PID Versus Fuzzy Logic Based Intelligent Controller Design for a Refined Cascade PID Control for Power Plant Industrial Boiler Control System

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Abstract **- This paper discusses the importance of tuning methods in setting up the PID controller process gains, which is to be used for controlling non-linear processes like temperature of an industrial furnace. PID controller in cascaded architecture is the best choice compared to single loop control system for controlling these nonlinear processes. However, it is constrained in choosing the better PID gains. Hence, this paper is such an approach to set the values of PID gains for better disturbance rejection, transient period reduction, and stability improvement of the system. Conclusively, the performance of the proposed controller architecture is evaluated by finding the dynamic performance characteristics. The entire system is modeled by using MATLAB/Simulink, and the simulation results have shown that the proposed controller has rapidity, good robustness and good dynamic performance.**

Keywords - Cascade control system, Dynamic performance analysis, PID (Proportional plus Integral plus Derivative) controller, Temperature process control, Matlab/Simulink, Tuning concepts

I. INTRODUCTION

The cascade control system has better characteristics: ability, quickness, flexibility and control quality. Cascade control system in contrast make use of multiple signals for one manipulated variable (MV), utilizing cascade can also allow a system to be more responsive to disturbances. Furnace is most important thermal equipments in metallurgical industry. Basic automatic control methods have been realized, for example, constant control for the main process variables in the furnace, cascade control of furnace temperature and fuel flow. The furnace temperature is primarily regulated by the gas flow control. While the control of furnace gas flow is the typical process control, and the furnace temperature control system has larger capacity lag, so it most suits for cascade PID control. The best flexibility with PID controllers is that by using two PIDs together, which achieves a better dynamic performance compared with single PID. This is known as cascaded PID controller.

By pre-regulating the interference which influences the intermediate variables, the dynamic quality of the whole system will be improved. Cascade control system has advantages over single loop in anti-jamming capability, rapidity, flexibility and quality control.

II. DESIGN OF FURNACE CASCADE CONTROL SYSTEM

Figure.1 shows the furnace temperature control system.

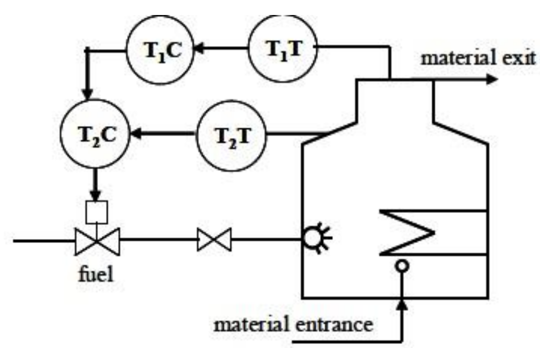

Figure.1 furnace temperature control system

T_1C – main controller
T_2C – deputy controller
T_1T – measure temperature for the exports of raw materials
T_2T – measure temperature of the furnace hearth

In the heating process, material is heated to the specified temperature from the entrance to the exit. From fuel combustion to the raw material export, the system temperature comprises of three capacity components: furnace, hearth and the heated raw materials. System disturbances are one hand, load disturbance and the disturbance in raw materials side; and the other hand: the disturbance in the burning side, such as fuel pressure, air flow. In the furnace temperature control system, furnace wall and raw materials compose the main object, raw material temperature in export is the main controlled variable, raw material flow (load) and inlet temperature of material are primary disturbance; furnace hearth composes sub-object, furnace hearth temperature is sub-controlled variable, the fuel pressure before valve, the heat value of fuel and air supply of Furnace hearth, etc. are secondary disturbances. In the choice of design parameters, must pay attention to the matching problem of time constants for the main loop and sub loop, which is the primary condition for cascade control system normally operating and fundamental measure for ensuring safe production and preventing resonance. In the cascade control system fuel Combustion chamber to the raw material export, there are three capacity components in System temperature. They are boiler, hearth and the heated raw materials. Disturbances of load and in raw materials side are the system disturbances in one side and on the other side are the disturbances in the burning side, such as fuel, pressure, and air flow.

