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Intelligent Controller for Temperature Process

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Abstract

The goal of any temperature controller design is to keep the temperature of the target device on the desired value defined by the user as accurately as possible and using as little energy as possible. . The very control of temperature can be achieved by causing heater power to be simply switched on and off according to an under or over temperature condition respectively. Ultimately, the heater power will be regulated to achieve a desired system temperature but refinement can be employed to enhance the control accuracy. The temperature process is highly nonlinear and design of robust controllers for such nonlinear systems is a challenge. This paper proposes a novel method for the control of temperature process. The traditional PI controllers which are in practice produce high overshoot and the design procedure seems complex. The proposed intelligent controller offers better performance in terms of overshoot and settling time and thus increases the robustness of the system. This paper describes the modeling of the temperature process in detail and discusses how the process responds to conventional and intelligent controllers.

Keywords: *Fuzzy Controller, PID controller, Peak overshoot, Integral Absolute Error*

1. Introduction

A basic temperature controller provides control of industrial or laboratory heating and cooling processes. In closed loop control system, the output temperature is measured continuously and manipulated to maintain a constant output at the desired temperature. The performance of a temperature controller is assessed based on its response time or rise time, peak overshoot, oscillations and Integral Absolute Error (IAE) [1]. Gain scheduling PI controller and intelligent Fuzzy Logic Controller were designed and its performance measure was compared. Fuzzy logic controllers convert linguistic variables into control signals and because of its ease in design this controllers find lots of application in engineering [8]. Conventional non-Linear controllers can yield a satisfactory response if the process is operated close to a normal steady state value or a fairly linear region. But design of intelligent controllers gives a satisfactory response for nonlinear system with a reduced overshoot and oscillations, thus improving the stability of the system [9].

Section 2 deals with the proposed methodology, section 3 describes the process, section 4 explains the system identification, the controller design is discussed in section 5 and section 6 focuses on the results obtained.

2. Proposed Methodology

The conventional PID controller was designed and the controller values were chosen by Ziegler Nichols tuning method. The step response of the system was taken and the process

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gain and time constant was calculated using step test method. Then the PI controller settings were tuned using Ziegler Nichols Controller tuning method. This conventional controller response was compared with that of a intelligent Fuzzy logic Controller. The intelligent fuzzy logic controller were designed using fuzzy rules developed by trial and error method. The Design and implementation of the same was done using Matlab and LabVIEW.

3. Process Description

The control of temperature process can be done in two ways, in one method the power to the heater alone is controlled keeping the air flow through the blower as constant; in the second method the power to the heater as well the air flow through the blower is controlled. The temperature process uses a K-type thermocouple to measure the temperature. The milli-volt output of the thermocouple is amplified to 0-5V for the temperature change of 00C to 1000C. The desired temperature value and the thermocouple output are compared and the control signal is given to the power control circuitry. The figure below describes the temperature process setup.

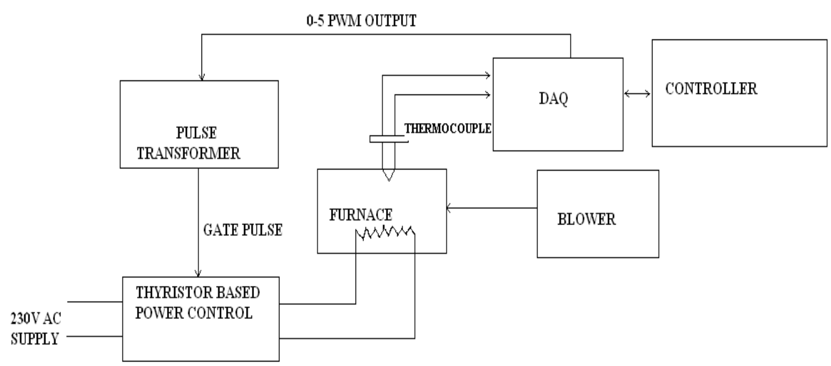

Figure 1. Block Diagram of the Temperature Process

The two SCRs connected in anti parallel forms the thyristor based power control circuitry. The gate pulse will be generated from the output of the controller. The output from the controller is converted to AC voltage, and passed through a full wave rectifier so that the SCR will receive positive gate pulses. The DC signal with ripples will be converted to ramp signal. This ramp signal is given as the inverting input to the opamp and the non-inverting terminal is grounded. This PWM circuit will produce a square pulse according to the voltages coming on the inverting input of the Opamp. And if this longer duration square pulses are used to trigger the gates of the SCR may raise the device temperature. Pulse transformer is used for isolation.

