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First Order Plus Dead Time (FOPDT) model acquired for temperature process with Conventional PID

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I. INTRODUCTION

PID controllers are standard tools for industrial applications because, they are facile and potent. But it is difficult to characterize the PID controller parameters accurately. Therefore auto tuning methods are advanced. In any of the process control and automation industries, controller designing and automatic controlling is the utmost important part. The objective of this paper prompts the analysis of temperature process control and robust controller. Control or maintaining the temperature at a desired state is an influential and common task in all process industries. Traditional controllers are easy to understand and implement. PID controllers are felicitous to many control problems, but they perform poorly in some control applications. It suffers deficiencies in the face of plant non-linearity and uncertainty present in the plant. These conventional techniques were unable to give satisfactory results for the process output [1–8]. To design and tune the controller to achieve the better performance it is essential to;

1. Obtain the dynamic model of a system to control.
2. Specify the desired closed loop performance on the basis of known physical constraints.
3. Adopt controller strategies that would achieve the desired performance.
4. Implement the resulting controller using suitable platform.
5. Validate the controller performance and modify accordingly if required.

EXPERIMENTAL SETUP

The process setup consists of heating tank fitted with SSR controlled heater for on-line heating of the water. The flow of water can be manipulated and measured by Rota meter. Temperature sensor (RTD) is used for temperature sensing(Figure 1).

1. Control Unit: Digital indicating controller with RS 485 communication;
2. Communication: USB port using RS 485-USB converter;
3. Temperature Sensor: Type RTD, PT 100;
4. Heating Control: Proportional power controller (SSR), input 4–20 mA D.C., Capacity 20 A;
5. Rota meter: 6–60 LPH;
6. Process Tank: SS304, Capacity 0.5 l, insulated;
7. Overall dimensions: 400w*400d*330h mm.

This explores the system schematic arrangement of UT_321. A step input is applied to solid state relay (SSR) and temperature of RTD (PT 100) is recorded in excel format. Stored data is used to plot open loop step response in MATLAB. The procedure followed is:

1. Connect the sensor before the delay line.
2. Start the set up and select the open loop control.
3. Set the controller output as 40% and allow the process to reach the steady state.
4. Then apply step change by increasing the controller output to 60% and allow the process to reach the steady state.

The process transfer function has been determined by the experimental process mentioned above. The experiment is carried out and the response is taken until the steady state is reached without the use of the controller. The response of that process without controller will be a curve with some dead time and steady state time. By that, gain of the process can be determined which is the ratio of output to the input, time constant can be calculated which is the time difference from dead time to steady state and dead time (i.e.,) the time period for which the output is not responding to the input is also determined.