III. CASCADE PID CONTROL

A proportional-integral-derivative controller is a generic control loop feedback mechanism the furnace temperature control system. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The primary object is the raw material and the secondary object is the hearth in the boiler. The main controlled variable is the temperature of raw material in the export and sub controlled variable is the temperature of the hearth in the furnace. The primary disturbances are flow of the raw material and temperature of material at the inlet. The secondary disturbances are the pressure of the fuel before the valve, the heat value of fuel-air mixture supplied to the hearth etc.

Tuning methods commonly used in engineering are :

- Successive approximation method
- Two step tuning method
- One step tuning method
- Ziegler-Nicholas PID controller tuning method

Successive approximation method is that debugging parameter of the main loop and sub loop again and again in order to gradually close to the optimal approach.

Two step method is that in the case of closed main loop and closed sub loop respectively setting the parameters of main loop and sub loop according to single-loop system approach, and then using the characteristic so the main and sub loop adjustable parameters.

One step tuning method is that first, setting deputy controller parameters based on the experience, and then directly tuning regulator parameters of master controller according to single loop systems as a general method. Specific steps are following: apply pure proportional control law to debug deputy regulator. Secondly, set the pure proportion to master regulator, and put cascade control system into operation, setting main regulator parameters with the any tuning method of single-loop. Third, observed operation process with interference, according to matching principle of TC1 and TC2, appropriately adjust the regulator parameters, and ensure the main regulator to meet the best quality control.

IV. MODEL AND SIMULATION OF REFINED CASCADE PID CONTROL SYSTEM

According to the above parameter setting method, use traversal method. The refined cascade PID control system model has been shown in Figure 2.

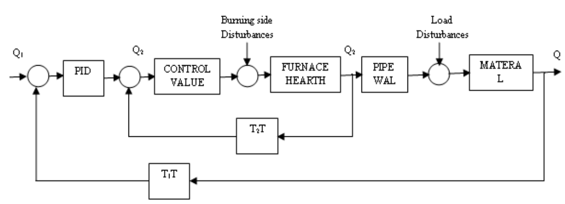

Fig.2 Refined cascade PID control system model

$$G_1(S) = \frac{1/90}{\left(S+\frac{1}{30}\right)\left(S+\frac{1}{3}\right)} \ldots\ldots(1)$$

$$G_2(S) = \frac{1/10}{\left(S + \frac{1}{10}\right)(S+1)^2} \quad \text{……(2)}$$

The two PID controller parameters are adjusted based on traversal method; use Matlab/Simulink to simulate the system. Step output of the system in the system output under the second step disturbance the system output under first step disturbance. The choice of these KP, KI, and KD values will cause for the changes in the transient response specifications. When the proportional gain (KP) is increased, then rise time decreases, overshoot increases, error decreases and a small change in settling time. When integral gain increases, rise time decreases, overshoot increases, settling time increases, and error decreases significantly. When derivative gain increases, overshoot decreases, settling time decreases, minor decrease in rise time, and no effect on error.

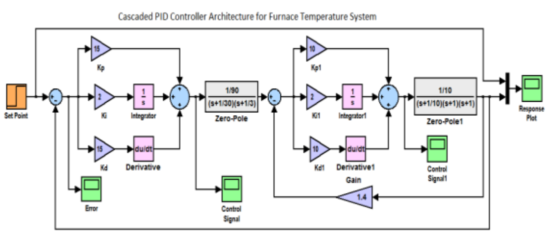

Fig.3 MATLAB/Simulink Model for Furnace cascade PID control system model

The PD controller is used to have fast settling; PI controller is used to have less steady state error. And PID controller is used to have all individual control actions. Hence, different combinations of controllers should be selected properly to get the desired characteristics.

