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Control Modes Comparison Results Focused on Real Heat Exchanger System Response

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Abstract: This paper focus on the heat exchanger system temperature control design based on mathematical model. The mathematical model is constructed using dynamics and real parameters of the heat exchanger. The heat exchanger model is QAD MODEL BDT921. Two types of control are applied; they are Proportion Integral Derivative (PID) controller and Fuzzy Proportional (FD) controller. PID is a generic control loop feedback mechanism attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action. While FD is a controller that it base on the logical of the human expert. The two controllers are simulated using Matlab Simulink software. The results show that FD controller response better than PID controller. It means FD controller is a suitable control to improve the performance of the heat exchanger QAD MODEL BDT921 model.

Keywords: Heat exchanger, PID controller, FD controller

1. Introduction

Heat exchanger is most important equipment in manufacturing and industrial plant in order to maintain and control temperature weather as a boiler or cooling system. This system is not stable as the temperature output can easily disturb by noise and other disturbance such as surrounding temperature.

PID controller has widely used in Heat exchanger QAD MODEL BDT921 to control the output process. PID is a generic control loop feedback mechanism attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action [1,2].

In this paper, the performance of the heat exchanger QAD MODEL BDT921 model is improved using two types of controller. They are PID controller and FD controller. The controllers are designed based on mathematical model of the heat exchanger that it determined applying dynamics and real parameters. To analyze the controller responses, the two controllers are simulated using Matlab Simulink software.

2. Modeling of Heat Exchanger System

The temperature control system of heat exchanger in district heating is a complex process control system whose properties are large heat inertia, slow time varying and so on. The system is shown in Fig. 1.

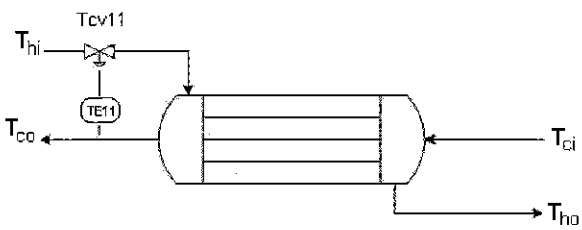

Fig. 1 Model of heat exchanger system

By using the energy balance equation [1], the energy supplied to the exchanger must equal to the energy removed. For precise analysis, the heat loss to the environment must be determined. Here, however, to simplify the analysis well insulated for heat exchanger is assumed. The mathematical model of the system described as below:

$$\dot{T}_{co}(t) = \frac{w_c}{\rho_c V_c}\left(T_{ci}(t) - T_{co}(t)\right) + \frac{U_c A_c}{\rho_c V_c C_{pc}} \left(T_{ho}(t) - T_{co}(t)\right) \quad (1)$$

$$\dot{T}_{ho}(t) = \frac{w_h}{\rho_h V_h}\left(T_{hi}(t) - T_{ho}(t)\right) + \frac{U_h A_h}{\rho_h V_h C_{ph}} \left(T_{co}(t) - T_{ho}(t)\right) \quad (2)$$

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Where, T_{ci}, T_{co}, T_{hi}, T_{ho} are inlet and outlet cold and hot fluid temperature °C; w_c, w_h *are* mass flow rate of cold and hot fluid kg/sec; C_{pc}, C_{ph} are the heat capacity of cold and hot fluid J/kg.°C; ρ_c, ρ_h are the density of cold and hot fluid kg/cm^3; V_c, V_h are volume cm^3; , A_c, A_h are the heat transfer surface area of cold and hot fluid cm^2, U_c, U_h are the heat transfer coefficient of cold and hot fluid W/cm^{2}C^0..

Equation (2) is nonlinear because the state variable $T_{ho}(t)$ is multiplied by the control input w_c. The equation can be linearized about $\tilde{T}_{ho}(t)$ (a specific value of $T_{ho}(t)$). So that $T_{hi}(t) - T_{ho}(t)$ is assumed constant for purposes of approximating the nonlinear term, which we will define as ΔT_h. In order to eliminate the $T_{ci}(t)$ term in equation (1), it is convenient to measure all temperatures in terms of deviation in degrees from $T_{ci}(t)$.

3. Heat Exchanger Control Loop Block Diagram

The block diagram is shown in Fig. 2. It represents the cold fluid temperature control loop for the heat exchanger:

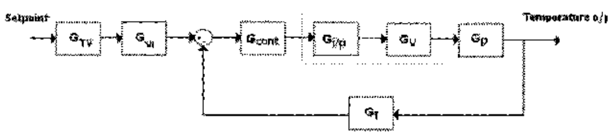

Fig.2 Cold fluid temperature control loop for HE.