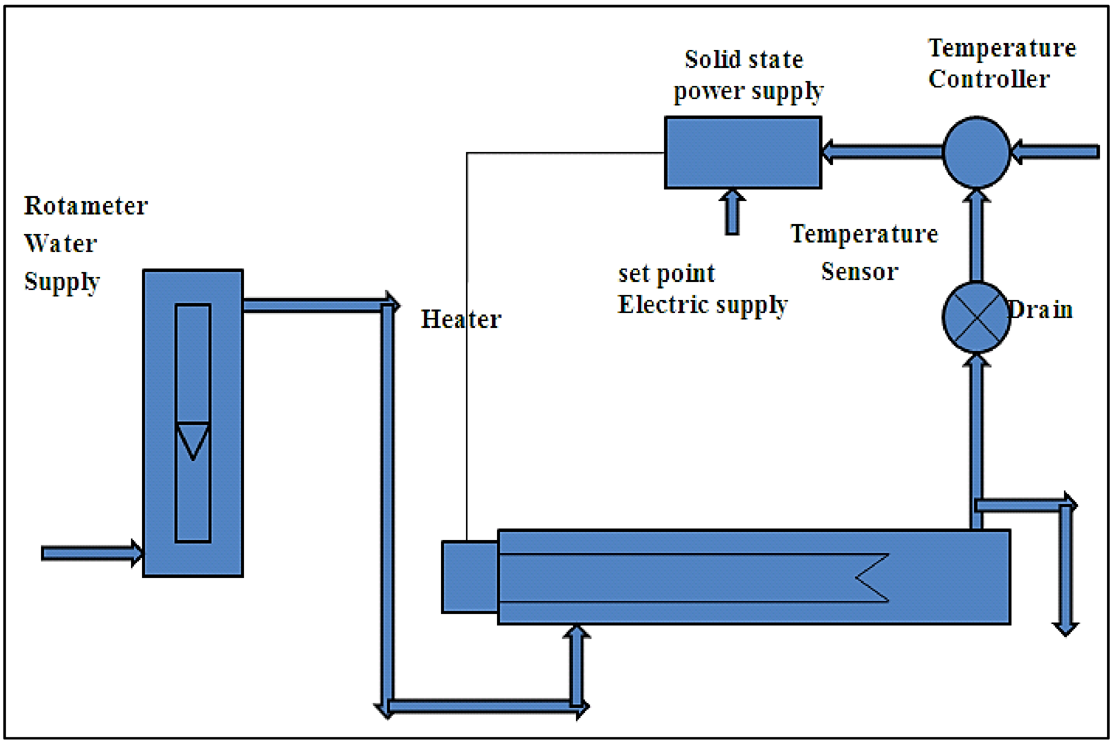

Fig. 1: *Experimental Setup.*

Fig. 2: *Laboratory Temperature System Control Unit.*

LABORATORY TEMPERATURE SYSTEM CONTROL UNIT

Temperature often has to be set on large machines or process or systems. The setting should not change the process parameters when faults occur. Such tasks are undertaken by closed-loop controllers. The controlled variable is first measured and an electrical signal is created to allow an independent closed loop controller to control the process variable. In the temperature closed-loop control system the task is to keep the outlet temperature at the desired value or to pursue the desired-value curve (Figure 2).

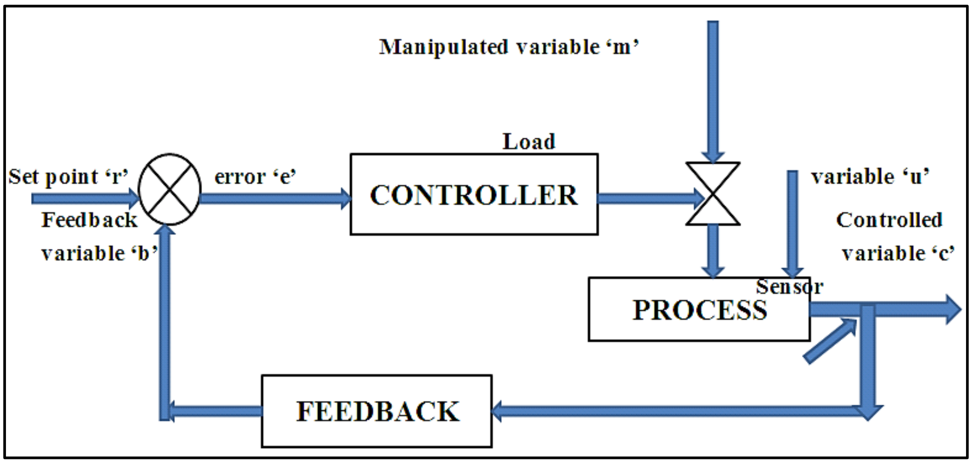

Fig. 3: *Determination of SystemModel.*

DETERMINATION OF SYSTEM MODEL

This step (Figure 3) response locates the system parameters like steady state gain, time delay and the time constant of the processfrom which model obtained is of general form as,

$$G(s) = \frac{kpe^{-tdS}}{\tau s + 1}$$

where,$k_p$is steady state gain of system,$\tau$is time constant of system,$t_d$is dead time of system.Hence, we obtain the First Order Plus Dead Time (FOPTD) transfer function form the above temperature process by using S-K method.

$$Gp(s) = 0.55 * \frac{e^{-390.15s}}{67s + 1}$$

where,$Gp(s)$is the Process Transfer function.(water flow through rotameter is kept at 40 l/h).