V. PID Controller Tuning

The ultimate cycle/ ultimate gain/ cyclic oscillations methods are the simple and more effective ways for setting up the PID controller process gains. Basically, these methods are of five types, mentioned as follows

- Ziegler-Nichols PID controller tuning method
- Modified Ziegler-Nichols PID controller tuning method
- Tyreus-Luyben PID controller tuning method
- Pessen's overshoot PID controller tuning method
- Pessen's Integral PID controller tuning method

The boiler temperature in the industrial production has non-linear, time-varying and delay characteristics. Hence, we cannot create an absolute mathematical model. It is always a painful and challenging task to select proper values for KP, KI, and KD gains. To reduce the above problems and to improve transient response specifications, the outer loop PID is tuned by using tuning algorithms. Figure.4 shows the process flow of PID controller gain settings. The Flow chart for PID tuning procedure The parameter gain values obtained for PID controller.

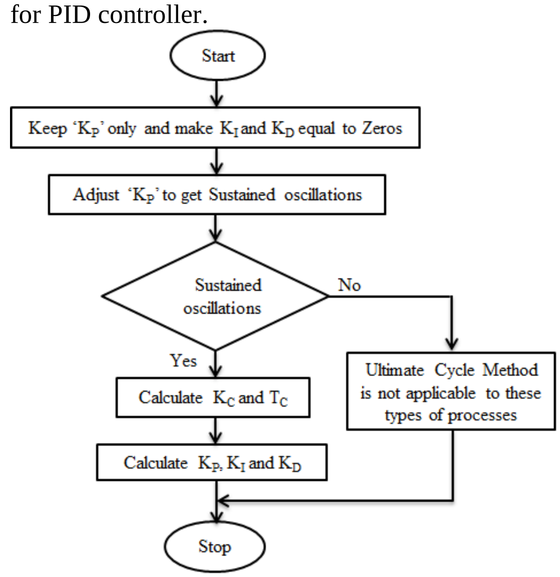

Fig.4 Flow chart for PID tuning procedure

The parameter gain values obtained for PID controller design with different tuning methods are listed in Table.1.

TABLE.1 PARAMETER GAINS OBTAINED FOR DIFFERENT PID CONTROLLERS

S. No.	Method Name	K_P	T_I	K_I	T_D	K_D
1	Ziegler-Nichols	24.24	5.238	4.627	1.309	31.742
2	Modified Ziegler-Nichols	8.08	10.476	0.771	3.492	28.215
3	Tyreus-Luyben	18.18	23.047	0.788	1.662	30.215
4	Pessen's Overshoot	13.332	5.238	2.545	3.492	46.555
5	Pessen's Integral	28.28	4.190	6.748	1.571	44.439

temperature process control. Fuzzy control has become one of the most successful methods to design a sophisticated control system. which are left vacant by purely mathematical and purely intelligent approaches in the design of the system. A fuzzy control system is the one that is designed on fuzzy logic. The fuzzy logic system is a mathematical system that analyses the input analog values in terms of logical values between 0 and 1 as shown in figure.7

