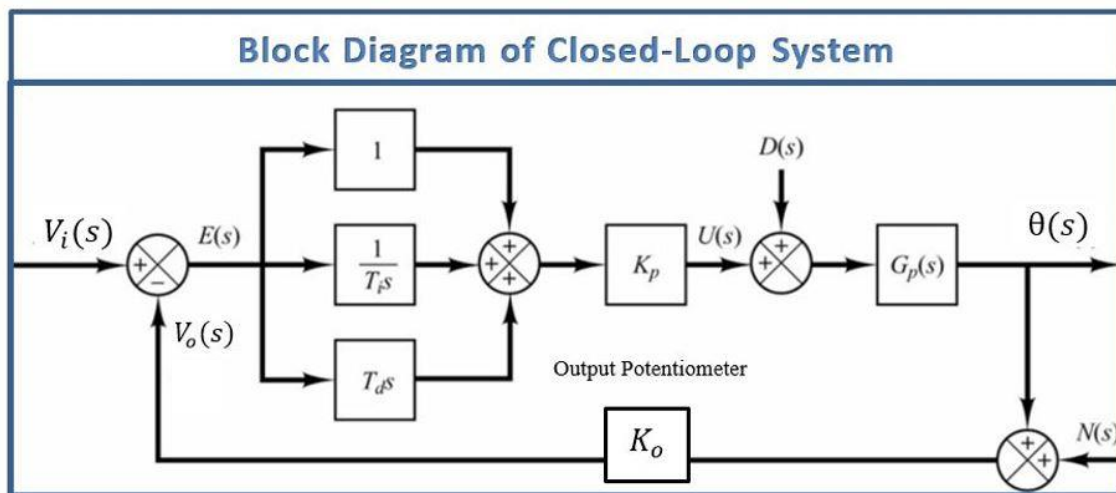


Figure 1

- The transfer function of the PID controller is given by $G_c(s) = K_p + \frac{K_i}{s} + K_d s$
- $V_i(t)$ is the input voltage in Volt, which is the sum of the output of the input potentiometer unit and the signal output of the function generator shown in Figure 2
- $G_p(s)$ is the transfer function of the DC motor, where the input $U(s)$ is the voltage and the output is the angle θ of the motor
- The output potentiometer is utilized as sensor for motor position, where $V_o = K_o \theta$

- Connect the devices as shown in Figure 2.