CONTROLLER DESIGN BY Z-N METHOD

It is a simple technique for tuning of PID controllers and can be refined to give better approximation of the controller. In the 1940's, Ziegler and Nichols devised two empirical customs for obtaining controller parameters. Their methods were used for non-first order plus dead timesituations and involved intense manual calculations.

The below block diagram (Figure 4) is the representation of closed loop Ziegler-Nichols Method. The eminenceof using Z-N method is:

- Easy to experiment,it includes dynamics of whole process, which gives a more accurate picture ofhow the system is behaving [5–10];
- Hence the Z-N method gives the following model,

Kp=1.464, Ki=0.0062, Kd=86.37.

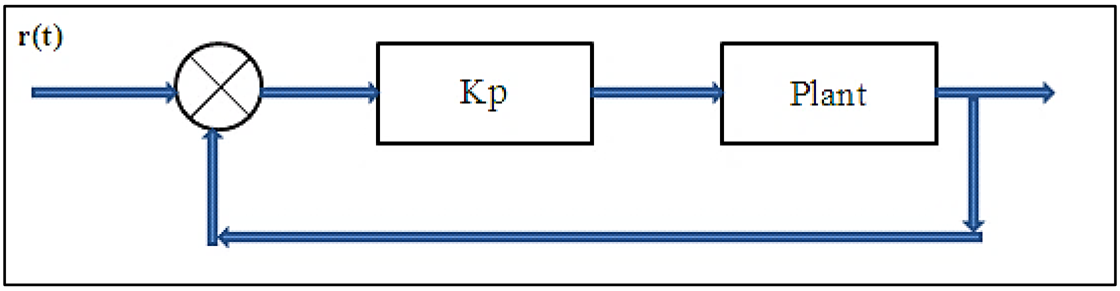

Fig. 4 : *Ziegler-Nichols Method.*

Controller Designby Internal Model Based Controller

This method of tuning can also be called as lambda tuning. It offers a stable and robust alternative to other techniques. The IMC tuning method was developed for use on self-regulating processes.

The IMC tuning method offers the following advantages,
Once tuned using the IMC tuning rules, the process will not overshoot its setpoint after set point changes.

- The tuning is very robust, meaning that the control loop will remain stable even if the process characteristics change substantially from the ones used for tuning.
- The user can specify the desired control loop response time(the closed loop time constant). This provides a single “tuning factor” that can be used to speed up and slow down the loop response [9–12].

The disadvantage is, it sets the controller integral time equal to the process time constant. If the process has a very long time constant, the controller will consequently have a very long integral time.
Kp=0.156, Ki=0.002332, Kd=60.8634.

