APPENDIX C : Technical Paper

Development of Control System for Water Level Process Plant

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***Abstract* - The aim of this project is to study the control system for water Level Control Trainer System Model WCT-03N which installed at Process Control Laboratory, Faculty of Electrical Engineering, UiTM Shah Alam. The control system for the process plant is evaluated using ideal, serial and I-PD control structures method. The process model is obtained via open loop step response test. Then, the PID parameters are adjusted using Ziegler-Nichols tuning method and the control system performance is analyzed in terms of the transient response of the process. The results indicate that the I-PD control structure gives the best performance with settling time equal to 77.54sec.**

Keywords- Water level control; ideal PID control structure; serial PID control structure; I-PD control structure; Ziegler-Nichols Tuning Method

I. INTRODUCTION

Water level control system is wide used in many industrial nowadays. Various system and devices have developed for controlling the water level [1]. Water level control system is commonly found in industrial process such as beverage, food, solution filtration and chemical production [2].

In the field of process control system, it is well known that the PID control method have proved their usefulness in providing satisfactory control [3]. The PID control is a combination of proportional, integral and derivative control. It offers rapid proportional response to error, while having an automatic reset from the integral part to eliminate steady state error. The derivative action will stabilize the controller and allows it to respond rapidly to changes in error [4]. This combination will improve the process performance and enhance the process controllability.

In this paper, it is aim to study the controllability of water Level Control Trainer System Model WCT-03N using ideal, serial and conventional PID control structure method [5]. The control performance of the system is then evaluated in terms of the transient response of the process.

II. OBJECTIVES

The objectives of the study are as follows:

(1) To find the best controller parameters for the process.
(2) To evaluate the process performance using three different PID control structures.

III. SYSTEM DESCRIPTION

The schematic diagram of the process plant shown in Figure 1 is a system available in UiTM, Shah Alam used for water level control system and measurement. The unit has been designed in order to make industrial process control with three different modes of operations: local, Supervisory Control and Data Acquisition (SCADA) and Distributed Control System (DCS).

The process plant is consists of three tanks which equipped with the differential pressure transmitter and pumps. These three tanks are designated as Level Tank 2, Level Tank 3 and Sump Tank 1. In this work, the measurement and control of water level is taken in Level Tank 3 in which the process is started when water from the Sump Tank is pumped through a pneumatic control valve.

The water level in Level Tank 3 is measured using differential pressure technique in which the differences in pressure reading determine the level of the water in the tank. This differential pressure transmitter is linked to the microprocessor-based controller. The controller is used to control the flow rate of the water delivered by the pump so that the water level is within the desired target. The block diagram of the level control trainer system is shown in Figure 2.

