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Fuzzy-PID Based Self-Tuning Control of Shell and Tube Heat Exchanger

N.Bagyalakshmi[1], T.Surendran[2], R.Narmatha[2], C.Sakthivel[2]

Assistant Professor, Department of EIE, Adhiyamaan College of Engineering, Hosur, Tamil Nadu, India [1]

UG Student, Department of EIE, Adhiyamaan College of Engineering, Hosur, Tamil Nadu, India [2]

ABSTRACT: Heat exchanger is a mechanical device which provides a flow of thermal energy between two or more fluids at different temperatures. The main purpose of heat exchanger is to maintain the temperature of outlet fluid. This paper involves a mathematical modelling of shell and tube heat exchanger using MATLAB. The mathematical modelling is done through system identification method. Transfer function of model is obtained by the system identification. The model is simulated using SIMULINK and the PID parameters are obtained by using fuzzy. The results obtained from Fuzzy self-tuning PID was successful than comparing to the classical PID controller. The results were shown in the graphical form.

KEYWORDS: System Identification, Shell and Tube Heat Exchanger, Self-tuning, Fuzzy PID.

I.INTRODUCTION

Currently, heat exchangers have a wide range of industry applications. They are widely used in space heating, power plants, petrochemical plants, petroleum refineries and sewage treatment [1]. The flow in a heat exchanger can be arranged as parallel flow, counter flow, and cross flow. The overall heat transfer coefficient (U) method requires detailed calculations and knowledge of the geometry of the exchangers [7]. Recently, FLC have been successfully applied to a huge range of industrial processes [9-11]. The field of Fuzzy control has been making rapid progress in recent years. The outlet temperature of the heat exchanger system has to be maintain at a desired set point. Firstly a classical PID controller is used. PID controllers exhibits high overshoot. To reduce the overshoot, a fuzzy self-tuning PID controller is used along with a feedback controller. The fuzzy self-tuning PID gives a much better result than the feedback PID controller.

II.MATHEMATICAL MODELLING

The mathematical model is one which promotes the system dynamics and the mathematical formulations. It requires the calculation of certain parameters according to the type of system employed and the derived knowledge from the nature of the plant. Prior information about the basic outline of the system is necessary for the modelling purpose.

$$T_{co}(t) = \frac{W_c}{\rho_c V_c (T_{ci}(t) - T_{co}(t))} + \frac{U_c A_c}{\rho_c V_c C_{pc} (T_{ho}(t) - T_{co}(t))} \quad (1)$$

$$T_{ho}(t) = \frac{W_h}{\rho_h V_h (T_{hi}(t) - T_{ho}(t))} + \frac{U_h A_h}{\rho_h V_h C_{ph} (T_{co}(t) - T_{ho}(t))} \quad (2)$$

Where, T_{ci}, T_{co}, T_{hi} and T_{ho} are inlet and outlet cold and hot fluid temperature respectively (°C), W_c and W_h are mass flow rate of cold and hot fluid respectively (kg/sec), C_{pc} and C_{ph} are the heat capacity of cold and hot fluid respectively (J/kg.°C), V_c and V_h are volume of cold and hot fluid respectively (cm³), A_c and A_h are heat transfer surface area of cold and hot fluid respectively (cm²), U_c and U_h are the heat transfer coefficient of cold and hot fluid respectively (W/cm² °C). ρ_c and ρ_h are the density of cold and hot fluid respectively (kg/ cm³).

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III.MODEL ESTIMATION

Model estimation of the Shell and Tube heat exchanger is done by system identification method. Data examination is done to obtain a good data. Model structure can be in form of linear, non-linear or intelligent model. The model can be accepted if it satisfies the percentage of fit and other criterions [14], [15]. The figure 1 shows the simulation results for the shell and tube heat exchanger. All procedures to estimate the model is done by using System Identification.

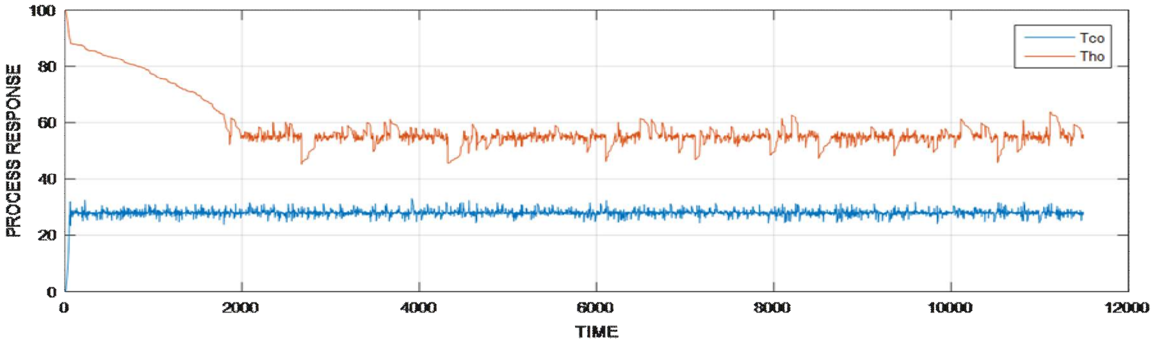

Figure 1 Response of Model

The model structures are ARX-The simplest model structure that is often a first choice. Enter in Order field: na,nb,nk, the orders and input delays. ARMAX, OE, BJ -Covers a wide family of noise models for single output systems. Process models are very popular for describing system dynamics in many industries. Transfer function is ratio of output to input. It is given by

