Modified Pi-Pd Controller for Avoiding Overshoot in Temperature of Barrel Heating System

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***Abstract*— Plastic molding machine is used to manufacture plastic products such as bottle caps, chairs, small containers, toys, etc. The raw pellets are fed from the hopper into the barrel cylinder. The barrel is heated with resistive heater bands in different zones. The number of heating zones differs from machine to machine based on the end product. The reciprocating screw present inside the barrel cylinder rotates to push the melt towards the mould end. The melt is forced into the mould space, where it gets harden by cooling. It is necessary to maintain the temperature of the melt at a desired value, in order avoid unfinished products.**

The challenging job in the plastic molding process is the control of machine process parameters due to their interrelations. The barrel temperature of the process directly influences the polymer viscosity and is need to be controlled effectively. For the considered plastic molding machine, the implementation of the PID controller will lead to overheating and high rise time, which will deteriorate the product quality. In view of this PI-PD controller-a modified structure of PID controller has been considered. The controller will be tuned using Fuzzy logic technique which will improves the performance. The proposed PI-PD controller will implement in such a way that to maintain the temperature of the melt at desired value. The controller will be modeled in MATLAB/SIMULINK. The expected simulation results will shows that the fuzzy tuned PI-PD with wide dynamic range of control over a temperature.

Keywords: PID controller, PI-PD Controller, Fuzzy Logic, Ziegler-Nichols Tuning, Rise Time, Overshoot and Settleing Time.

1. INTRODUCTION

The challenging job in the plastic molding process is the control of machine process parameters due to their interrelations. The barrel temperature of the process directly influences the polymer viscosity and is need to be controlled effectively.

Even though the conventional PID controller has a drawback of producing an overshoot and slow response in industrial process, this controller is widely used in almost all industrial control actions where this drawback has less significant impact. For the considered plastic molding machine, the implementation of the PID controller will lead to overheating and high rise time, which will deteriorate the product quality.

In view of this PI-PD controller-a modified structure of PID controller has been considered. The controller is tuned using Fuzzy logic technique which improves the performance. The remaining section of the paper is outlined as follows: The Process flow and controller structure are detailed in section IT. The Process model and its Ziegler-Nichols Tuning are presented in Section TTT. Section IV describes the concept of Fuzzy logic controller, Fuzzy tuned PID and PI-PD Controller. Simulation results and performance comparison are analyzed in Section V. Section VI concludes the findings of this paper.

2. BARREL HEATING PROCESS AND PI-PD CONTROLLER :

A. Plastic molding machine and Barrel heating system

Plastic molding machine is used to manufacture plastic products such as bottle caps, chairs, small containers, toys, etc. The raw pellets are fed from the hopper into the barrel cylinder. The barrel is heated with resistive heater bands in different zones. The number of heating zones differs from machine to machine based on the end product. The reciprocating screw present inside the barrel cylinder rotates to push the melt towards the mould end. The melt is forced into the mould space, where it gets harden by cooling. It is necessary to maintain the temperature of the melt at a desired value, in order avoid unfinished products. The proposed PI-PD controller is implemented in this part of process in order to maintain the temperature of the melt at 200 degree.

B. PI-PD Controller

In PI-PD controller, the PI action is on the error (steady state error) and the PD action is on the process variable (temperature). The block diagram of the proposed PI-PD controller is shown in Fig. 1.

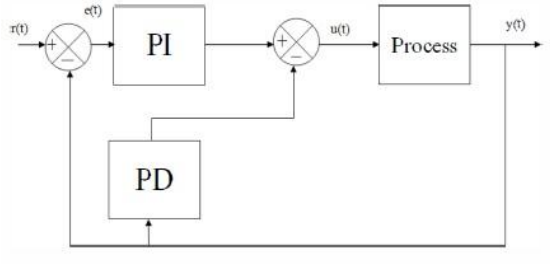

Fig. 1. PI-PD controller

K_p - Proportional Gain
T_i - Integral Time and
T_d - Derivative Time

The proposed PI-PD controller minimizes the derivative kick and reduces the response time and overshoot. The error e(t) is the difference between the set point, ret) and the measured process variable yet). Here the u(t) is the output of the controller and the input to the process.

