EXPERIMENT KW8: ROTATIONAL SPEED FOLLOWER CONTROL WITH PID CONTROLLER (OPEN-ENDED)

Related course: KIE3006 (Control System)

OBJECTIVES:
To test and evaluate the rotational speed control with a PID controller

EQUIPMENT:
Process Control Board, Oscilloscope, strapping plugs, 2 mm connecting wires

INSTRUCTIONS:
1. Record all your results and observations in a log book or on a piece of paper
2. Follow the demonstrator's instructions throughout the experiment

REFERENCE(S):
Refer to the main references of KIE3006

Strapping plug

2 mm connecting wire

TESTS:
TEST 1: Analysis of Rotational Speed Control Path
TEST 2: Determination of the Path Data
TEST 3: Calculation of the Controller Settings
TEST 4: Rotational Speed Follower Control with PID controller

INTRODUCTION:

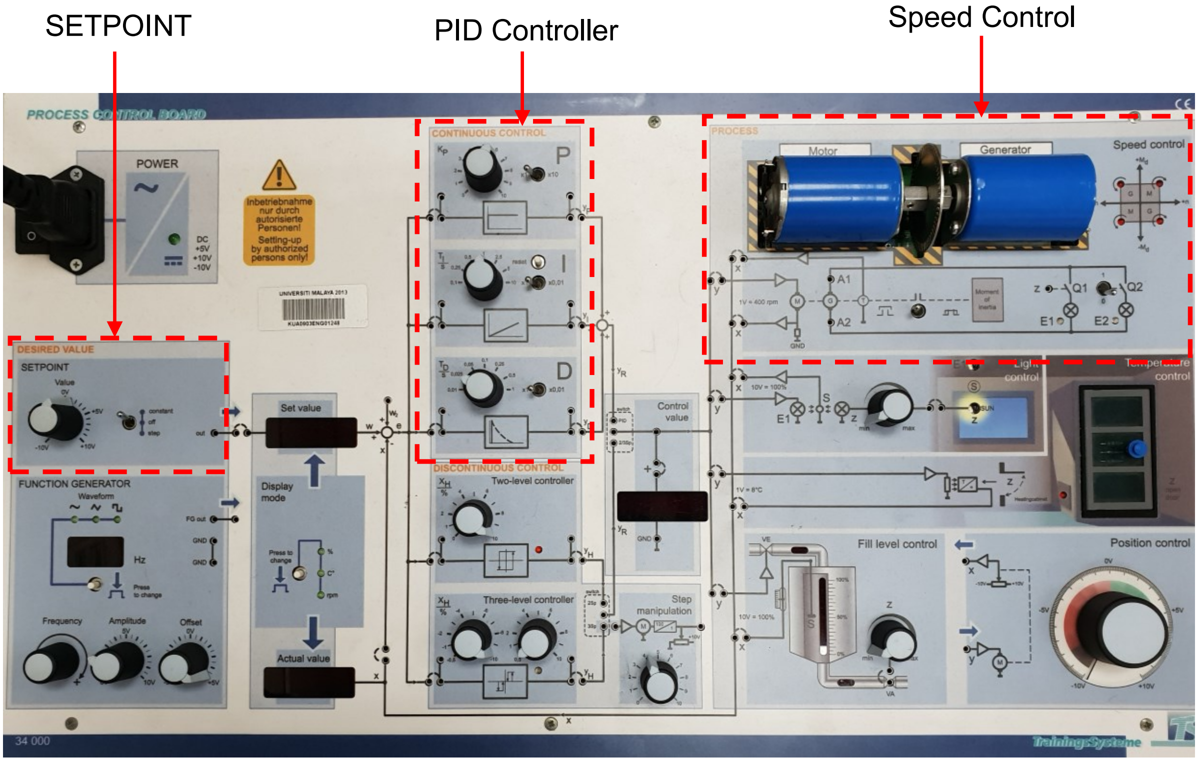

Figure 1: Process Control Board

The rotational speed of an electric motor is to be dynamically set between 1000 rpm and 3000 rpm. Exact compliance with the rotational speed specifications is required. This is to be achieved by a follower control with a continuous-action PID control device. Follower controls are optimised to good reference behaviour. The optimisation objective is temporary control deviations must be corrected as quickly as possible and without overshooting, where a permanent control deviation cannot be accepted.

The control must have sufficient stability reserves in all operating states. The motor-generator set is run on no-load during this task. The generator loads and the electronically implemented flywheel must be switched OFF. The measuring instrument for the formation of a feedback signal through digital sampling of a slitting disk is already integrated. It provides a standardised voltage signal of ±10V corresponding to a rotational speed of ±4000rpm.