$$G(S)=K/(1+T_{p1}s)(1+T_{p2}s) \quad (3)$$

Hence the process model is generated and the transfer function is given by

$$G(s)= 1.094/(s^2+4.594s+0.03178)$$

IV.TUNING OF CONTROLLERS

A.Conventional PID controllers

PID controller is the most popular controller which is widely used to improve the performance in industry, because it's easy to operate and very robust. The performance specifications of the systems such as rise time, overshoot, settling time and error steady state can be improved by calculating value of parameters K_p, $K_i$and $K_d$of the PID controller. Mathematically PID controller is represented as

$$y(t) = \left[k_p e(t) + k_d \frac{d(e)}{d(t)} + k_i \int_0^t e(t)d(t)\right] (4)$$

Where: $K_i = K_p/T_i$ and $K_d = K_p. T_i$.

1) Tuning of PID parameters

Tuning of PID parameters refers to the tuning of its various parameters (P,I and D) to achieve the desired response. The basic requirements of output will be stability, desired rise time, peak time and overshoot.

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B.Self-tuning fuzzy PID controller

1) Fuzzy logic background

Fuzzy logic controller as shown in Figure 2 consists of main parts fuzzification, rule base, inference engine and defuzzification. This whole process of decision making is mainly the combination of fuzzy IF-THEN rules and fuzzy reasoning. The inference system makes use of the IF-THEN statements and with the help of connectors (OR and AND).

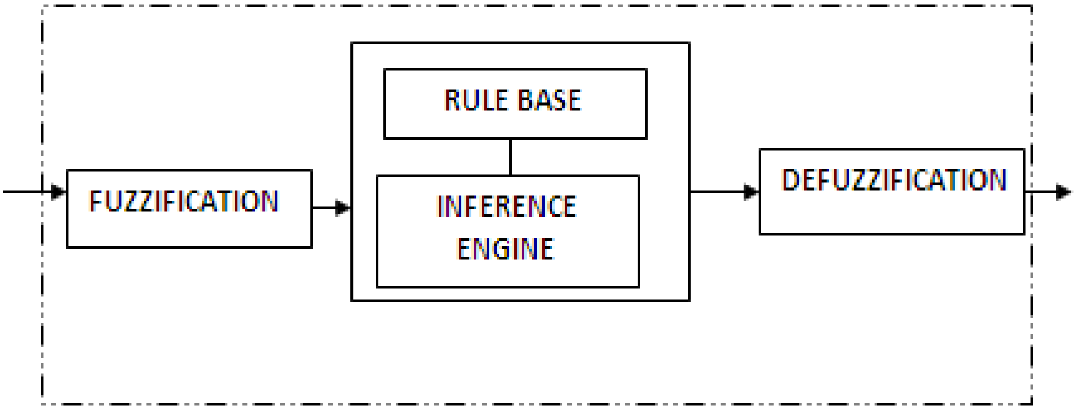

Figure 2 Fuzzy logic controller

Fuzzification is the process of converting crisp input into normalized input. Defuzzification is the process of converting normalized output into crisp output.

2) Design and structure of self-tuning fuzzy PID controller

The self tuning fuzzy PID controller, which takes error (e) and change in error (ec) as the input to the controller makes use of fuzzy control to modify PID parameters. Self-tuning fuzzy PID controller means the parameters of PID controller are tuned by using fuzzy tuner [17], [18]. Figure 2 shows the structure of self-tuning fuzzy PID controller.

Table 1 shows the fuzzy set rules for the process.The rules designed are based on the characteristic of the heat exchanger and properties of the PID controller. The fuzzy reasoning of fuzzy output sets are gained by aggregation operation of fuzzy sets and the designed fuzzy rules.

Where, NB: negative big; NM: negative medium; NS: negative small; Z: zero; PS: positive small; PM: positive medium; PB: positive big. The figure 3 shows the membership function of e, ec, k_p, k_i, k_d.
Where e(t) is the error between desired position set point and the output, de(t) is the derivation of error. The PID parameters are tuned by using Fuzzy, which provide a nonlinear mapping from the error and derivation of error to PID parameters.