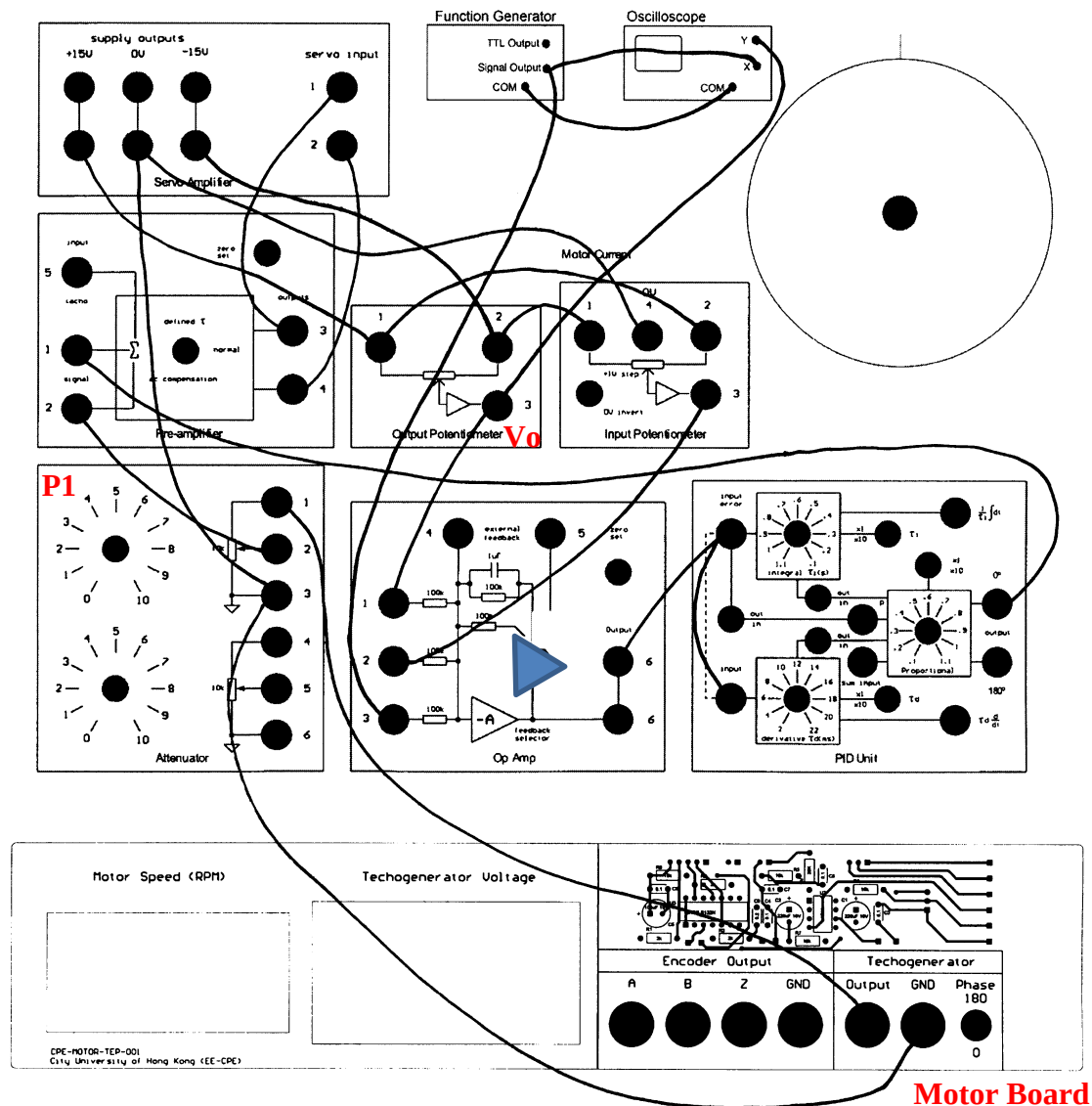


Figure 2

Part 1: P Controller

A controller in the form of $G_c(s) = K_p$ is applied to the closed-loop system.

- Switch the proportional control on
- Set both the integral control switch and the derivative control switch to “out” (off)
- Keep $P1 = 0$
- Set input r as a square wave with peak-to-peak magnitude 4V at a frequency below 200 mHz
- Set the input dial at 0°
- Gradually increase K_p starting from 0.1. Describe (if any) the effect of K_p on the transient and steady-state responses

- Gradually increase K_p and find the minimum value K_{cr} at which the motor output exhibits sustained oscillations
- What is the corresponding period P_{cr} of the motor output?

$K_{cr} = \underline{\hspace{2cm}}$ $P_{cr} = \underline{\hspace{2cm}}$

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Part 2: Tuning of PID Controller

Task 2.1 Second Ziegler-Nichols or Tyreus-Luyben tuning method

- Make use of the second Ziegler-Nichols tuning method or Tyreus-Luyben method shown in the Guidelines (see Appendix)
- Determine the values of K_p , K_i , and K_d for
 - P control,
 - PI control, and
 - PID control
- Fill out Table 1.

Table 1: Calculated controller gains

Type	Method	K	T_i	T_d
P	Ziegler-Nichols			
PI	Tyreus-Luyben			
PID	Tyreus-Luyben			

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Task 2.2 Controller Responses

- Keep $P1 = 0$
- Change the controller gains to the values found in Task 2.1 (Table 1 above)
- Set the input as a square wave with peak-to-peak magnitude 4V at a frequency below 200 mHz. Observe the first two peaks of the output response.