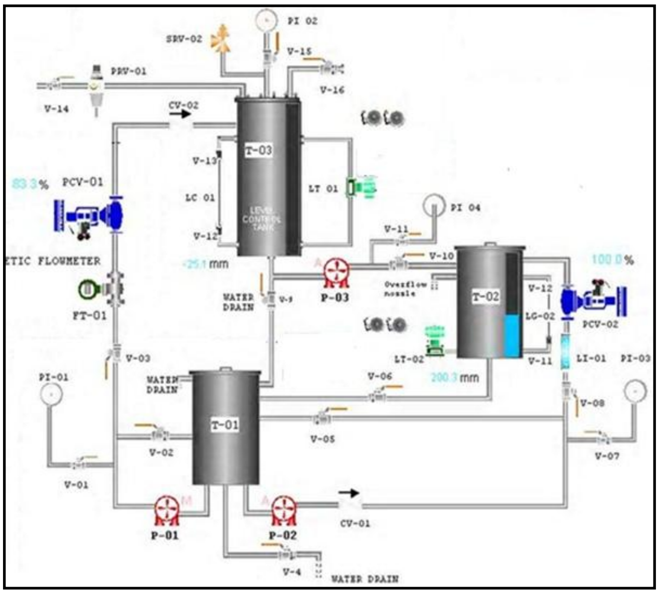

Figure 1: Schematic diagram for water level control system

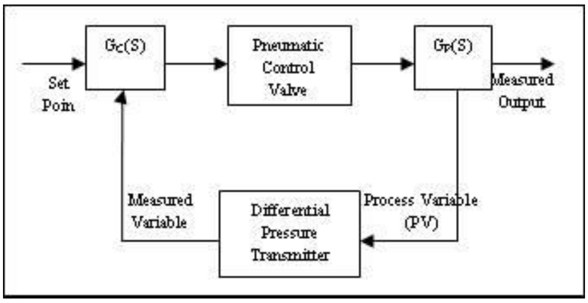

Figure 2: Block diagram for water level control system

IV. PROCESS MODEL

In general, the process model can be obtained from standard the open-loop step response test and the model usually can be describe using the transfer function known as first order plus dead time (FOPDT) model [6] shown in Eq.(1).

$$G_p(s) = \frac{k_p e^{-t_o s}}{\tau_p s + 1} \quad \text{.......}Eq.\ (1)$$

Where $K_p = \frac{\Delta Y}{\Delta U}$ = Process gain

τ_p = Process time constant

t_o = Process transport delay

The corresponding response for the open-loop step test is shown in Figure 3.

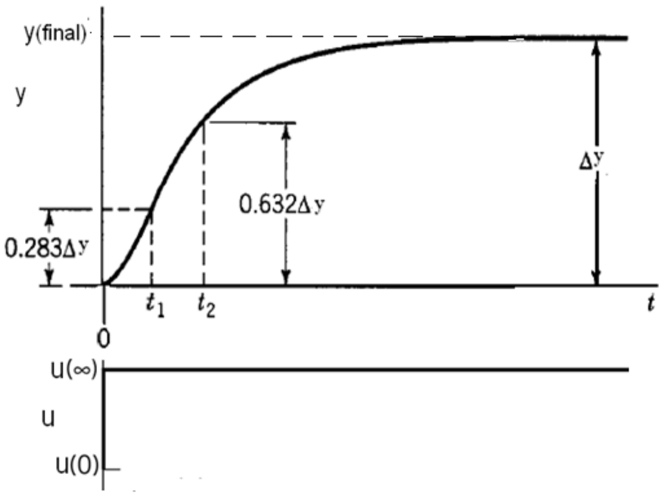

Figure 3: Open-loop step test response

V. PID CONTROL

The PID control technique lies on the three terms of proportional, integral and derivative actions [7]. The functionalities of these three-terms are as follows:

- The proportional term-reducing the rise time and will reduce the steady-state error, but never eliminate. Its output is proportional to input error signal which provides an overall control action proportional to the error signal. While the steady-state error will highlight if there is only proportional term in the control system.
- The integral term-eliminating steady-state errors through low frequency compensation by an integrator but it may affect the transient response that makes the transient response worse.
- The derivative term-increasing the stability of the system, reducing the overshoot, and improving the transient response. Its output proportional to the derivative of input error signal and improves transient response through high-frequency compensation by differentiator.

The individual effects of these three terms on the closed loop performance are as shown in Table I.

TABLE I: EFFECT OF INDEPENDENT P, I AND D PARAMETERS

Parameter	Rise Time	Overshoot	Settling Time	Steady-State Error
K_P	Decrease	Increase	Small Change	Decrease
K_I	Decrease	Increase	Increase	Eliminate
K_D	Small Change	Decrease	Decrease	No Effect

A. *Ideal Control Structure*

The ideal PID control structure is shown in Figure 4. In this structure, all three controller parameters are arranged in parallel in which the input to these parameters is the difference between the measured and the desired value.

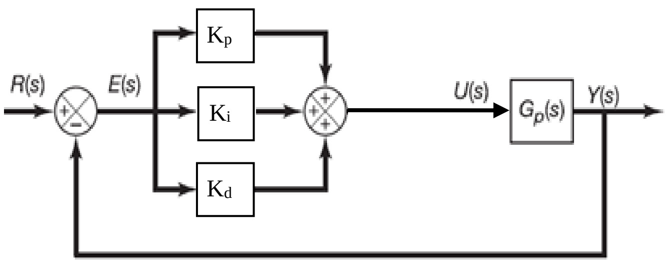

Figure 4: Ideal PID control structure

The mathematical expression of ideal PID control structure is as shown in Eq.(2) where E(S) is the error, K_p, T_i, and T_d is the coefficients of proportional, integral and derivative actions respectively.

$$U\ (S) = Kp[E(S) + \frac{1}{TiS}E(S) + \frac{TdS}{1 + \frac{Td}{Kd}S}\ E(S)\ ] \quad Eq.(2)$$

B. Serial Control Structure

The serial PID control structure is shown in Figure 5 and its mathematical form is as shown in Eq.(3).