PID Controller

Proportional, Integral and Derivative (PID) controllers are the most widely-used controller due to their simplicity, robustness and successful practical application. It is described by the following transfer function in the continuous s-domain:

$$G_c(s) = K_p + \frac{K_i}{s} + K_d s \qquad \text{or} \qquad G_c(s) = K_p\left(1 + \frac{1}{T_i s} + T_d s\right)$$

where, K_p is the proportional gain, K_i is the integration coefficient and K_d is the derivative coefficient. T_i is the integral action time and T_d is the derivative action time.

A block diagram of PID controller in a closed-loop control system is shown in Figure 2. This controller has three different adjustments that interact with each other. For this reason, it is very difficult and time consuming to tune these three parameters to obtain the best performance according to the system design specification.

There are several methods to tune the controller parameters in PID controllers. In this experiment, Chien, Hrones and Reswick (CHR) method is used. This method is the modified version of the Ziegler-Nichols method, which provides a better way to select a compensator for process control applications. The controller parameters from CHR set point response method are summarized in Table 1 (TEST 3).

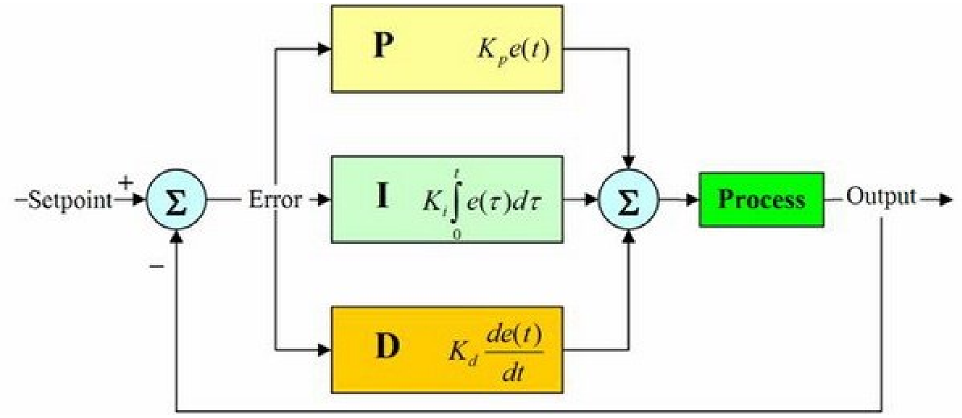

Figure 2: Block diagram of PID controller in closed-loop control system

TEST 1: Analysis of Rotational Speed Control Path

The rotational speed control path consists of an electric motor, which rotational speed is acquired by an incremental encoder and as a voltage that is proportional to the rotational speed as a feedback variable. The rotational speed sensor returns a voltage U_n=0.0025xn, where n=speed in rpm. The system limit is specified by the maximum rotational speed of ±4000rpm.

Perform the following procedure on the Process Control Board for analysis of the rotational speed control path:

1. Remove all connections (if any) from the Process Control Board.
2. Switch **ON** the Process Control Board. The switch is at the top-left corner of the board.
3. In **Display Mode** box, select the display unit of the integrated measurement system to **rpm** by pressing the button labelled with **Press to change**.
4. Connect the output of the **SETPOINT** to the **Set Value** box using a strapping plug.
5. Adjust the switch of the **SETPOINT** to **constant**.
6. Turn the knob of the **SETPOINT** until the **Set value** shows 0 rpm.
7. Adjust the switch of the **SETPOINT** to **off**.
8. Use a strapping plug to connect the input of the rotational **Speed control** (in **PROCESS** box) with the actuating variable **y** (The input is labelled as ─▷─). Use another strapping plug to connect the output of the rotational **Speed control** to the feedback quantity **x** (The output is labelled as ─◁─).
9. In **Speed control** box, turn OFF the switches for the disturbance feedforward of the rotational Speed control (not connecting **Moment of inertia** and set load **Q2** switch to 0).
10. Using a 2 mm connecting wire, connect the output of the **SETPOINT** (labeled **out**) to the **Control Value** box. Using a strapping plug, connect the input of the voltmeter in the **Control Value** box (the bridge labelled **+**).

    At this stage, the motor is at standstill. The **Control value** is showing 0.00 V. The **Set value** is showing around 0 rpm but the **Actual value** is showing around 30 rpm. This is due to the method of operation of the incremental encoder.

    Q1: What is the control variable ‘x’ of the control path?

