Temperature Control System and its Control using PID Controller

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***Abstract*— Temperature control is required in nearly each and every field of application such as household, industrial, research and other such applications. In this paper, we present the mathematical modeling of temperature control system and its control using PID controller. Based on the experimental data taken in the laboratory, we develop a transfer function model of an oven under observation and then design a PID controller in order to improve its step response characteristics.**

Keywords*— *Control System Design; PID Controller; Stability Margins .

I. INTRODUCTION

The temperature control system is used widely in industries. In this, the plant is an electric oven or a heater whose temperature is to be controlled with respect to the reference input and control. In this paper, we present the mathematical modeling of an electrical oven and its tuning using a PID controller.

The organization of the paper is as follows. In this section we describe the mathematical model of the oven. PID controller is described in the next section. In the third section we obtain the transfer function model of the system using the experimental data. The tuning of the PID controlled temperature system is presented in the fourth section and finally in the last section the conclusions are presented.

In temperature control system, there is the transfer of heat from the heater coil to the oven and the leakage of heat from the oven to the atmosphere. There are three modes of heat transfer viz. Conduction, convection and radiation. Heat transfer through radiation may be neglected in the present. For conductive and convective heat transfer is given by equation (1)

$$\theta = \alpha \Delta T \qquad (1)$$

Where, θ is the rate of heat flow in joule/sec

ΔT = temperature difference in

α = constant

Under assumptions of linearity, the thermal resistance is defined as

R= temperature difference/ rate of heat flow = (θ/ ΔT).
This is analogous to electrical resistance defined by I=V/R.

In the similar pattern thermal capacitance of the mass is given by equation (2)

$$\theta = C\, d(\Delta T)/dt \qquad (2)$$

Which is analogous to the V-I relationship of a capacitor, namely I=CdV/dt. In the case of heat,

C= rate of heat flow /rate of temperature change.

The equation of an oven may now be written by combining the above two equations, implying that a part of the heat input is used in increasing the temperature of the oven and the rest goes out of loss. Thus

$$\theta = C\, d(T)/dt + R^{-1}T \qquad (3)$$

With an initial condition $T(t=0)=T_{amb}$. Now, taking Laplace transform with zero initial condition

$$T(s)/\theta(s) = R/(1+sCR)$$

II. PID CONTROLLER

PID controller [1] is the most widely used controller in the industry. A PID controller has three parameters- proportional constant 'K_P', integral constant 'K_I' and the derivative constant 'K_D'. These three parameters are meant to take care of the present, future and the past errors. A PID controlled process having system transfer function 'G_s' and unity feedback is shown in Fig. 1.

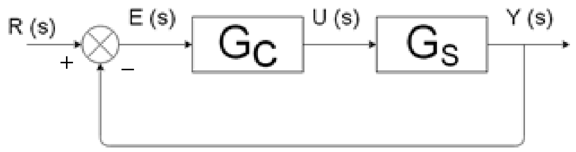

Fig.1. PID Controller

'G_c' is the transfer function of the PID controller and is given by equation (4) and (5)

$$G_c = K_P + \frac{K_I}{s} + K_D s \qquad (4)$$

$$G_c = K_P\left(1 + \frac{1}{T_i s} + T_d s\right) \qquad (5)$$

Proportional action is meant to minimize the instantaneous errors. However, by itself it cannot make the error zero and provides a limited performance. The integral action forces the steady state error to zero, but has two disadvantages: due to the presence of a pole at the origin, it may result in system instability and the integral action may create an undesirable effect known as wind-up in the presence of actuator saturation. The derivative action acts on the rate of change of error and it may result in large control signals when the error signal is of high frequency.

III. TRANSFER FUNCTION MODEL OF THE TEMPERATURE CONTROL SYSTEM

The step response of the open loop system is obtained and the experimental data are shown in Table.1. From the step response of the open loop system, the transfer function model is obtained and is given by equation (6).

$$G(s) = \frac{104e^{-2.6s}}{1+15.783s} \qquad (6)$$

Table. 1. Experimental Data of open loop system

Temperature (degrees)	Time Interval (sec)
35	0
35.5	17
37	7
38	4
39	4
40	5
41	3
42	3
43	5
44	2
45	4
46	3
47	4
48	4
49	4
50	4
51	4
52	4
53	5
54	4
55	4
56	3
57	7
58	4
59	6
60	6
61	5
62	7
63	5
64	7
65	7
66	7
67	7
68	8
69	9
70	9
71	10
72	11
73	11
74	12
75	13
76	15
77	17
78	16
79	18
80	25
81	24
82	30
83	35
84	40
85	42
86	48

IV. CONTROL USING PID CONTROLLER

The process of selecting the controller parameters to meet given performance specifications is known as controller tuning. Ziegler and Nicholas [2] suggested rules for tuning PID controllers (meaning to set values K_p, T_i and T_d) based on experimental step responses or based on the value of K_p that results in marginal stability when only proportional control action is used. Ziegler–Nichols rules, which are briefly presented here, are useful when mathematical models of plants are not known.

There are two methods called Ziegler–Nicholas tuning rules: the first method and the second method.

