



## Optimal Tuning of Temperature Control System using Genetic Algorithm

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**Abstract:** During the last years, the use of intelligent strategies for tuning of controller has been growing. The evolutionary strategies have won an important place thanks to their flexibility. PID tuning plays an important role in operations or tuning in the complex process such as the temperature of an oven used in many industrial applications. However, many tuning technologies for strictly maintaining the temperature are difficult to tune with conventional optimization methods since the process has many difficulties; delay or transportation lag, rate of temperature depends on thermal resistance, temperature oscillations about its nominal value etc. Up to the present time, since the gain of the controller has to be manually tuned by trial and error, it is very difficult to achieve an optimal gain with no experience. This paper addresses comparison of tuning methods of the PID Controller using various tuning techniques and genetic algorithm based tuning technique on temperature control system.

**Keywords:** temperature control system, PID controller, tuning technologies,

## I. INTRODUCTION

Plant to be controlled is an electric oven, the temperature of which must adjust itself in accordance with the reference or command. This is a thermal system which basically involves the transfer of heat from one section to another. In the present case, we are interested in the transfer of heat from the heater coil to the oven and 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 case since the temperature involved is quite small.

Difficulties are however faced in the system due to following reasons:

- The temperature rise in response to the heat input is instantaneous. A certain amount of time is needed to transfer the heat by convection and conduction inside the oven. This requires a delay or transportation lag term,  $\exp(-sT_1)$ , to be included in the transfer function, where  $T_1$  is the time lag in seconds.
- Unlike the equivalent electrical circuit of figure 1. The heat input in the thermal system cannot have negative sign. This means that, although, the rate of temperature rise would depend on the heat input, or the rate of temperature fall would depend on thermal resistance  $R$ . The conventional analysis methods then become inapplicable.

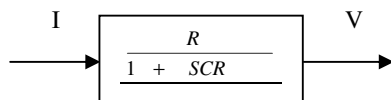


Figure 1

- Referring to the closed loop oven control system of figure 2, it may be seen that in the steady state the error  $e_{ss} = \lim_{t \rightarrow \infty} (T_{ref} - T) = T_{ref} / (1 + AR)$

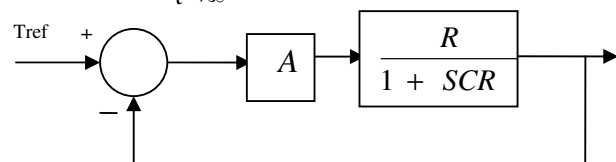


Figure 2

In this system,  $A$  cannot be increased excessively in an attempt to reduce error, since a large gain is likely to lead to instability due to transportation lag. Also, every time  $(T_{ref} - T)$  becomes negative, the heat input is cut off and the oven must cool down slowly. The temperature  $T$  therefore oscillates around nominal value.

The objectives that have been realized through the above difficulty are the following:

- To identify the oven parameters with the help of plant response.
- To determine the transfer function of the oven including its actuator.
- To investigate the response of various control tuning methodologies using MATLAB.
- To compare the above responses with the controller tuning designed by using GENETIC ALGORITHM.

In this paper, a GA was used to automate the tuning of temperature control system in order to get insight of the advantages of using a GA, the results were compared against the open loop system, closed loop system, Ziegler-Nichols first method and Ziegler-Nichols modified closed loop method.

## II. PID CONTROLLER TUNING METHODS

### A. Ziegler-Nichols First method

Ziegler-Nichols method applies to the open loop transfer function [2]. It is simpler to calculate because the guess work is taken out as opposed to the closed loop method where the accuracy of 'steady oscillations' becomes estimation at best. The control law settings are then obtained from the table 1.1. Here L is delay time and T is time constant.