4. System Identification

The temperature process considered here can be assumed as a first order process with dead time. The system identification can be done mainly in three ways one is the mathematical modeling (Katalin Hangos *et al.*, 2001) and the other is the empirical modeling. The third method make use of some system identification tool box for obtaining the transfer function model of the system. In this work the second method is used to model the system. The open loop response of the system was obtained and the process reaction curve method was used to obtain the time constant, process gain and dead time.

Table 1. Experimental Data

Input Change	(ΔPV *.632) + I.S.S	Process Gain	Time constant (sec)	Dead Time (sec)
0	-	-	-	-
0-1	30.34	4.5	323	0
1-2	38.89	10.9	214	26
2-3	53.64	17	271	21
3-4	67.99	12.8	183	22

The temperature process was modeled using the experimental data collected and the model developed in transfer function form was used to simulate the system and finally the simulated controller values were used in testing the system in real-time. The model obtained is as follows:

Table 2. Ttransfer function model

Sl.No	**Operating Region**	**Transfer Function Model**
1	29.2˚C-33.3 ˚C	$G1(s) = \frac{4.1e^{-40s}}{98s+1}$
2	33.3˚C-46.5 ˚C	$G2(s) = \frac{13.3e^{-30s}}{231s+1}$
3	46.5˚C-68.08 ˚C	$G3(s) = \frac{21.9e^{-20s}}{260s+1}$
4	68.08˚C-77.49 ˚C	$G4(s) = \frac{18e^{-18s}}{180s+1}$

5. Controller Design

The temperature process was modeled and controllers were designed and tested using Matlab. The desired temperature was achieved using Gain Scheduling PI controller and intelligent fuzzy logic controller. The design of these controllers is discussed below:

5.1 Gain scheduling PI controller

The Gain Scheduling PI controller can be termed as an adaptive controller in the sense that an adaptive controller must have an adaptation mechanism and an adaptable parameter (Karl J Astrom *et al.*, 2002). In a Gain Scheduling Controller the adaptation mechanism is the Gain Schedule and the Adaptable parameter is the controller gain values. In order to design a Gain Scheduling controller a Scheduling variable must be chosen. The scheduling variable is the one which reflects the process operating condition or the changes in the operating condition. Gain scheduling PI controller is simple in structure and design. They enable good control performance and are therefore widely applied in industry [2]. The PI controller for the temperature process was designed and the kp, ki and ti values was obtained using Ziegler Nichols tuning method [3]. The design of PI controller was easy but the overshoot offered by PI controller was very high which led to the need for designing intelligent controllers. Hence fuzzy logic controller was designed, which will reduce the overshoot, oscillations and Integral Absolute Error (IAE) [4].

5.2 Fuzzy logic controllers

The PID controller values depend basically on the gain and time constant of the controlled system. A different situation exists when the temperature set point is different from the balanced temperature. The farther the set point is from the balanced temperature, the farther the PID constants will be from their optimal values. Just how far depends on how far the set point is from the balanced temperature and whether the current temperature is below or above the set point [5]. Fuzzy Logic controllers offer a better option for such adaptive mechanism. In reality, any implementation of fuzzy logic or fuzzy control is based on classical numerical processing. The design generally comprises of three steps: fuzzification, applying the fuzzy rules, and defuzzification. Fuzzification aims to convert a single (crisp) input value into corresponding fuzzy-set values. Applying the fuzzy rules, entails processing the "fuzzy" information. The third step, defuzzification, converts the internal fuzzy results back to a crisp output value [6].

