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Implementation and analysis of PID Control for Radiator temperature in a mini automated plant

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Abstract: For stable operation of any process the constants of the PID controller (K_p, K_i, K_d) needs to be adjusted. Automatic tuning adjusts the constants for stable operation. However when automatic tuning is not available then manual methods based on the Nichol's rules are used to determine the optimum PID constants values for smooth loop operation and to control process variables. In this paper, manual tuning PID controller is incorporated and then controller is implemented to stabilize the radiator temperature in a mini automated plant.

Keyword: Mini radiator; Proportional-integral-derivatives (PID) controller; time proportional power; Ziegler Nichols.

1. INTRODUCTION

The conventional PID control is most widely used method in the process industries because of its simplicity and easy implementation (Astrom and Hagglund 2004). The statistics of chemical, food and metallurgical industry shows that 97% of the control systems are PID type (Chen 1996) (O'Dwyer, 2009). PID is a three term controller in which function is based on the reaction to the error on current basis and its constant is termed as (k_p) which is said to be the gain of controller and proportional control only will eliminate existing error and resultant in reaction curve is an offset error. With addition of Integral function the sum of recent errors are accumulated and the reaction curve is improved and eliminates the residual steady state error (Heong, *et al.,* 2005) (Samin, *et al.,* 2011). The integral action (k_i) can cause the overshoot which can be avoided with the addition of derivative function (k_d) which is based on speed at which current error is changing or can predict the changes in error. Combined proportional, integral and derivative action can stabilize and improve controllability of the process variable (Rice, *et al.,*) Improper tuning of the PID parameters can lead to the cycling and slow recovery, poor robustness and the worst case scenario may be the collapse of system operation (Astrom and Hagglund 2004),(Astrom and Hagglund 1988). Equation (1) represents the weighted sum of three individual terms to adjust the final control element for regulating any process variable.

$$V_m(t) = K_p e(t) + K_i \int e(t)\, dt + K_d . e(t)\, de/dt \tag{1}$$

It has always remained an expert work to tune the PID controller for optimum response without knowing the mathematical model of plant. practicing engineers most often use conventional methods (i.e. Zeigler Nichols) to tune the PID controller. During commissioning of a controller the closed loop tests are performed on real plant by adjusting proportional gain by setting K_i and K_d to zero and with careful observation of reaction curve of process variable K_u (ultimate gain) and T_u (ultimate period) can be found from the reaction curve of temperature showing sustained oscillations. Known K_u and T_u are then used to calculate the PID constant K_p, T_i and T_d of controller. In this paper we have presented an approach to find PID constants and realized a controller for smooth temperature control of mini automated plant.

Section II focuses on the layout, experimental setup and finding the controller constants. Section III presents analysis of the control loop with PID controller to maintain a set point of the plant with and without disturbance. Section IV summarizes the conclusion.

2. METHODOLOGY

The layout of the test plant is shown in **(Fig.1)** having a PID controller, final control element relay, heater, and radiator, thermocouple as measuring device and temperature transmitter are connected in the feedback to realize a loop. Temperature transmitter displays the temperature and incorporates the signal conditioning required by the thermocouple signal *i.e.* amplification and linearization. This section is further divided into two parts, first part discusses the test to get the sustained temperature oscillation and in the second

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*Department of Telecommunication Engineering, MUET, Jamshoro, Pakistan part implementation of PID controller in the process is explained.