3. PROCESS MODEL AND ITS ZIEGLER-NICHOLS(ZN) TUNING :

A. Process Model :

The barrel cylinder of the mold system consists of six zones, with each zone consisting of heater band, thermocouple and a controller. The temperature response models of three front end zones in the barrel cylinder are selected from.

$$Zone1 = \frac{62.612e^{-29.4s}}{(153.037s+1)^2} \quad (2)$$

$$Zone2 = \frac{62.7337e^{-27.8s}}{(145.299s+1)^2} \quad (3)$$

$$Zone3 = \frac{31.4213e^{-23.4s}}{(113.3369s+1)^2} \quad (4)$$

B. Ziegler-Nichols(ZN) Tuning :

ZN tuning method is the widely used method of controller tuning [II]. With the critical gain (K) and period of sustained oscillation (Pu), the three controller parameters are obtained from.

$$K_p = 0.6K \quad (5)$$
$$T_i = 0.5Pu \quad (6)$$
$$T_d = 0.125Pu \quad (7)$$

The controller parameter values of each zone are given in the Table I.

Zone	Zone -1	Zone -2	Zone -3
k_p	0.106	0.106	0.198
T_i (Sec)	151.389	143.433	116.366
T_d (Sec)	37.847	35.858	29.091

T ABLE I. TUNING PARAMETERS USING ZIEGLER NICHOLS METHOD

4. FUZZY LOGIC CONTROLLER, FUZZY TUNED PID AND PI-PD CONTROLLER :

A. Fuzzy Logic Controller:

Fuzzy controller is a fuzzy logic based controller which comprises of three steps namely fuzzification, inference and defuzzification. Fuzzification converts the real time crisp quantity into fuzzy values. Based on the rules of Fuzzy Inference System (FIS), decisions are made. Defuzzification converts the fuzzy decisions into system accepted crisp quantity. Fuzzy controller has two inputs, viz error and change in error, and control output is obtained from FIS.

E \ EC (U)	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PB	PB	PM	PS	ZO
NM	PB	PB	PB	PM	PM	ZO	NS
NS	PB	PM	PM	PS	ZO	NS	NM
ZO	PB	PM	PM	PS	ZO	NS	NM
PS	PM	PS	ZO	NS	NM	NM	NB
PM	PS	ZO	NM	NM	NB	NB	NB
PB	ZO	NS	NM	NB	NB	NB	NB

TABLE 2. RULE BASE OF Fuzzy LOGIC CONTROLLER

The real time values are mapped to fuzzy membership values by membership functions. For fast and simple computation triangular membership function is chosen rather than the Gaussian membership function. Mamdanifuzzification and centroid method of defuzzification are used.

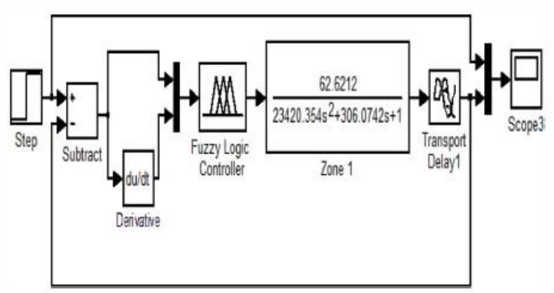

Figure 2. Simulink block diagram for Barrel heating system with Fuzzy logic Controller for zone 1

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 9, September- 2014

B. Fuzzy Tuned PID and PI-PD Controller:

Fuzzy tuned PID Controller has two input variables and three output variables. The input variables are error and rate of change of error. The output variables are gains of the controller, i.e. K_p, K_i and K_d. Forty Nine set of rules are framed with Triangular membership functions. The input and output variables are partitioned into seven parts namely, NB, NM, NS, ZO, PS, PM and PB. Mamdani type of FIS (Fuzzy Inference System) and centroid method of defuzzification are used. In fuzzy tuned PI-PD, the tuned controller parameters are given to the modified controller structure.