Table I: Tuning parameters for Ziegler Nichols First Method

Type of controller	$K_p$	$K_i$	$K_d$
P	$\frac{T}{L}$		
PI	$0.9 \frac{T}{L}$	$\frac{L}{0.3}$	
PID	$1.2 \frac{T}{L}$	$2L$	$0.5L$

### B. Ziegler-Nichols Closed Loop Method

The method is straightforward. First, set the controller to P mode only then set the gain of the controller ( $K_c$ ) to a small value. Make a small set point (or load) change and observe the response of the controlled variable. If  $k_c$  is low, the response should be sluggish. Increase  $k_c$  by a factor of two and make another small change in the set point or the load. Keep increasing  $k_c$  by a factor of two until the response becomes oscillatory. Finally, adjust  $K_c$  until a response is obtained that produces continuous oscillations. This is known as the ultimate gain ( $K_u$ ). Note the period of the oscillations ( $P_u$ ). The control law settings are then obtained from the table 1.2.

Table II: Tuning Parameters for Ziegler Nichols Closed Loop Ultimate Gain Method

Type of controller	$K_c$	$K_i$	$K_d$
P	$K_u/2$		
PI	$K_u/2.2$	$P_u/1.2$	
PID	$K_u/1.7$	$P_u/2$	$P_u/8$

It is unwise to force the system into a situation where there are continuous oscillations, as this represents the limit at which the feedback system is stable[3]. Generally, it is a good idea to stop at the point where some oscillation has been obtained. It is then possible to approximate the period ( $P_u$ ) and the gain at this point is taken as the ultimate gain ( $K_u$ ), then this will provide a more conservative tuning regime.

### C. Genetic Algorithm

Genetic algorithms are search algorithms based on the mechanics of natural selection and natural genetics. They combine survival of the fittest among string structures with a structured yet randomized information exchange to form a search algorithm with some of the innovative flair of human search. Genetic algorithms have been developed by John Holland, his colleagues, and his students at the University of Michigan. The goals of their research have been two fold:

[a] To abstract and rigorously explain the adaptive processes of natural systems

[b] To design artificial systems software that retains the important mechanism of natural systems.

Genetic algorithms are different from more normal optimization and search procedures in four ways:

- [1] GAs work with a coding of the parameter set, not the parameters themselves.
- [2] GAs search from a population of points, not a single point.
- [3] GAs are payoff (objective function) information, not derivatives or other auxiliary Knowledge.

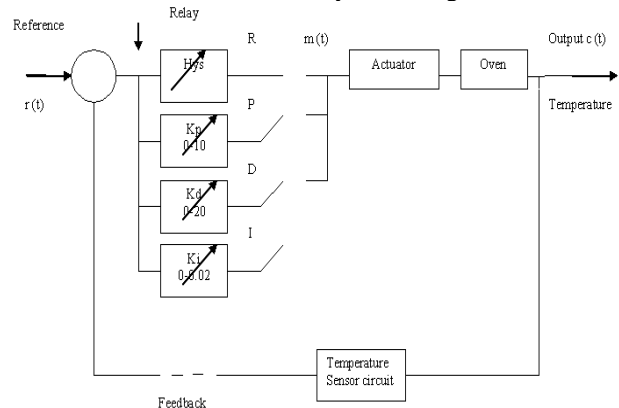


Figure.3

[4] GAs use probabilistic transition rules, not deterministic rules.

## III. CONTROL CHARACTERISTICS FOR DESIGNING OF CONTROLLER

### A. Control Characteristics in Temperature Control System

Temperature control is one of the most common industrial control systems that are in operation. This equipment is designed to expose the learner to the intricacies of such a system in the friendly environment of a laboratory, free from disturbances and uncertainties of plant prevalent in an actual process. The temperature data may be obtained manually, thus avoiding expensive equipment like an X-Y recorder. A solid state temperature sensor converts the absolute temperature information to a proportional electric signal. The reference and actual temperatures are indicated in degree Celsius on a switch selectable digital display. In the analysis of any control system is to derive its mathematical model. The various blocks are shown in figure 3.

### B. Designing of Controller using Genetic Algorithm

For Design of controller for temperature control system, a Genetic algorithm based Matlab Program is constructed. This program uses the  $K_p$ ,  $K_i$  and  $K_d$  parameters as three chromosomes of each individual of a population. Genetically these parameters are tuned so that the fitness function (Integral Square of the error) is minimized. It is a simple Genetic Algorithm with one point crossover in analog form, simple mutation and Roulette Wheel selection method is used. For last iteration, a result of step response is checked to determine rise time, peak overshoot and settling time[3].