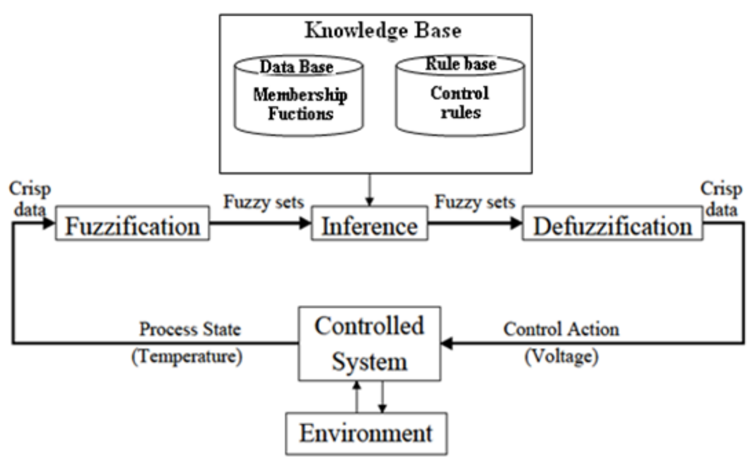

Figure 2. Block Diagram of Fuzzy Logic Controller

The implementation of the fuzzy logic controller in process control is based on the fuzzy logic based term, output = F [(e (t),) Δ e (t)]. In this the fuzzy sets e(t) and de (t) acts as the input to map F to the output. Associated with the map F is a collection of Linguistic values that represents the term set for the input and output variables of F. For the design of fuzzy logic controller for this process seven linguistic variables are used. Each membership function (MF) is a map from the real line to the interval [-1 +1] for the error and rate of change of error. In this application the MF used is triangular [7].The rules used for the control of this process is given in Table 3. Here the output of the Fuzzy Logic Controller is the SCR voltage. The range for the membership values of the Gains are chosen depending on the operating region.

Table 3. Rule Base Table

e \ de	NB	NM	NS	ZE	PS	PM	PS
NB	PB	PB	PB	PB	PM	ZE	ZE
NM	PB	PB	PB	PB	PM	ZE	ZE
NS	PM	PM	PM	PS	ZE	NS	NS
ZE	PM	PM	PS	ZE	NS	NM	NM
PS	PS	PS	ZE	NS	NM	NM	NM
PM	ZE	ZE	NM	NB	NB	NB	NB
PB	ZE	ZE	NM	NB	NB	NB	NB

The fuzzy Logic Controller was designed based on the rule base prescribed in Table 3. The performance of fuzzy logic controller was found to be better compared to gain scheduling PI controller in terms of overshoot and oscillations

6. Results and Discussions

The simulation results for the temperature process for various set- points like 45^0, 50^0 and 55^0 were simulated using Matlab. The results were obtained for conventional PI, gain scheduling PI and Fuzzy Logic Controller.