Where:

- Gain for conversion between the temperature to voltage G_{TV}:

$$G_{TV} = 0.093V / C^o$$

- Gain for conversion between the voltage to current G_{Vi}:

$$G_{Vi} = 4mA / V$$

- Gain current to pressure converter "$G_{I/P}$":

$$G_{I/P} = 0.74 psi / ma = 0.0527 kg / cm^2.mA$$

- Gain transmitter "G_t":

$$G_t = 0.372 mA / C^o$$

Valve transfer function: the valve gain depends on the open and closes the valve control of hot fluid flow rate. From the study case of valve opening percentage and effect the pressure on the valve we get:

$$G_{TV} = \frac{1.45}{0.37s + 1} \qquad (3)$$

The parameters of the heat exchanger plant are below:

$T_{ci} = 26C^o$, $\rho_c = 9.96x10^{-4} kg / cm^3$, $q_{ci} = 2kg / \sec$, $C_{pc} = 4183 J / kgC^o$, $V_c = 18613 cm^3$, $A_c = 9443 cm^2$, $T_{hi} = 60C^o$, $\rho_h = 9.8x10^{-4} kg / cm^3$, $C_{ph} = 4187 J / kgC^o$, $V_h = 13847 cm^3$, $A_h = 6768 cm^2$.

4. Controller

A continuous process has continuous input and outputs. The value of at least one input is changed in a manner that tends to maintain the controlled variable equal to the set point. The output of continuous process controller is determined by one or more modes of control. The most common control modes are proportional integral and derivative modes. [7]

Usually, the proportional mode is combined with the integral and /or derivative modes to from two or three modes controller.

Continuous process controller can be grouped into two categories; those in which the set point is constant for long periods of time and those in which the set point is constantly changes. Control system analysis and design methods work equally well on systems in either category:

1. Describe the proportional, derivative, and integral control mode.
2. Describe the conditions for which of the following control modes will be a good choice.

The fuzzy logic controllers from best controllers, it is used on many control operations In these days, one of the main advantages of using fuzzy logic (FL) is to overcome the need for a precise mathematical model of the controlled system. Furthermore in this application the FL has many advantages include short development times, easy transfer to different rules, and we can connect fuzzy control with another controller like proportional or proportional-Derivative control for doing more accurate response for our systems.

4.1 Proportional Integral Derivative Controller

A proportional plus integral plus derivative (PID) control IS used to improve both steady state and transient response.

The PID controller has three terms; the proportional term P corresponding to proportional control, the integral term I giving a control action that is proportional to the time integral of the error. And the derivative term D proportional to the time derivative of the error.

The equation of PID controller:

$$u(t) = K_p \left(e(t) + \frac{1}{T_i} \int_0^t e(t) dt + T_d \frac{de(t)}{dt} \right) \qquad (4)$$

By taking Laplace transform we get:

$$\frac{U(s)}{E(s)} = K_p(1 + \frac{1}{T_i s} + T_d s) \tag{5}$$

A proportional controller (K_p) will have the effect of reducing the rise time and will reduce, but never eliminate, the steady-state error. An integral control (K_i) will have the effect of eliminating the steady-state error, but it may make the transient response worse. A derivative control (K_d) will have the effect of increasing the stability of the system [10]. The flow chart of how PID controller works as the following:

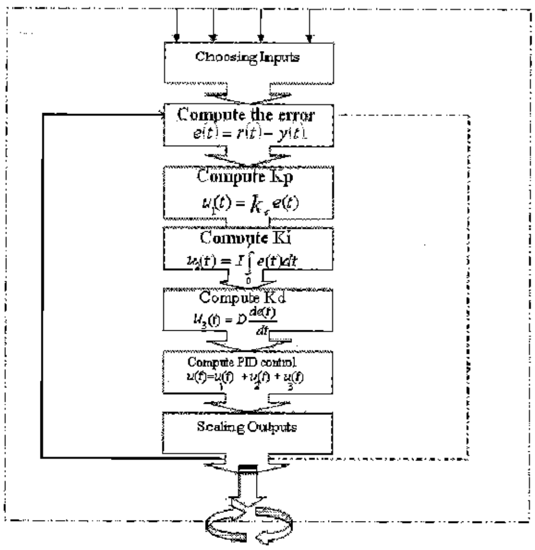

Fig. 3 PID control operation flowchart.

By using Ziegler-Nucleus method for calculate PID parameters. Ziegler-Nucleus based on transient response show in Fig 4.

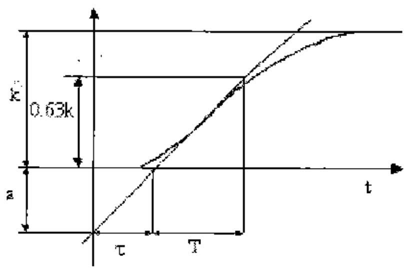

Fig. 4 Unit step response of a typical industrial process plant.

The value of a is determined as below:

$$a = e^{k.\tau/T} \tag{6}$$

Where, k is the static gain, τ τ is time delay, and T is the time constant [5].

Table 1 presents the PID controller parameters based on Ziegler-Nucleus tuning method.