Figure 3 Membership Function of e, ec, k_p, k_i, k_d

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e \ ec	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PM	PS	Z	Z
NM	PB	PB	PM	PS	PS	Z	NS
NS	PM	PM	PM	PS	Z	NS	NS
Z	PM	PM	PS	Z	NS	NM	NM
PS	PS	PS	Z	NS	NS	NM	NM
PM	PS	Z	NS	NM	NM	NM	NB
PB	Z	Z	NM	NM	NM	NB	NB

Table 1 Fuzzy Rules

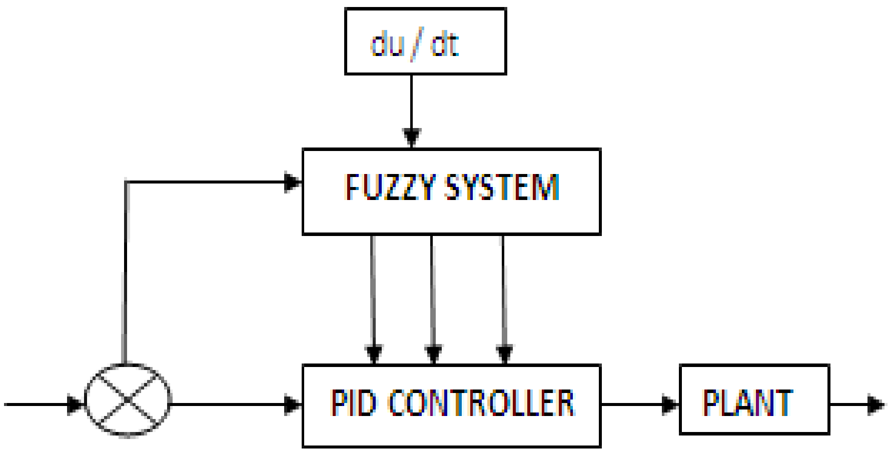

Figure 4 Structure of Self-Tuning Fuzzy PID Controller

V. RESULTS AND DISCUSSION

Self-tuning Fuzzy PID regulator subsystem block consists of Fuzzy and PID block with some changes refers to the formula which is applied to calibrate the value of K_p, K_i and K_d from fuzzy block to obtain the value of K_p, K_i and K_d. Each parameter has it's own calibration. The value of parameter K_p, K_i and K_d are tuned by using signals from fuzzy logic based on the changes in the error between step signals and output signals. The outputs of the simulation for step input is represented in Figure 5. Figure 5 shows the performance of the control system with respect to step input signal. The system response to step input compared with conventional PID controller and self-tuning fuzzy PID controller. The self-tuning fuzzy PID controller achieves better response than conventional PID controller.

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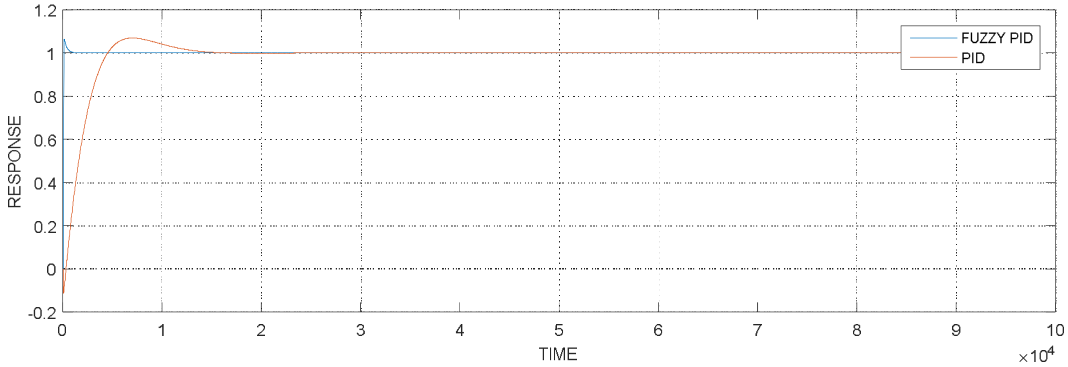

Figure 5 Simulation Results

VI.PERFORMANCE ANALYSIS

It shows the comparison of PID and self-tuning fuzzy PID overshoot, rise time, settling time and IAE and ISE. From these, self-tuning fuzzy PID was better than PID response. Table 2 shows the performance analysis of PID and self-tuning fuzzy PID.

s.no	Controller	IAE	ISE
1	PID	163.1	668.3
2	Fuzzy PID	156.5	774.8

Table 2 Performance Analysis of PID and self-tuning Fuzzy PID

The self-tuning fuzzy PID controller improves the performance by slightly decreasing the maximum error (IAE). As the disturbance increases the difference of performances becomes more considerable. The self-tuning fuzzy PID controller is able to eliminate a very big disturbance. The table 1 shows the improved robustness of the self-tuning FuzzyPID controller.

VII.CONCLUSION

In this work, mathematical modelling of heat exchanger and self-tuning fuzzy PID controller is proposed successfully. System Identification technique is employed to obtain a model. Fuzzy controller is applied to tune the PID controller. The amount of overshoot for the response is successfully decreased using the above technique. The response indicates that the performance of the system is improved and satisfied compared to conventional PID controller.

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