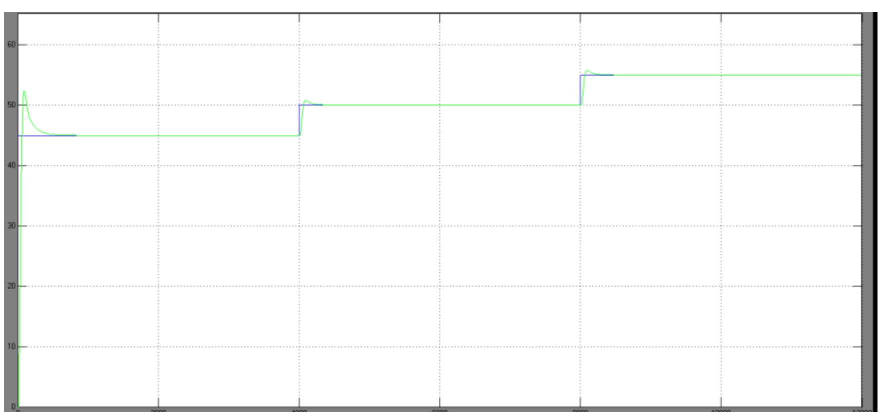

Figure 3. Output of Gain Scheduling PI Controller

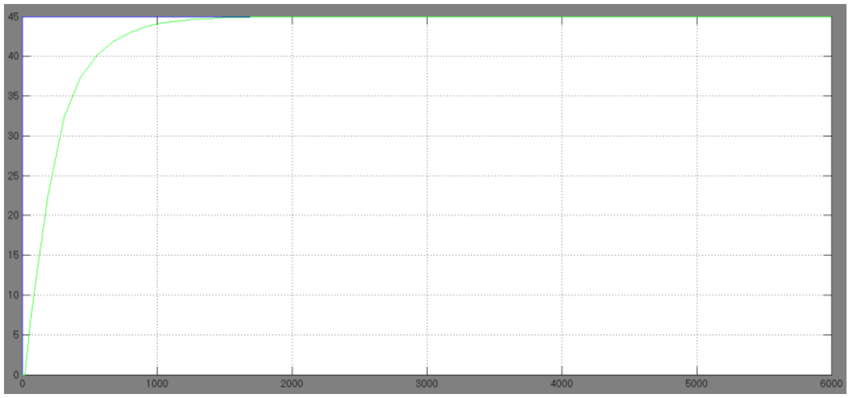

Figure 4. Output of Fuzzy Logic Controller for set point 450c

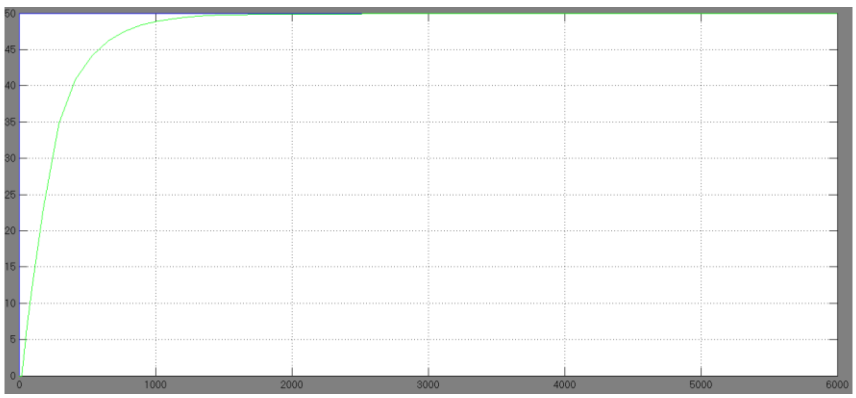

Figure 5. Output of Fuzzy Logic Controller for set point 500c

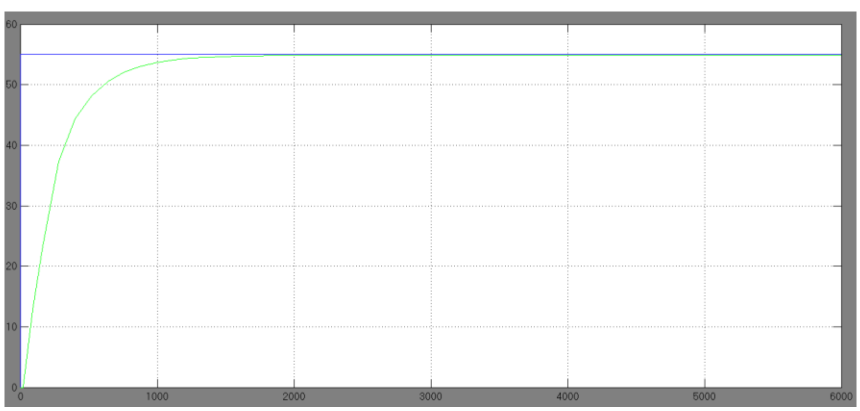

Figure 6. Output of Fuzzy Logic Controller for set point 550c

Table 4. Perfomance measure

CONTROLLERS	SET POINT	RISE TIME(s)	SETTLING TIME(s)	OVERSHOOT (%)	IAE
PID CONTROLLER	45	21	315	60.4	1550
	50	17.4	210	62.4	2120
	55	17.5	318	65	1105
FUZZY CONTROLLER	40	49.2	435	0	944
	50	44.5	310	0	1322
	55	48.8	269	0	923

Thus conventional and intelligent controllers were designed and its performance measures were analyzed to conclude on the best controller design. The performance measure analysis shows that fuzzy logic controller is better compared to PI controller.

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