Table 2: Measured controller responses

Type	Overshoot of the 1 st peak, V_1	Overshoot of the 2 nd peak, V_2 (if any)	V_2/V_1 (Calculated)
P			
PI			
PID			

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Task 2.3 Effect of K_i

- Set the PID controller gains to the ones found in Task 2.1 (see Table 1 above)
- Keeping K_P and K_d constant, change K_i and describe its effect on percentage overshoot, rise time, and settling time.

Table 3: Measured effects of K_i

T_i (s)	$K_i = K_P/T_i$ (calculated)	% Overshoot	Rise Time (s)	Settling Time (s)
0.5				
1				
5				
11				

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Task 2.4 Effect of K_d

- Set the PID controller gains to the ones found in Task 2.1 (see Table 1 above)
- Keeping K_P and K_i constant, change K_d and describe its effect on percentage overshoot, rise time, and settling time.

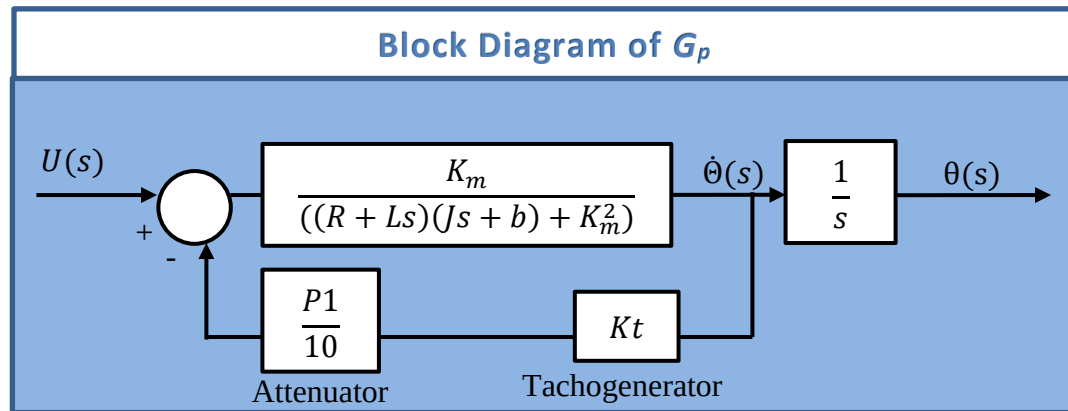
Table 4: Measured effects of K_d

T_d (ms)	$K_d = K_P T_D$ (calculated)	% Overshoot	Rise Time (s)	Settling Time (s)
2				
10				
20				
40				

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Part 3: Second Closed-Loop Control

- Set the PID controller gains to the ones found in Task 2.1 (see Table 1 above)
- Set the input as a square wave with peak-to-peak magnitude 4V at a frequency below 200 mHz
- Keep the phase at the tachogenerator unit at 0°
- Suppose that G_p is represented by the block diagram in Figure 3, where K_t is the tachogenerator gain constant, and K_m , R , L , J , and b are motor parameters.

**Figure 3**

- Rotate the dial and adjust the attenuator parameter P1. Record the transient response. Fill out Table 5.

Table 5

P1	Overshoot (%)	Rise Time (s)
0		
1		
2		
3		

- What is the role of this control loop?
- As the system parameters changed, adjust K , T_i and T_d manually until the output reach your desired performance.

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Part 4: Frequency Response of PID Controller(s)**Task 4.1 Frequency Response of Proportional Controller**

- **Disconnect** the controller from the motor unit
- Switch both integral control switch and derivative control switch to “out” (off)
- Set the proportional control gain $K_p = 1$
- Set the input e to the controller as a sine wave with peak-to-peak magnitude 2V at the frequencies f shown in Table 6.

Table 6: Measurements of frequency response for the P controller

f (Hz)	Measured f (Hz)	$ u $ (Volt)	Phase (u/e)
0.1			
1			
10			
100			
1k			

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Task 4.2 Frequency Response of Derivative Controller

- Switch both proportional control switch and integral control switch to “out” (off)
- Set the derivative control time scaling constant $T_d = 0.1$
- Set the input e to the controller as a sine wave with peak-to-peak magnitude 2V at the frequencies f shown in Table 7.