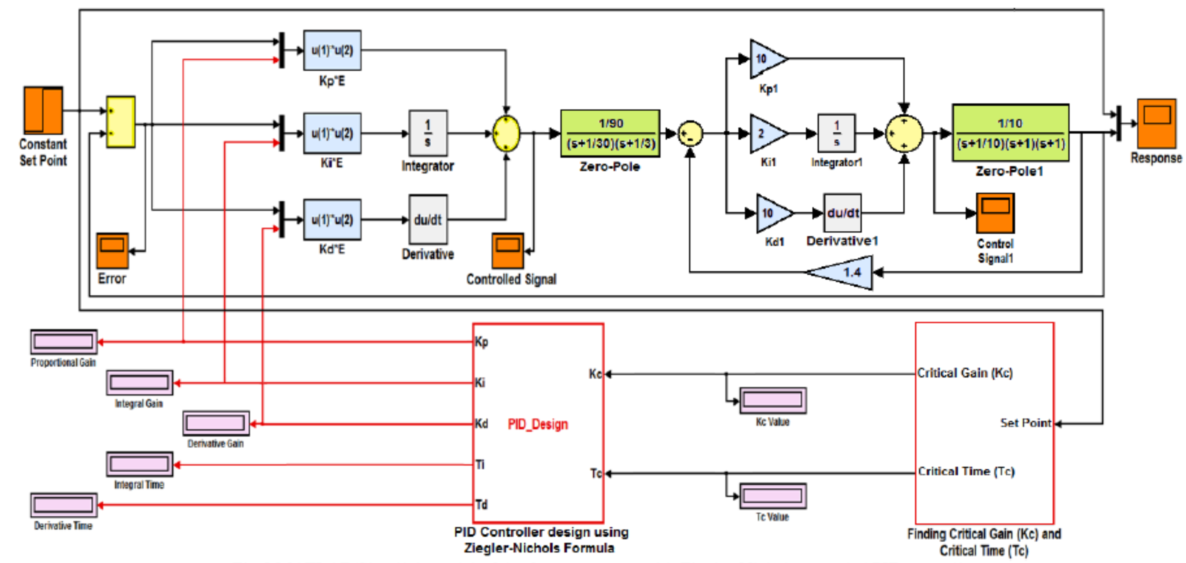

Fig.5 MATLAB/Simulink model of the furnace system with Ziegler-Nichols cascaded PID controller

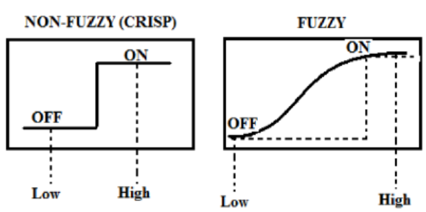

Fig.6 Difference between crisp and fuzzy

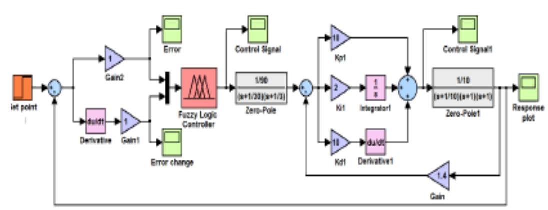

Fig.7 MATLAB/Simulink model for Fuzzy logic controller

shows the MATLAB model of the system. Designed with fuzzy logic controller. It takes two inputs namely error signal and change in error.

VI. SYSTEM DESIGN WITH FUZZY LOGIC CONTROLLER

Fuzzy logic control can be used even when the process is a non-linear, time varying. The control temperature of the Industrial furnace is a non-linear. Hence, we can apply fuzzy control to the

.

VII. SIMULATION RESULTS

The system designed with conventional PID controller when it is tuned with Ziegler-Nichols, Modified Ziegler-Nichols, Tyreus-Luyben, Pessen's Overshoot and Pessen's Integral PID tuning algorithms. Figure.8 shows the comparison of responses of the system designed with above different PID tuning methods, among all the responses Tyreus-Luyben method gave good response.

Figure.9 shows the response of the system design with fuzzy logic controller. Here the system response suppress the oscillations and produces smooth response, But it is giving a less steady state error. Figure.10 shows the response of the system design with fuzzy-PID controller. Where the PID gains are tuned by using fuzzy logic controller, the response of the system produce smooth and error also reduces to 0% while keeping the advantages of fuzzy controller. The comparison of different tuning methods transient response/dynamic performance characteristics are calculated and tabulated as shown in the table.4.