11. Set the switch of **SETPOINT** to **constant**.
12. Turn the knob of the **SETPOINT** slowly in the positive direction until +7V. Observe the reaction of the motor. Compare the **Set value** and **Actual value** display.
13. Turn the knob of the **SETPOINT** slowly in the negative direction until -7V. Observe the reaction of the motor. Compare the **Set value** and **Actual value** display.

    Q2: What is the actuating variable ‘y’ of the control path and how does it act on the control variable ‘x’ if there is no disturbance variable present? Comment about the polarity of the actuating variable.

14. Turn the knob of the **SETPOINT** until the **Set value** shows 0 rpm. The motor will stop.
15. Turn the knob of the **SETPOINT** slowly in the positive direction until the motor rotates.

    Q3: Determine the starting voltage in the positive direction (from Control value).

16. Turn the knob of the **SETPOINT** until the **Set value** shows 0 rpm. The motor will stop.
17. Turn the knob of the **SETPOINT** slowly in the negative direction until the motor rotates.

    Q4: Determine the starting voltage in the negative direction (from Control value).

18. Turn the knob of the **SETPOINT** slowly until the **Set value** shows 2000 rpm. Observe the reaction of the motor. Compare the **Set value** and **Actual value** display.
19. Repeat step 18 for 5 different values of **Set value**. Observe the reaction of the motor. Compare the **Set value** and **Actual value** display.

    Q5: What is the effect of the constant specification of an actuating variable ‘y’ on the control variable ‘x’ of the control path?

TEST 2: Determination of the Path Data

Perform the following procedure on the Process Control Board for recording the step response:

1. Remove the 2 mm connecting wire that is attached between the **SETPOINT** output and the **Control Value**.
2. Remove the strapping plug between the output of the **SETPOINT** and the **Set Value** box. Remove the strapping plug from the input of the voltmeter in the **Control Value** box (the bridge labelled **+**).
3. Set the switch of the **SETPOINT** to **constant**.
4. Turn OFF the switches for the disturbance feedforward of the rotational Speed control (not connecting **Moment of inertia** and set load **Q2** switch to 0).
5. Set the **FUNCTION GENERATOR** with the following parameters:
    - Signal form rectangular _⊓_
    - Frequency = 0.4 Hz
    - Amplitude = 1.25 V
    - Offset = 5 V
6. Using a 2 mm connecting wire, connect the output of the **FUNCTION GENERATOR** (**FG out**) to the **Control value** (or point **y**). The motor now starts to rotate cyclically in the clock pulse of the given frequency with two rotational speeds.
7. Connect the actuating variable **y** and the **Actual value** (feedback variable **x**) to an oscilloscope. To do this, connect point **y** to the probe hook of oscilloscope CH1 and point **x** to oscilloscope CH2. Connect both oscilloscope probe ground to the ground of the Process Control Board.
8. Set both CH1 and CH2 to 500 mV/div and time setting to 25 ms/div. Press **Run/Stop** to observe the pulse. Capture and save the oscilloscope figure.

Q6: Determine the time delay T_e and the equalisation time of the path T_b graphically from the oscilloscope CH1 and CH2. Then, determine the proportional coefficient of the path K_{PS} (refer to Figure 3 on how to determine these values).

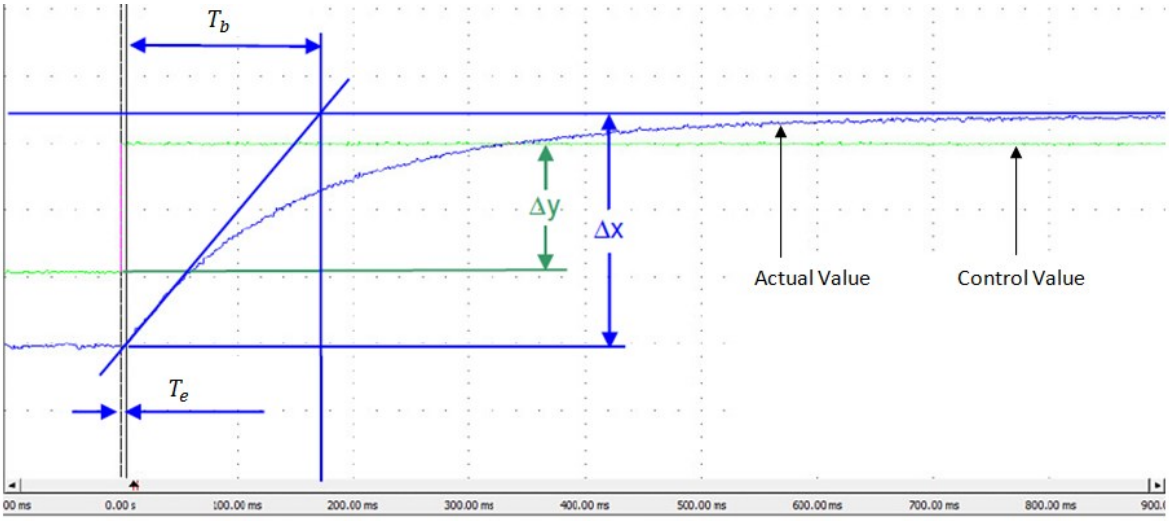

Figure 3

Write down the answers here:

T_e = ________________

T_b = ________________

$$K_{PS} = \frac{\Delta x}{\Delta y} = = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

TEST 3: Calculation of the Controller Settings

Calculate the controller settings (K_p, K_i, K_d) for a PID controller by using the determined T_e, T_b and K_{PS} from TEST 2 and the equations of setting rules for paths with equalisation optimised to the reference behavior as shown in Table 1 (look at row 3 in Table 1 for PID controller equations):

- Proportional controller, K_p = ___________________
- Integral controller, $K_i = \frac{K_p}{T_i}$ = ___________________
- Derivative controller, $K_d = K_p \cdot T_d$ = ___________________

Table 1: Controller setting for paths with equalisation optimised for reference according to Chien, Hrones and Reswick (CHR)

Controller	K_P	T_i	T_d
P	$0.3 \times \frac{T_b}{T_e \cdot K_{PS}}$	-	-
PI	$0.35 \times \frac{T_b}{T_e \cdot K_{PS}}$	$1.2 \cdot T_b$	-
PID	$0.6 \times \frac{T_b}{T_e \cdot K_{PS}}$	$1 \cdot T_b$	$0.5 \cdot T_e$

TEST 4: Rotational Speed Follower Control with PID controller

Perform the following procedure on the Process Control Board to evaluate the rotational speed follower control:

1. Remove the 2 mm connecting wire between the output of the **FUNCTION GENERATOR** and the **Control Value**.
2. Set the **FUNCTION GENERATOR** with the following parameters:
   - Signal form rectangular _⊓_
   - Frequency = 1.0 Hz
   - Amplitude = 2.5 V
   - Offset = 5 V
3. Close the feedback of the control path using a strapping plug (the bridge just on the right side of the **Actual value** display).
4. Insert the control element **P** in the **CONTINUOUS CONTROL** box by placing a strapping plug at the input of the **P**-control element and another plug at its output.
5. Using a strapping plug, connect the sum output of the regulator in the **Control value** box to the actuating variable **y** (the PID point in the **Control value** box to **y**).
6. Set the proportional coefficient **K_P** that you have determined in TEST 3 in the **P**-element.
7. Using a 2 mm connecting wire, connect the output of the **FUNCTION GENERATOR** to the input of the **Set value** box. The motor now starts to rotate cyclically in the clock pulse of the given frequency with two rotational speeds.

8. Connect the reference variable (the output of the **FUNCTION GENERATOR**) to oscilloscope CH1 and the **Actual value** (feedback variable **x**) to oscilloscope CH2. Connect both oscilloscopes probe ground to the ground of the Process Control Board.
9. Set both CH1 and CH2 to 2 V/div and time setting to 100 ms/div. Press **Run/Stop** to observe the pulse. Capture and save the oscilloscope figure.

   Q7: Observe and discuss the result.

10. Insert the control element **D** in the **CONTINUOUS CONTROL** box by placing a strapping plug at the input of the **D**-control element and another plug at its output. Now the controller becomes a PD-controller.
11. Set the differential time $\mathbf{T_D}$ that you have determined in TEST 3 in the **D**-element. Capture and save the oscilloscope figure.

    Q8: Observe and discuss the result.

12. Insert the control element **I** in the **CONTINUOUS CONTROL** box by placing a strapping plug at the input of the **I**-control element and another plug at its output. Now the controller becomes a PID-controller.
13. Set the integral time $\mathbf{T_I}$ that you have determined in TEST 3 in the **I**-element. Capture and save the oscilloscope figure.

    Q9: Observe and discuss the result.

14. **Open-ended tasks (do this task during lab session):**

    Using trial-and-error method, fine tune the value of K_p, T_i, and T_d (by adjusting the P, I and D knob directly) so that the difference between the peak value of the reference variable (output of the **FUNCTION GENERATOR**) and the **Actual value** is less than 10%. Record the response displayed on the oscilloscope. Compare the performance of this method with the CHR method in step 13. Discuss the advantages and drawbacks of both methods.

15. Once done with all tests, switch OFF the Process Control Board and remove all wires and plugs from the board. Keep them neatly in the storage box.

END OF EXPERIMENT