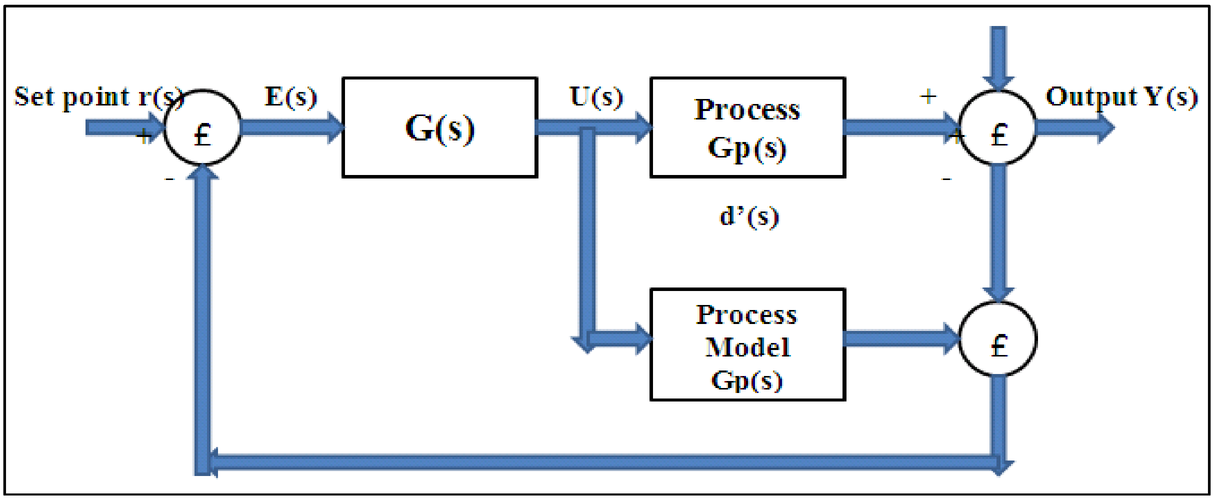

***Fig. 5 :** Tavakolie Method*

Controller Design byTavakolie Method
This is an optimal method based on a dimensional analysis and numerical optimization techniques, for tuning the PID controllers, for first order plus dead time systems (FOPTD). The values of controllers produced, (Figure 5)
Kp=0.7727,Ki=0.00513,Kd=0.5748

Controller Designby Suyama Method
A simple design for PID control, and this method was brought into existence in the year 1992. Out of different controller tuning methods Suyama outperforms well with no overshoot and also it provides adequate step responses. The values obtained,
Kp=0.635, Ki=0.003385, Kd=27.346(Table 1).

Controller Design by Unification Method
This is one of the efficient methods for PID tuning, and the advantage of using this is it gives no overshoot. In addition, experimental results confirmed improved generalization performance, because over-training can significantly be suppressed. The values produced:
Kp=0.3096, Ki=0.0045, Kd=59.88(Table 2).

FORMULA USED

***Table 1:** Experimental Results.*

Tuning Rule	Kp	Ki	Kd
Z-N	Ku/1.7	Pu/2	Pu/8
IMC	$1/K(\tau/\tau_{c+}\tau_d)$	T	τ_c
Tavakolie	$0.8/K_p(\varepsilon+0.1)$	$\tau_d(0.3+(1/\varepsilon))$	$0.06\tau_d/(\varepsilon+0.04)$
Suyama	$((0.7236/\varepsilon)+0.2236)/K_p$	$\tau+0.309\tau_d$	$2.236\tau\tau_d/(7.236\tau+2.236\tau_d)$
Unification	$T_i/(k_p*(\lambda+\tau_d)$	T	$0.5*\tau_d$