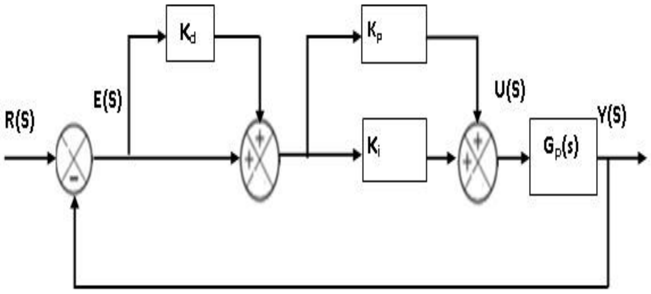

Figure 5: Serial PID control structure

$$U\ (S) = Kp\ \left[1 + \frac{TdS}{1 + \frac{Td}{Kd}S}\right] [E(S) + \frac{1}{TiS}E(S)] \quad Eq.(3)$$

In this structure, all three controller parameters are arranged in series in which the input to these parameters is the difference between the measured and the desired value.

C. I-PD Control Structure

The other form of PID control algorithm also known as I-PD or conventional control structure [8] is shown in Eq.(4). The corresponding structure is shown in Figure 6.

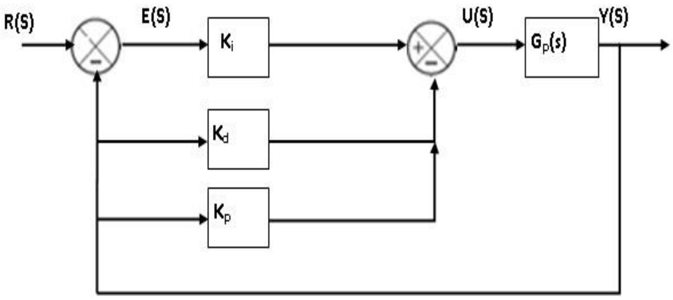

Figure 6: I-PD control structure

$$U\ (S) = Kp\ [-Y(S) + \frac{1}{TiS}E(S) - \frac{TdS}{1 + \frac{Td}{Kd}S}\ Y(S)\ ] \quad Eq.(4)$$

The coefficients of integral and derivative actions can also presented in terms of gain as shown in Eq. (6) and Eq. (7).

$$Ki = \frac{Kc}{Ti} \quad \textit{Eq.(6)} \qquad\qquad Kd = Kc.Td \quad \textit{Eq.(7)}$$

The proper use of derivation can increase stability and help maximize the integral gain for better performance [9]. In this case, filter is used in all PID structure to filter out high frequency components from the controller output in order to spare actuator from unwarranted action.

VI. PID TUNING

There are many established tuning method available in an open literature. The most popular online tuning method is known as Process Reaction Curve Tuning Method [12] shown in Table II.

TABLE II: REACTION-CURVE ZIEGLER-NICHOLS TUNING METHOD

Controller Type	Proportional Gain, K_P	Integral Time, T_I	Derivative Time, T_D
P	$\frac{1}{K}\left(\frac{\tau}{to}\right)$	-	-
PI	$\frac{0.9}{K}\left(\frac{\tau}{to}\right)$	3.33 t_o	-
PID	$\frac{1.2}{K}\left(\frac{\tau}{to}\right)$	2 t_o	0.5 t_o
Note: K = process gain, τ_p = process time constant, t_o = process time delay			

VII. METHODOLOGY

A. Process Model Determination

The steps taken for the PID control implementation are as follow [10]:

- Select the DCS mode from YS1700 controller panel.
- Set point is adjusted to 200mmH20.
- Set the higher limit (HL) and lower limit (LL) for PID control. In this case HL = 600mm and LL = 0mm.
- Set the control valve between 46% - 49%.
- Start the pump and observe the process response.