### C. Identification of Oven Parameters

Plant identification is the first step before an attempt can be made to control it. In the present case, the oven equations are obtained experimentally from its step

response. In the open loop testing, the oven is driven through the P-amplifier set to its maximum gain10. The input to the amplifier is adjusted through reference potentiometer.

The constant for oven plus controller is given by  $K = \text{Oven temperature at steady state} / \text{Input (volt)}$

Hence, 
$$K = \frac{49}{50} = 0.99 \approx 1$$

$T_1, T_2$  as measured from the open-loop graph is:  
 $T_1 = 3.3 \text{ sec}; T_2 = 0.41 \text{ sec}$

Transfer function can be written as:  

$$\text{Transfer Function} = \frac{K e^{-T_2 s}}{T_1 s + 1}$$

So, transfer function = 
$$K \frac{e^{-0.41 s}}{3.3 s + 1}$$

Using Pade's Approximation 
$$e^{-0.41 s} = \frac{4 - 0.41 s}{4 + 0.41 s}$$

Hence 
$$G(s) = \frac{K (4 - 0.41 s)}{(4 + 0.41 s)(3.3 s + 1)}$$

Here  $K = 1$

So, 
$$G(s) = \frac{4 - 0.41 s}{1.353 s^2 + 13.61 s + 4}$$

**IV. RESPONSES OF VARIOUS CONTROL TUNING METHODOLOGIES**

**A. Open Loop Response**

Open loop response of the plant transfer function is shown in figure

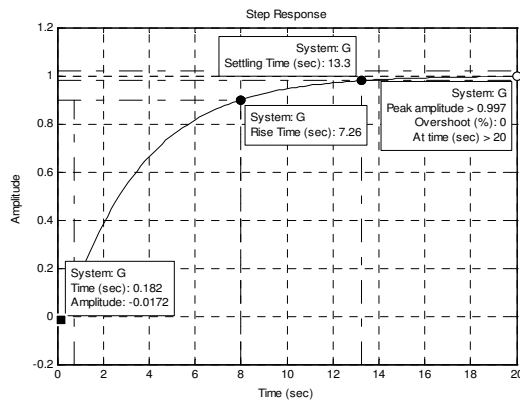


Figure 4. Open Loop Response of Temperature Control

**B. Closed Loop Response**

Closed loop response of the plant with unity feedback is as shown in figure5[5]. Rise time, settling time, peak overshoot are also shown in the figure.

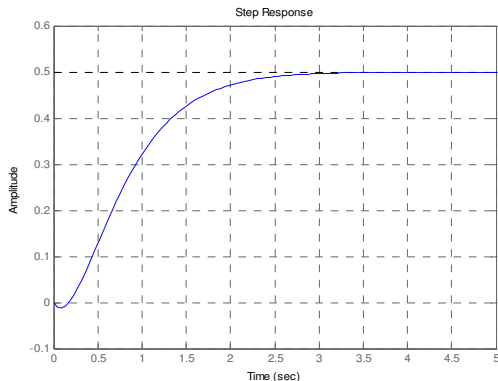


Figure 5. Closed Loop Response

**C. Eigler-Nichols First Method**

The results of PID tuning using Ziegler-Nichols method are as shown in figure 6. Here the values of  $K_p, K_i$  and  $K_d$  acc. to Ziegler-Nichols first method are as:

$K_p = 9.65$   
 $K_i = 1.2195$   
 $K_d = 0.205$

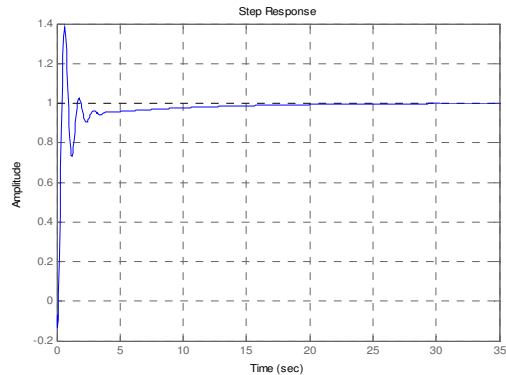


Figure 6. Step Response of Ziegler-Nichols based PID Controller Tuning

**D. Ziegler Nichols Second Method**

The results of PID tuning using Ziegler-Nichols method are as shown below in figure 7. Here the values of  $K_p, K_i$  and  $K_d$  acc. to Ziegler-Nichols second method are as:

$K_p = 9.6585$   
 $K_i = 1.666$   
 $K_d = 0.15$

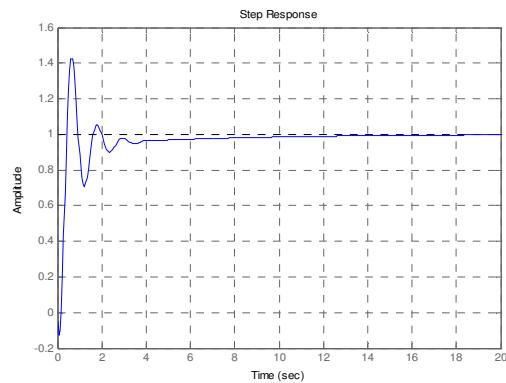


Figure 7. Step Response of Ziegler-Nichols Closed Loop based PID Controller Tuning

**E. Genetic Algorithm Response**

The step response for a time delay model is as shown above in figure 9, due to the exponential factor a dip is observed in the response [6]. When a GA tuned PID controller is used then the step response of the closed loop system is as given in figure 9.

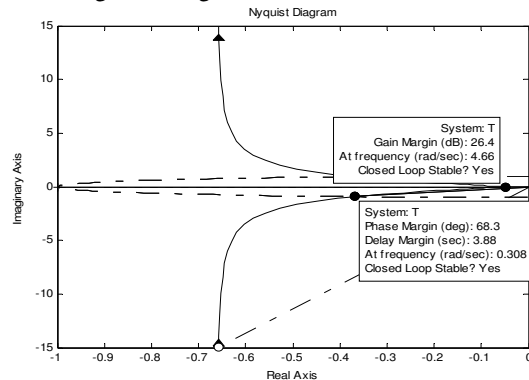


Figure 8. Nyquist Plot of GA based PID Controller

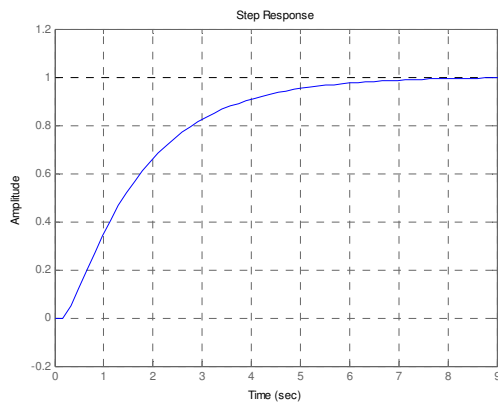


Figure 9. Step Response of Temperature Control plant with the addition of GA based PID Controller

Nyquist plot of the transfer function with addition of controller is shown in figure 8. It shows the relative stability of the plant. Points mentioned in the graph show the stability in that region.

## V. CONCLUSION

To design an optimal controller that can actually be operated on temperature control system, this paper focuses on designing of PID controller using Genetic algorithm, which can reduce the difficulties encountered during operation of plant. The characteristics of the PID controller tuned by genetic algorithm are compared with the results of PID controller based on Ziegler-Nichols first method and Ziegler-Nichols closed loop method for developing tuning technology on the temperature control system. It has been shown in the discussion that Genetic Algorithm based controller proved to be better as compared to other methods. As the main difficulty that came during the

operation of plant was delay or transportation lag and that have been removed using the genetic algorithm based controller.

In this paper, a new genetic approach is presented to make control of systems with oscillatory modes and time delay. Optimal tuning of temperature control system is obtained. It is intended that the Genetic PID approach can be connected easily as a backup controller for other adaptive controllers.

## VI. REFERENCES

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