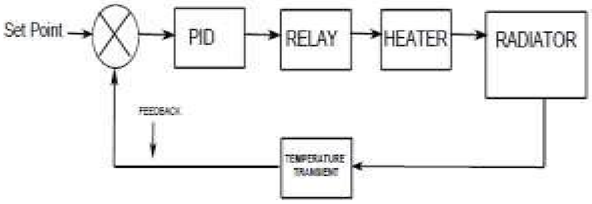

Fig 1: Layout of the mini plant

A. Test setup to get sustained oscillations

In order to get sustained oscillations in process variable the plant is brought to be in the closed loop and by enabling only P action with different set points. **(Fig.2)** shows the layout of the plant in which the process is disturbed and reaction curve is observed. K_p is modulated in such a way that oscillations in reaction curve may not die out but remain sustained. Three tests based on different constants (K_p =10, K_p=32, K_p=40) were performed with proportional action only having set point of 35ºC. A DC voltage of 3.5V equivalent to 35ºC is applied to error amplifier which compares the set point voltage and measured process variable *i.e.* radiator temperature and generates an error signal. The error signal is applied to proportional amplifier having already adjusted gains for three individual tests and resulting output voltages are shown in **(Fig.3)**.

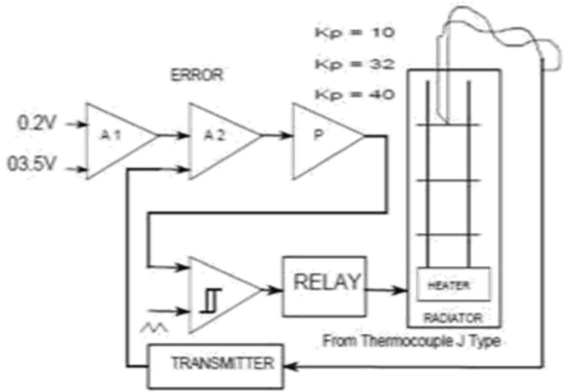

Fig 2: Experimental realization of P action of controller.

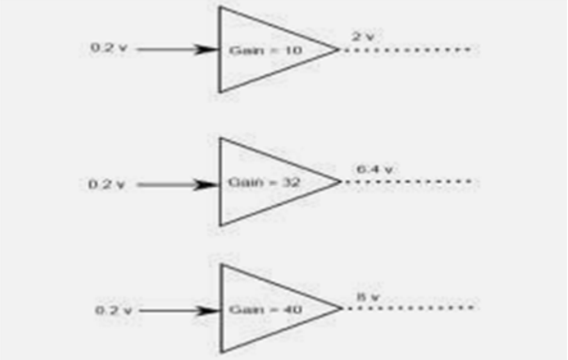

Fig 3: Adjustments of Proportional gains

The output of proportional amplifier is the level Hysteresis based comparator which produces time proportional power signal to solid state relay. As the heater generates heat by the average time proportional power signal developed by the solid state relay .The feedback sensor *J* type thermocouple measures the radiator temperature (in mV) and connects to a temperature transmitter (TT) which spans to 50ºC *i.e.* the maximum temperature of radiator in mini automation plant. TT incorporates amplification, linearization and cold junction compensation for thermocouple signal. TT displays radiator temperature in degree Celsius and also generates a 0 to -5V signal in correspondence to 0 to -50ºC. Temperature values for each test are recorded by observing the times at which minimum and maximum temperature occurs ranging from 2 minutes to 15 minutes and temperature curves are plotted are given in **(Fig.4, 5 and 6)** showing the behavior of process variable with the change in set point. Plot in Fig. 4 reveals that oscillations die out and is not suitable to find the controller constants using K_u and T_u. In Fig.6 it is not showing any sustained time periods in successive oscillations however it is not having any die out or increases in amplitudes but Fig. 5 is showing some similar successive periods of oscillations and stability in peaks. Hence taking K_u 32 and P_u as 152 seconds in Fig.5 the constants of PID controller are calculated using Ziegler Nichols rules as shown in **(Table. 1)**.