The two point method is used to determine the process time constant, τ_p and process time delay, t_o from the FOPDT model [11]. This method as shown in Eq. (8) and Eq. (9)

$$\tau p = \frac{3}{2}\ (t2 - t1)$$

$$to = t2 - \tau p$$

Where:

- t2 is time taken for the output to reach 63.2% of its total output change.
- t1 is time taken for the output to reach 28.3% of total output change.

B. PID Control and Tuning

Based on the process model parameters, the PID controller setting was determined using Ziegler-Nichols Reaction-Curve tuning method shown in Table II.

VIII. RESULTS

The responses for level control trainer system process correspond to the input signal when performing open loop test is shown in Figure 7. It is found that process gain, K_p = 8.57, process time constant, τ_p = 109.8 sec and process time delay, t_o = 10.2 sec.

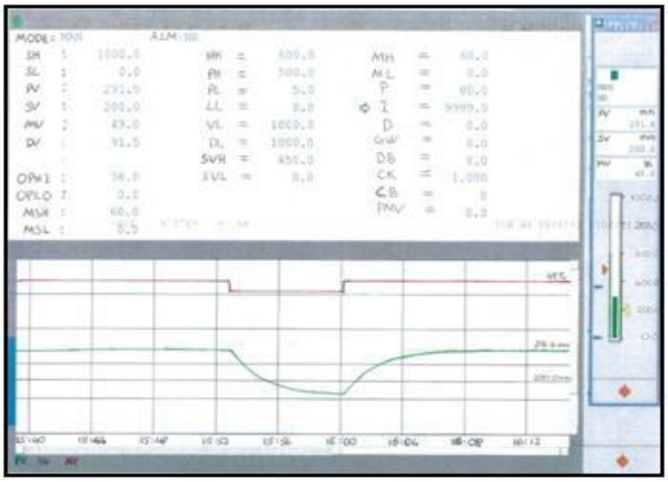

Figure 7: Open loop test process model

The controller parameter for open loop test process were found as K_p =1.507, K_i =0.074 and K_d =7.686 by using Reaction-Curve Ziegler-Nichols Tuning Method. Figure 8 show the closed loop process response before tuning and Table III show the corresponding transient response.

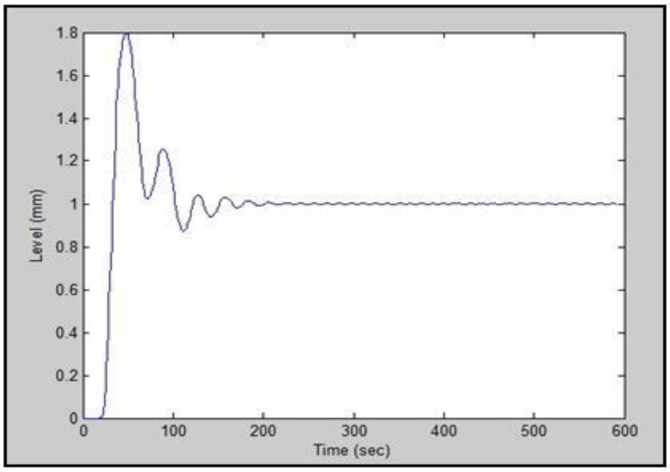

Figure 8: Closed- loop process response

TABLE III: TRANSIENT RESPONSE BEFORE TUNING

Transient Response	Before Tuning
Rs (sec)	8.29 sec
Ts (sec)	162.21 sec
Overshoot (%OS)	79.72%

Table IV show the controller parameters for three different PID structures.

TABLE IV: CONTROLLER PARAMETERS

Controller Structure	Controller Parameters		
	Kp	Ki	Kd
Ideal	0.201	0.002	5.856
Serial	1.101	0.002	5.075
I-PD	0.201	0.002	5.856

The responses of the process using tuned controller parameters tabulated in Table IV are shown in Figure 9, Figure 10 and Figure 11. The system performance when using each structure is shown in Table V.