Table 7: Measurements of frequency response for the D controller

f (Hz)	Measured f (Hz)	$ u $ (Volt)	Phase (u/e)
1			
10			
100			

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Task 4.3 Frequency Response of PID Controller

- Switch proportional, integral, and derivative controls on
- Set the PID controller gains to the ones found in Task 2.1 (see Table 1 above)
- Set the input e to the controller as a sine wave with peak-to-peak magnitude 2V at the frequencies f shown in Table 8.

Table 8: Measurements of frequency response for the PID controller

f (Hz)	Measured f (Hz)	$ u $ (Volt)	Phase (u/e)
0.1			
1			
10			
100			

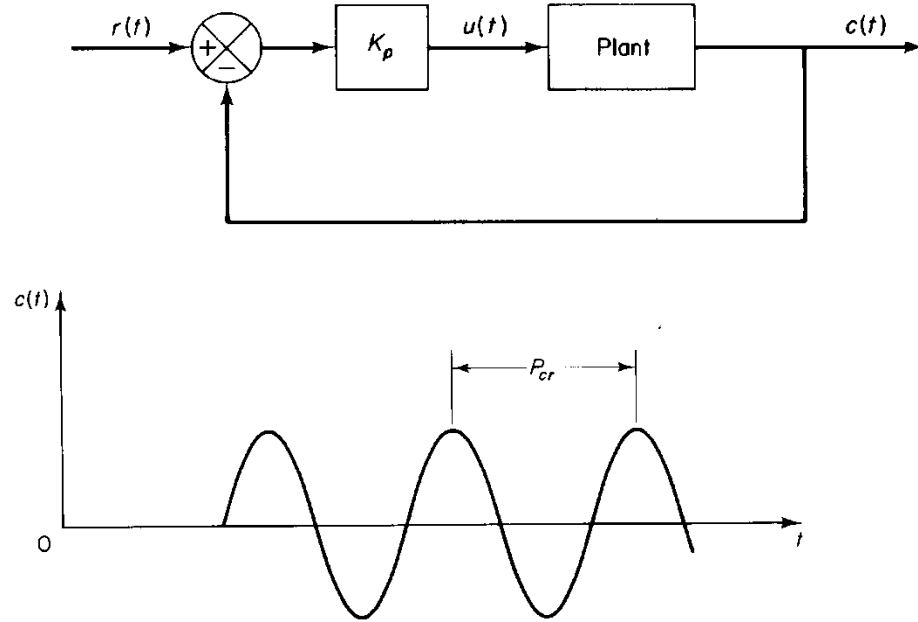
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Part 5: Effect of PID Control Gains

- Compare the systems in Part 2 with different control gains
- Summarize and discuss your findings

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- END -

Appendix: GUIDELINES**Second Ziegler-Nichols Method****Figure 4**

In this method, PID controller is inserted in the closed loop, with $K_i = 0 (T_i = \infty)$ and $K_d = 0 (T_d = 0)$. Then, an input signal $r(t)$ is applied to the system with increasing K_p from 0 to a critical value K_{cr} , where the output response exhibits sustained oscillations. (If output does not exhibit oscillation for any value of K_p , then this method does not apply.) The resulting transfer function of PID controller is: $G_c(s) = K_p \left(1 + \frac{1}{T_i s} + T_d s \right)$, with parameters in Table 9.

Type	K	T_i	T_d
P	$0.5K_{cr}$	∞	0
PI	$0.45K_{cr}$	$\frac{1}{1.2}P_{cr}$	0
PID	$0.6K_{cr}$	$0.5P_{cr}$	$0.125P_{cr}$

Tyres-Luyben Method

Same steps as the second Ziegler-Nichols method to find K_{cr} and P_{cr}

Type	K	T_i	T_d
PI *	$K_{CR}/3.2$	$2.2P_{cr}$	0
PID **	$K_{CR}/2.2$	$2.2P_{cr}$	$P_{CR}/6.3$