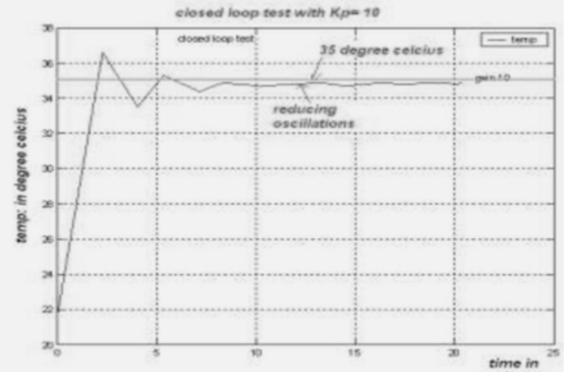

Fig 4: Reaction curve with K_p =10.

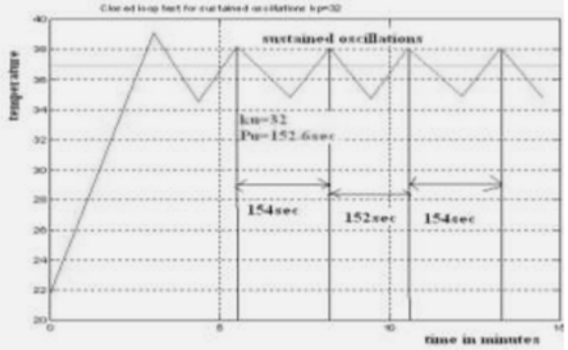

Fig 5: Reaction curve with K_p =32.

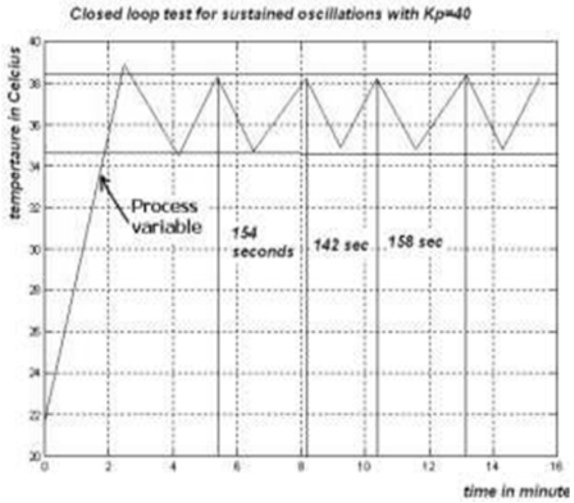

Fig.6: Reaction curve with K_p = 40.

Table-1: PID controller constant calculations.

P	I	D
$K_p = 0.9 \times K_u$ 0.9×32=28.8	$K_i = 0.625 \times P_u$ 0.625×152 sec	$K_d = 0.1 \times P_u$ 0.1×152 sec
K_p=28.8	K_i=94.5 sec	K_d=15.2 sec

B. Implementation of the PID process

In order to implement PID control action, proper adjustments of the individual constants K_p = 28.8, T_i = 94.5 seconds and T_d =15.2 seconds is performed manually on mini automation plant. The hardware connections are represented in the blocks as shown in **(Fig.7)**. Plant is brought in closed loop and a set point is adjusted to 37ºC and its equivalent signal of 3.7V is applied from dc power source out of 5V which is the maximum limit of voltage for 50ºC which is the span of temperature transmitter and maximum operation limit of mini automation plant. Cooling fan of radiator operates on lower and higher speed and is turned on at lower speed initially when the loop is brought in operation.

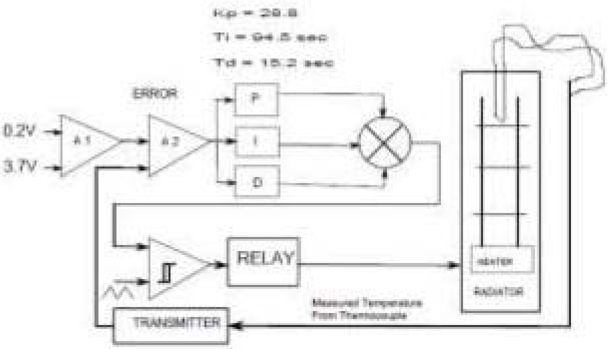

Fig7: Implementation of PID control.