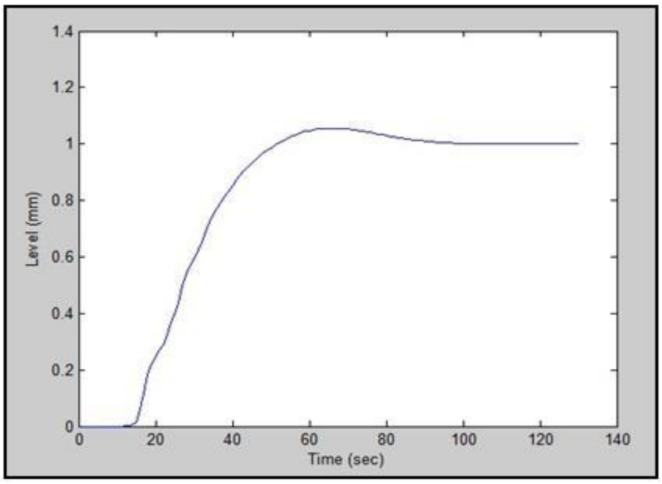

Figure 9: Process response for ideal PID control structure

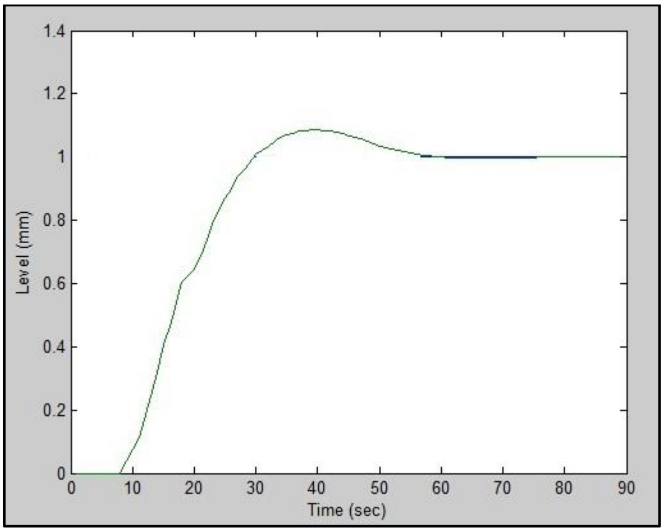

Figure 10: Process response for serial PID control structure

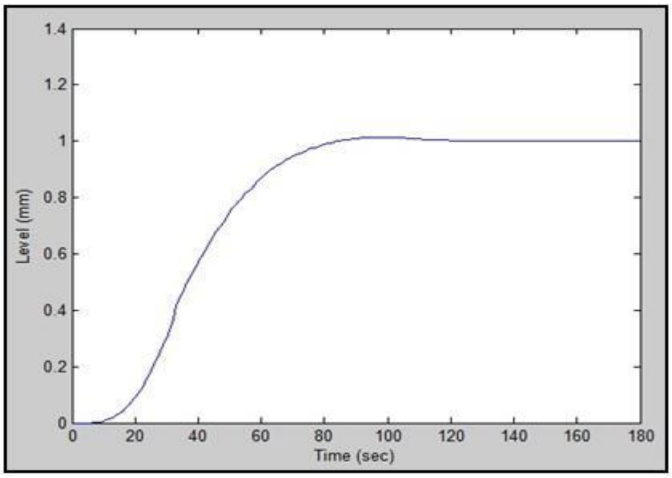

Figure 11: Process response for I-PD control structure

TABLE V: SYTEM PERFORMANCE

Transient Response	PID CONTROLLER STRUCTURE		
	Ideal	Serial	I-PD
Rs (sec)	25.97	15.35	42.43
Ts (sec)	84.16	52.79	77.54
Overshoot (%OS)	5.54	8.47	1.41

IX. CONCLUSION

The PID controller for different structure was successfully simulated and tested. The results revealed that the control system for level Control Trainer System WCT-03N is best performed using I-PD control structure. The result shows that I-PD control structure faster than the other control structure.

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