K_P		E_C						
		NB	NM	NS	ZO	PS	PM	PB
E	NB	PB	PB	PM	PM	PS	PS	ZO
	NM	PB	PB	PM	PM	PS	ZO	ZO
	NS	PM	PM	PM	PS	ZO	NM	NM
	ZO	PM	PS	PS	ZO	NS	NM	NM
	PS	PS	PS	ZO	NS	NS	NM	NM
	PM	ZO	ZO	NS	NM	NM	NM	NB
	PB	ZO	NS	NS	NM	NM	NB	NB

TABLE 3. RULE BASE OF K_p

K_i		E_C						
		NB	NM	NS	ZO	PS	PM	PB
E	NB	NB	NB	NB	NM	NM	ZO	ZO
	NM	NB	NB	NM	NM	NS	ZO	ZO
	NS	NM	NM	NS	NS	ZO	PS	PS
	ZO	NM	NS	NS	ZO	PS	PS	PM
	PS	NS	NS	ZO	PS	PS	PM	PM
	PM	ZO	ZO	PS	PM	PM	PB	PB
	PB	ZO	ZO	PS	PM	PB	PB	PB

TABLE 4. RULE BASE OF K_i

K_d		E_C						
		NB	NM	NS	ZO	PS	PM	PB
E	NB	PS	PS	ZO	ZO	ZO	PB	PB
	NM	NS	NS	NS	NS	ZO	NS	NM
	NS	NB	NB	NM	NS	ZO	PS	PM
	ZO	NB	NM	NM	NS	ZO	PS	PM
	PS	NB	NM	NS	NS	ZO	PS	PS
	PM	NM	NS	NS	NS	ZO	PS	PS
	PB	PS	ZO	ZO	ZO	ZO	PB	PB

TABLE 5. RULE BASE OF K_d

The fuzzy tuning rules for Kp, Ki and Kd for Fuzzy PID and Fuzzy PI-PD are tabulated in Tables 3, 4, and 5. The controllers are simulated by Matlab/Simulink. Fig. 3 represents the block diagram of barrel heating system's Zone 1 with Fuzzy tuned PID and Fuzzy tuned PI-PD controller respectively.

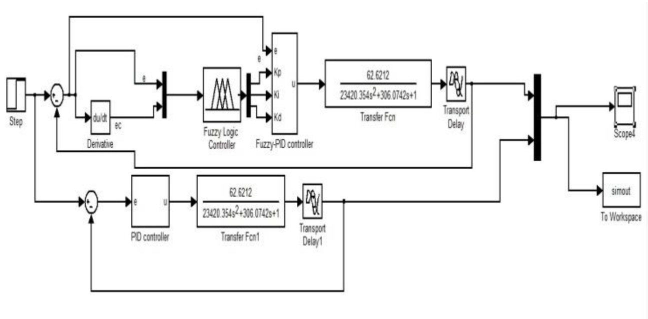

Figure 3. Simulink block diagram for Barrel heating systemwith Fuzzy PI-PD Controller for zone 1

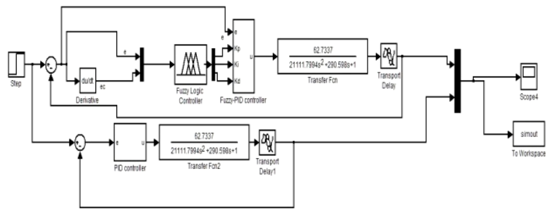

Figure 4. Simulink block diagram for Barrel heating system with Fuzzy PI-PD Controller for zone 2

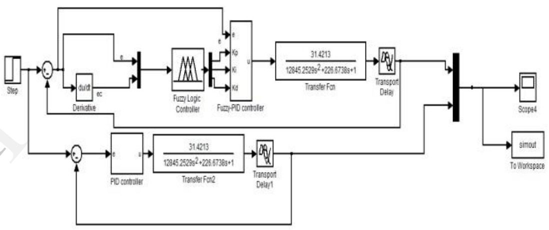

Figure 5. Simulink block diagram for Barrel heating system with Fuzzy PI-PD Controller for zone 3

5. RESULTS AND ANALYSIS :

Three performance indices namely settling time, rise time, and peak overshoot are compared between Fuzzy tuned PI-PD, PID and conventional PID controllers. Fig. 5 represents the simulation results with tuned controllers for zone 1.