3. ANALYSIS RESULT

The objective of PID controller is to generate a control signal in such a way that the heater turns ON and OFF and the average power generated heats the radiator and the desired temperature is maintained quickly and precisely. PID controller can produce best results if its constants are known and tuned properly. Temperature of radiator in this test is recorded for 19 minutes with a gap of every 30 seconds. Recorded temperature is plotted on y axis and time on x axis. **(Fig.8)** shows the radiator temperature being stabilized near 37ºC which is set point. **(Table 2)** presents the set point analysis of the loop which shows the radiator temperature stabilizes within 8 minutes, having Peak overshoot ratio of 10% and decay rate 8.4% near popular values and is being maintained at 36.8 ºC with an error of 0.2 ºC in steady state condition. **(Fig. 9)** represents the disturbance introduced to the same loop with PID at a set point of 37 ºC, by increasing the speed of radiator cooling fan from lower to higher at 20 minutes of operation. The Set point desired temperature 37 degree Celsius is initially stable and after introduction of disturbance it again stables at 37.1 ºC at the end of response curve of radiator temperature.

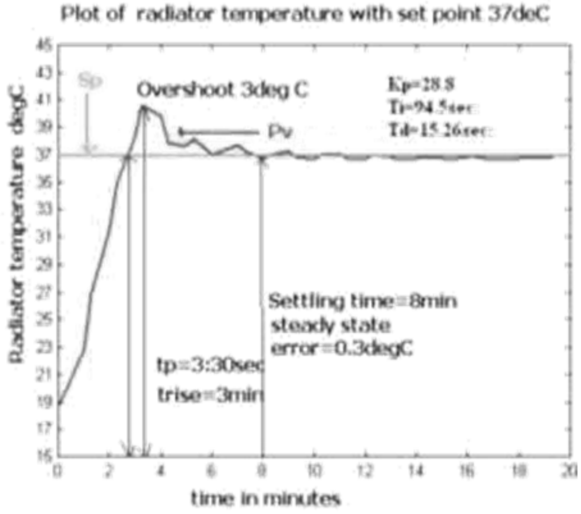

Fig 8: **Radiator temperature**

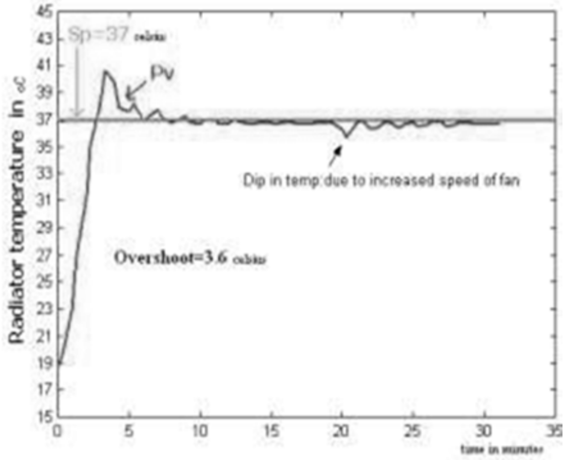

Fig 9: PID loop with disturbance.

Table.2: Set point Analysis.

	POR	**3.6 °C which is 10%**
Bump	**Decay Rate**	**Ratio of 2nd peak to 1st peak which is 8.4%.**
point	**Rise time(*t* rise)**	**3 minutes**
Set	**Peak time(*t* peak)**	**3.5 minutes**
	Settling time(*t* settle)	**8 minutes**

4. CONCLUSION

Having the knowledge of basic laws and any disturbance which can cause the unstable process variables in the control loop enables the Engineers and designers to identify, predict and analyze the difference between normal and abnormal conditions. Hence corrective measures can be taken by proper monitoring of the process loops. In this paper hardware based PID control was realized on mini automation plant. Temperature of radiator tracks the set point of 37°C and then the loop also remains stable when it is subjected to disturbance in the form of increase in speed of radiator cooling fan.

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