Table 1 Ziegler-Nucleus for transient response

controller	K_p	T_i	T_d
P	$1/a$	-	-
PI	$0.9/a$	3τ	-
PID	$1.2/a$	2τ 2τ	$\tau/2$

By calculate the PID parameters for the response we get: $K_p = 5$, $T_i = 24\sec$ and $T_d = 6\sec$.

4.2 Fuzzy Proportional (FP) Controller

Fuzzy logic is an innovative technology that allows the description of desired system behavior using everyday spoken language [3]. Fuzzy logic can be derived into three stages that is, Fuzzification, Fuzzy Inference and Defuzzification. In a typical application, all three stages must be employed. Block diagram of fuzzy logic control as shown in the following Fig 5.

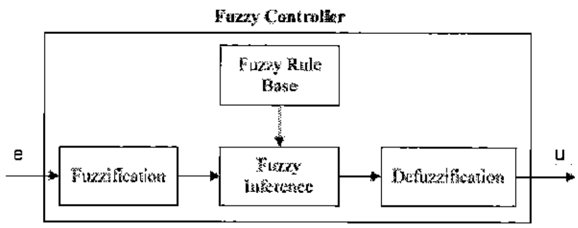

Fig.5 Fuzzy logic controller block diagram.

A proportional control defined as:

$$u(n) = K_p e(n) \tag{7}$$

Fuzzy proportional (FP) control has one input is error and one output is the control signal, as show block diagram Fig 6 and 7. Compared to crisp proportional controller K_p , fuzzy P controller has two gains GE and GU instead of just one. And the error is $E = GE * e$ and the output is $U = GU * u$ [8]. Where $e = y_{sp}(n) - y(n)$ is the error signal, the control signal $U(n)$ at time instant n is a nonlinear of the input $e(n)$.

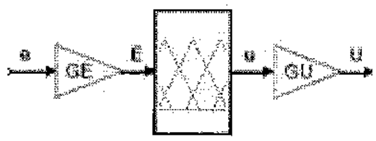

Fig. 6 Fuzzy Proportional FP controller

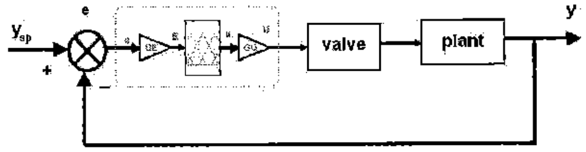

Fig. 7 Fuzzy proportional FP control

Output controller is given by:

$$U(n) = f(GE * e(n)) * GU \quad (8)$$

The function f denotes the rule base mapping. It is generally nonlinear, as mentioned; but with a favorable choice of design, a nonlinear approximate is:

$$f(GE * e(n)) \approx GE * e(n) \quad (9)$$

Insertion into equation (8) yields the control signal:

$$U(n) = GE * GU * e(n) \quad (10)$$

Compare equation (10) with (7) the product of gain factor for the linear controller corresponds to the proportional gain:

$$GE * GU = K_p \quad (11)$$

The accuracy of the approximation depends mostly on the membership functions and the rules.

5. Experimental Result

Proportional fuzzy controller having one input the error (E) and as one output the control action (U). The linguistic terms for input are: NLE (negative large error), NSE (negative small error), ZE (zero error) and PSE (positive small error), PLE (positive large error). And for output are: u0 (valve 0-10), u25 (valve 0-25), u50 (valve 25-75), u75 (valve 50-100), u100 (valve 75-100).

After design the rule by fuzzy-P we can found the gain:

$$GE * GU = K_p = \frac{1}{a} = 4.167, GE = 0.6 \text{ and } GU = 6.65$$

Fig. 8 shows the comparison of each controller response.

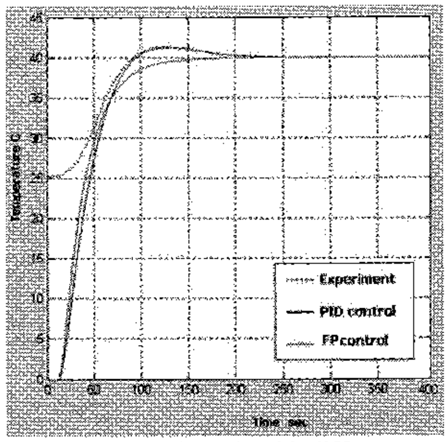

Fig. 8 Comparison real result with different controller

Table 2 Parameters of system responses for each controller

Controller	T_s (sec)	T_r (sec)	$O.V$ % %	E_{ss} %
PID Exp	237	58	3.25	0
PID Sim	233	53	3.07	0
FP control	220	51	0	4

6. Conclusion

The PID controller is most popular and widely used industrial controller in the process industries. From real experiment we found the response of the system similar to PID simulation response, but the overshoot still high until FP control used to get accurate response with no overshot and give more accurate settling time for the system.

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