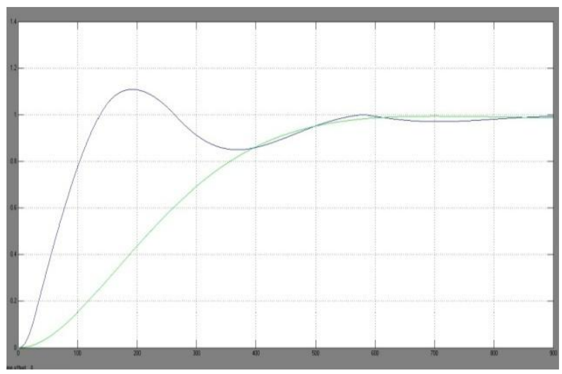

Figure 6. Response of Barrel Temperature Control in Zone-I

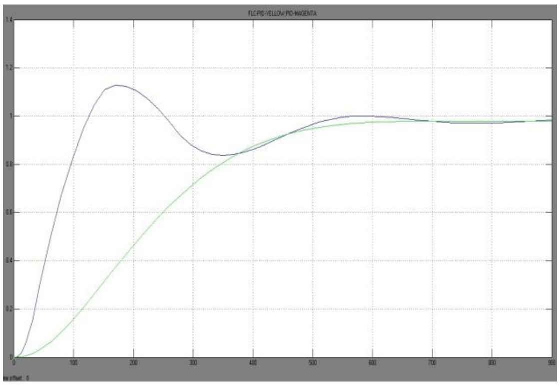

Figure 7. Response of Barrel Temperature Control in Zone-II

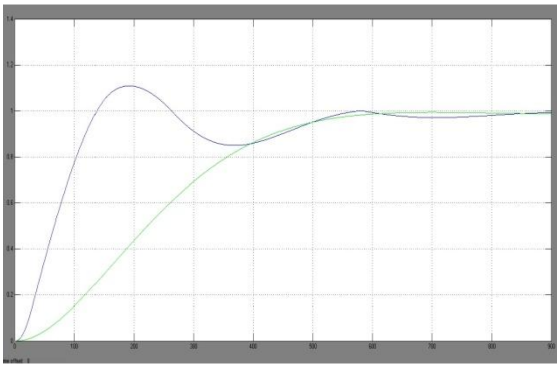

Figure 8. Response of Barrel Temperature Control in Zone-I

Performance Indices comparison of three zones is given in Figure 5. From the Figure it is observed that the proposed controller reduces the overshoot and settling time.

6. CONCLUSION :

Performance Indices		ZN-PID	FUZZY-PID	FUZZY-PI-PD
Zone 1	SETTLING TIME (min)	22.08	16.33	13.97
	PEAK OVERSHOOT (%)	60.85	13.5	2.5
	RISE TIME (min)	2.2	4.45	9.07
Zone 2	SETTLING TIME (min)	21	15.92	12.08
	PEAK OVERSHOOT (%)	61	13	1.75
	RISE TIME (min)	2.08	4.28	8.82
Zone 3	SETTLING TIME (min)	16.67	15.67	13.07
	PEAK OVERSHOOT (%)	59.5	11.5	0.75
	RISE TIME (min)	1.7	3.98	8.375

Fuzzy tuned PI-PD controller reduces the overshoot and settling time and thus it is found that there is significant reduction in Proportional Kick and Derivative kick. The proposed controller reduces the settling time by 14.45% in zone 1, 24.12% in zone 2, and 16.59% in zone 3, compared to Fuzzy PID controller. Overheating is reduced over 80 % in all the zones with the fuzzy tuned PI-PD controller. In future the Controller tuning can be done using Evolutionary algorithms in order to improve the performance.

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