* <http://pubs.acs.org/doi/pdf/10.1021/ie00011a029>

** <http://pubs.acs.org/doi/pdf/10.1021/ie9600699>

REFERENCES

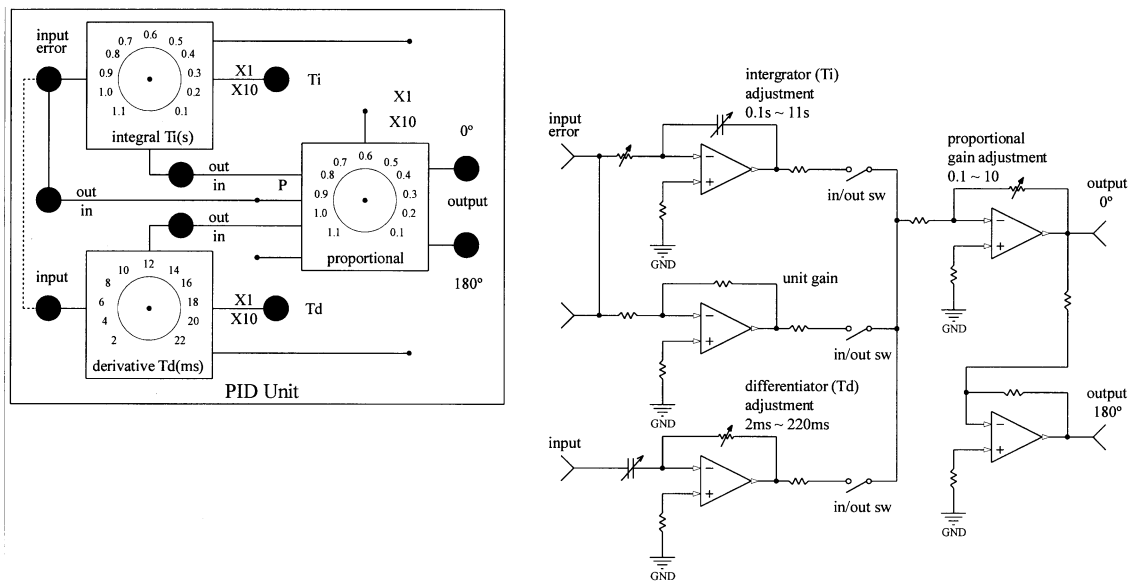


Figure 5 Circuit diagram of the PID unit

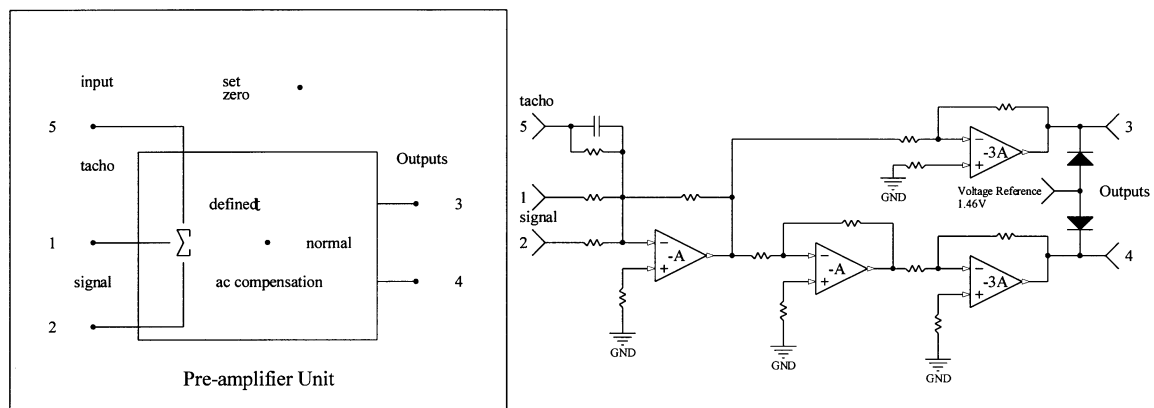


Figure 6 Circuit diagram of the pre-amplifier unit