A. First Method:

This method applies if the response to a step input exhibits an S-shaped curve. Such step-response curves may be generated experimentally or from a dynamic simulation of the plant. The S-shaped curve may be characterized by two constants, delay time L and time constant T. The delay time and time constant are determined by drawing a tangent line at the inflection point of the S-shaped curve and determining the intersections of the tangent line with the time axis and line c(t)=K, as shown in Fig. 2. The parameters of the PID are taken as:

$$K_p = 1.2\,(T/L)$$
$$T_i = 2\,L$$
$$T_d = 0.5\,L$$

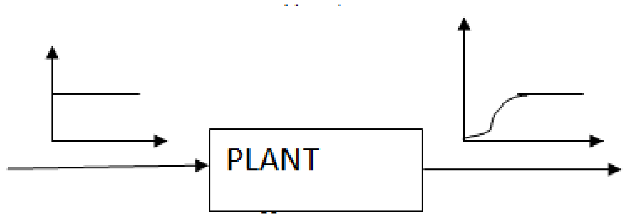

Fig.2. Ziegler-Nicolas Tuning Method-1

B. Second Method:

In the second method, we first set $T_i = \infty$ and $T_d = 0$. Using the proportional control action only (see Fig. 3.), we increase K_p from 0 to a critical value K_{cr} at which the output exhibits sustained oscillations. Thus, the critical gain K_{cr} and the corresponding period P_{cr} are experimentally determined. Ziegler and Nicholas suggested that we set the values of the parameters K_p, T_i , and T_d according to the formula shown below:

$$K_p = 0.6\,K_{cr}$$
$$T_i = 0.5P_{cr}$$
$$T_d = 0.125P_{cr}$$

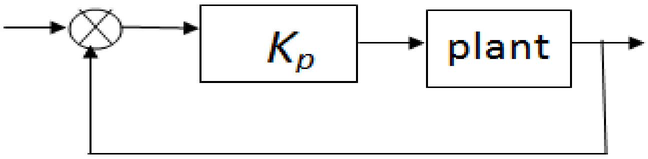

Fig.3. Ziegler-Nicolas Tuning Method 2

The open loop response of the temperature control system is shown in Fig. 4. The response is a S-shaped curve and so we use Ziegler-Nicolas tuning method-1, to find the parameters of the PID controller. From the open loop step response curve the values of L and T are found to be 3 and 24 respectively. Hence, the parameters of the PID are:

$$K_p = 1.2\,(T/L) = 9.6$$
$$T_i = 2\,L = 6$$
$$T_d = 0.5\,L = 3$$

$$G_c = \frac{14.4s^2 + 9.6s + 1.6}{s}$$

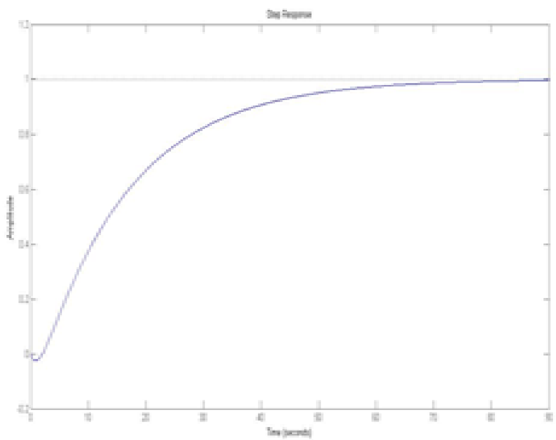

Fig.5. Step response of the closed loop system

The closed loop response of the temperature control system controlled using the PID controller is shown in Fig. 5. and the step response parameters are shown in Table. 2.

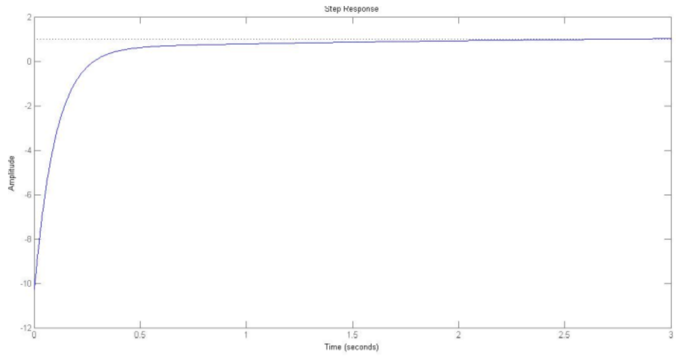

Fig.5. Step response of the closed loop system

Table. 2. Step response parameters

	Settling Time (sec)	Rise Time (sec)	Overshoot (%)
Open loop system	63.98	34.8	0
Closed loop system with PID	0.93	0.25	0

V. CONCLUSION

We have presented the transfer function model of a temperature control system. The step response characteristics of the system can be improved by using a PID controller. Ziegler-Nicolas tuning methods were discussed and using the plant model, the parameters of the PID controller were determined. Comparison of the open loop response of the system with respect to the closed loop response shows a significant improvement in the step response characteristics.

REFERENCES

[1] K.J. Astrom, T. Hagglund, "PID Controllers: Theory, Design and Tuning", 2nd Edition, Instrument Society of America, Research Triangle Park, 1995

[2] Ogata, K., "Modern Control Engineering," Prentice-Hall, Upper Saddle River, NJ, pp. 493-502, 2010