Time Domain Specifications

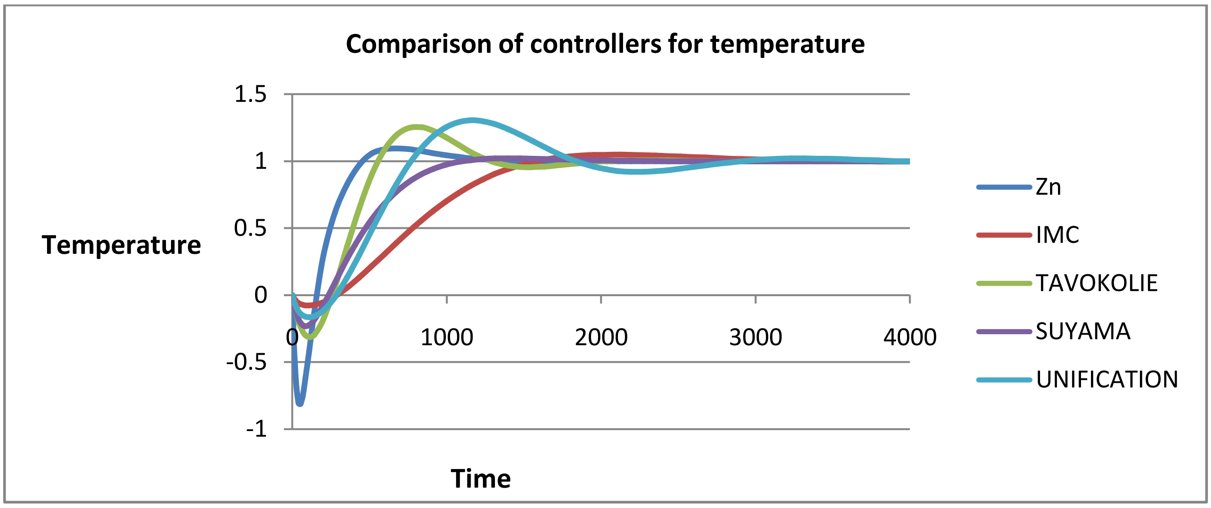

Fig.6 :*Comparison of Controllers for Temperature.*

Table 2: *Experimental Results.*

Controllers	Settling Time	Rise Time	Peak Time	Peak Overshoot
Z-N	1500	278	600	10
IMC	3200	1180	0	0
Tavakolie	2760	320	830	25.5
Suyama	2500	822.5	0	0
Unification	4980	437	1191.2	30.36

Performance Criteria

The shape of the complete closed loop response, from time t=0, until steady state has been reached, could be used for the formulation of a dynamic performance criterion. Unlike the simple criteria of this category are based on the entire response of the process.The most often used are,

- Integral of the Absolute Error (IAE) where;

IAE=$_0\int^{\infty}|e(t)|.dt$

- Integral of the Square Error (ISE) where;

ISE=$_0\int^{\infty}e^2(t).dt$

- Integral of the Time-Weighted Absolute Error (ITAE) where;

ITAE=$_0\int^{\infty}t|e(t)|.dt$

- Integral of the Time-Weighted Square Error or Mean Square Error (MSE) where;

MSE=$_0\int^{\infty}t.e^2(t).dt$

where e (t)=Ysp(t)–Y(t) is the deviation (error) of the response from the desired set point(Table 3).

Table 3: *Performance Criteria.*

Controllers	ISE	IAE	ITAE	MSE
Z-N	4.3094e+003	3.2685e+003	4.9048e+005	0.2873
IMC	6.2891e+003	8.689e+003	5.0564e+006	0.1906
Tavakolie	4.8946e+003	5.8586e+003	2.3403e+006	0.0979
Suyama	4.5789e+003	5.6413e+003	1.9425e+006	0.0916
Unification	5.1017e+003	7.6591e+003	5.2471e+006	0.1020

ROBUSTNESS INVESTIGATION

Robustness of controller is defined as its ability to tolerate a certain amount of change in process parameters without causing the feedback system to go unstable. One of the efficient properties of any controllers tuning method is its robustness to model errors.

In order to investigate the robustness of model in presence of uncertainties, the model parameters are randomly altered. Here the values of gain constant k, time constant τ_c and delay time $\tau_d$are deviated as much as ±20% of nominal values. In the proposed model of the experimental setup, the value of K is raised by 20% and the value of τ_c is raised by 20% and that of $\tau_d$is reduced to 20%.The transfer function by applying above procedure is,

$$G(s) = 0.99 * \frac{e^{-391.5s}}{60S + 1}$$

II. CONCLUSION

System identification is done and a First Order Plus Dead Time (FOPDT) model is acquired for temperature process. It can be seen that the performance by Zeigler-Nicholas is superior to four other methods. Since the settling time is very less. Even though the peak time and overshoot for IMC and Tavakolie is 0% it lags in settling time.The performance index of variant tuning rules are also achieved. The simulation outcomes proves that Zeigler-Nichols controller tuning technique is easily adaptable and more effective way to enhance stability of time domain performance of temperature process.

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