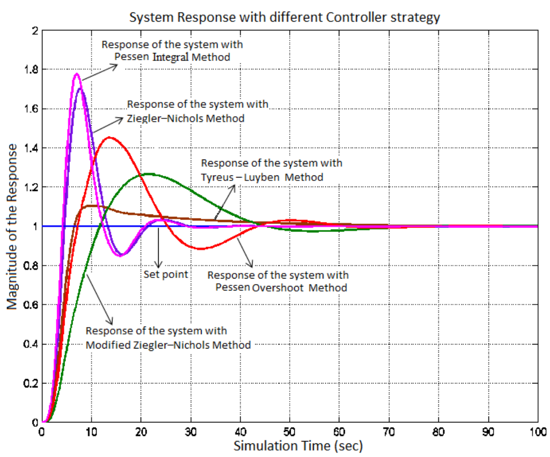

Fig.8 Comparison of all responses with various controllers

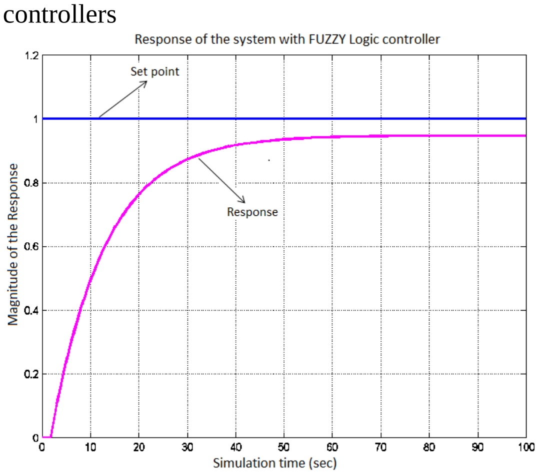

Fig.9 Response of the system with fuzzy logic controller

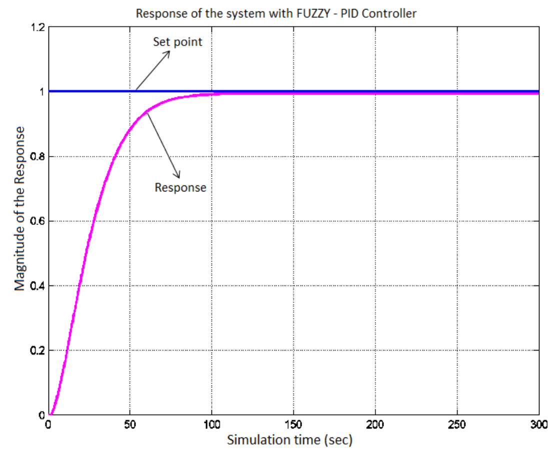

Fig.10 Response of the system with Fuzzy-PID controller

VIII. CONCLUSION

Cascade control system has better anti-interference ability, quickness, flexibility and quality control, it is widely used in complex process control. Furnace temperature is primarily regulated by the gas flow control. The furnace control system has larger capacity lags and suite for cascade PID control. In this paper, using off-line PID parameter selection method traversal method, the main loop and subloop of furnace cascade control system have been designed and simulation of the cascade PID control system has been done based on Matlab / Simulink. The results show that the system has excellent control accuracy and stability.

Hence, in this paper firstly, the conventional PID controller is used as temperature process controller for Electric Heating Furnace System. Later on fuzzy logic based intelligent controller is introduced for the same. the following parameters can be observed

1) In the case of Tyreus-Luyben PID Controller, the values of delay time, rise time, and settling time are better in comparison with Modified Ziegler-Nichols method, and approximate to the Ziegler-Nichols method. Also, it offers major advantage in terms of smooth transient behavior and less overshoot.

2) To suppress these severe oscillations Fuzzy logic controller is proposed to use. From the results, it can be observed that, this controller can effectively suppress the oscillations and produces smooth response. But it is giving a steady state error of 5.8%.

3) Furthermore, to suppress the steady state error, it is proposed to use Fuzzy-PID controller, where the PID gains are tuned by using fuzzy logic

concepts and the results show that this design can effectively suppress the error to 0% while keeping the advantages of fuzzy controller.

Hence, it is concluded that the conventional PID controller could not be used for the control of non-linear processes like temperature. So, the proposed fuzzy logic based controller design can be a preferable choice to achieve this to be used for controlling non-linear processes like temperature.

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