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Design of Digital Controller for Pressure Process

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ABSTRACT

Process control is one of the important problems in industries, control of pressure plays a vital role in industries. The most popular controller used in the process industries for closed loop control is Proportional Integral Derivative (PID) controller, as it can assure satisfactory performances with simple algorithm for a wide range of processes. The objective of the work is to maintain the pressure in the closed loop at desired set value. In this work we have designed discrete proportional integral derivative (PID) controller, deadbeat controller and Dahlin's controller for the pressure process using MATLAB software. The performances of the proposed digital controller are compared and analysed.

Keywords: Discrete PID, Deadbeat algorithm and Dahlin's algorithm.

1. INTRODUCTION

Every process industry is very essential to measurement of pressure, temperature, level and flow. In real time systems difficult to control process due to their dynamic behaviour of system, they may be classified into linear and non-linear processes. In this paper deals with nonlinear systems like pressure tanks. The Control of pressure in pressure station is a very complexity, because this system is nonlinear. These processes to be optimum controlled using controllers are discrete proportional integral derivative (PID) controller, deadbeat controller, Dahlin's controller. Those controllers are digital controllers, it design specific algorithm will be there, if used to design the controller to obtain optimum response using MATLAB software [1, 2].

Discrete proportional-integral-derivative (PID) controllers are widely used in industrial control systems because of the reduced number of parameters to be tuned. They provide control signals that are proportional to the error between the reference signal and the actual output (proportional action), to the integral of the error (integral action), and to the derivative of the error. The main features of discrete PID controllers are the capacity to eliminate steady-state error of the response to a step reference signal [3].

Deadbeat algorithm is to designed to drive a plant output from an arbitrary initial state to a desired final state in the minimum number of sampling times and in such way that after the output matches the input for the first time ,the output becomes identical to the input at all sampling instants, exhibiting little or no ripple between them and the design of the deadbeat algorithm depends on knowing the model of the plant, and it is normally carried out for a specific type of input ,such as a step or a ramp function [1].

For most practical industrial applications, the minimal prototype response is difficult to achieve. The requirement that the controlled variable move from one set point to another over the span of just a few sampling periods is often physically too demanding, and inaccuracies in the process model may cause poor closed-loop performance. Dahlin's algorithm, also derived independently by Higham, is obtained from the same basic design equation.

2. EXPERIMENTAL SETUP

This experiment is conducted at the Process Control Laboratory, Bannari Amman Institute of Technology, Sathyamangalam using pressure process station. Here the input pressure is feed through the compressor to the pressure tank and pressure at the tank is measured through differential pressure transmitter which is connected to the tank. The main objective of the system is to maintain the specific pressure value at a constant level. Here the pressure is kept at the particular set point and made to run untill it settle at a particular level, the computer is interface with the data acquisition and control and use the MATLAB simulation toolbox to obtain the first order plus dead time transfer function model.

$$G(s) = \frac{K_p}{\tau s + 1} e^{-t_d s} = \frac{0.4}{10s + 1} e^{-2s} \quad (1)$$

K_p → Proportional gain

τ → Integral time

t_d → Delay time

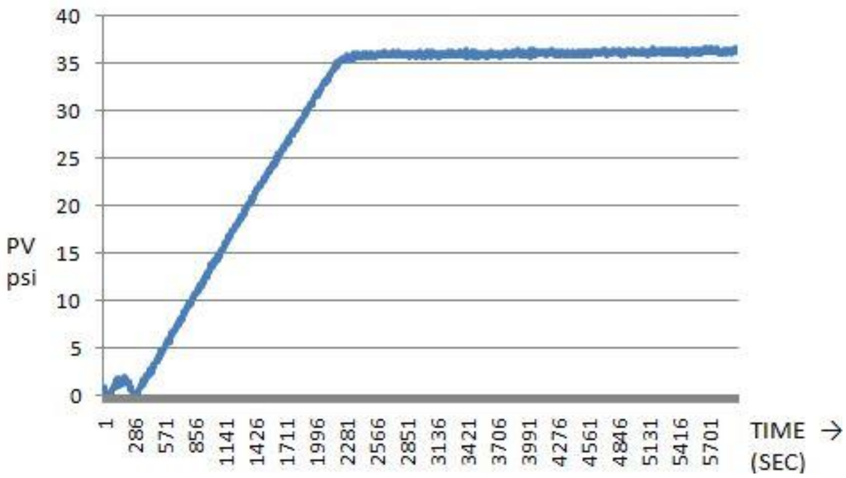

Figure 1: Open loop Response

3. DISCRETE PID CONTROLLER

Discrete of Proportional Integral Derivative controllers are widely used in industry. PID controller is type of feedback controller. PID controller is sum of Proportional Integral and Derivative controllers, it terms are P, I and D. The control action of PID controller is depend on error signal, error signal is different between reference and output value, then output of the controller is send to the final control element, it control the process [3]. The general equation of PID controller is

$$u(t)=K_p e(t)+K_i\int e(t)dt+K_d\frac{de(t)}{dt}+p_o \quad (2)$$

Above the equation (6) Kp , Ki and Kd are gain of the Proportional, Integral and Derivative.

Discrete PID controller tuning is nothing but to adjust the controller parameter in order to achieve an optimum response of process. Discrete PID tuning is classified into two type, it are Open loop method and close loop method. Open loop method is Cohen - coon method or process reaction curve method and close loop method is classified into two type, it are Damped oscillation method and Ziegler - Nichols (Z-N) method. In this paper Ziegler - Nichols (Z-N) method is used [4].

Parameter	K_p	Ti	T_d
Proportional	$U_g/2$	-	-
Integral	$U_g/2.2$	$U_p/1.2$	-
Derivative	$U_g/1.7$	$U_p/2$	$U_p/8$

Table 1: Z -N Tuning method

Ug→ Ultimate gain

Up→ Ultimate period

To find ultimate gain and period using MATLAB. Open the MATLAB model window and construct the close loop system, chose the controller is discrete PID. if tuning value of integral gain (Ki) & derivative gain is put into zero and is proportional gain (Kp) value is varied upto continuous oscillation of the response. that response above the X axis peak to peak is Ultimate gain (Ug) and below the X axis peak to peak value is Ultimate period (Up) from the response.

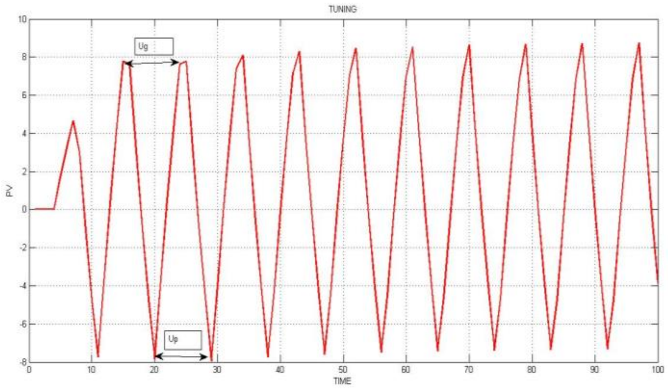

Figure 2: Tuning response of discrete PID Controller

Ug = 10 and Up=10

The discrete PID tuning parameter value is

Kp = 6

Ki = 0.2

Kd = 1.25

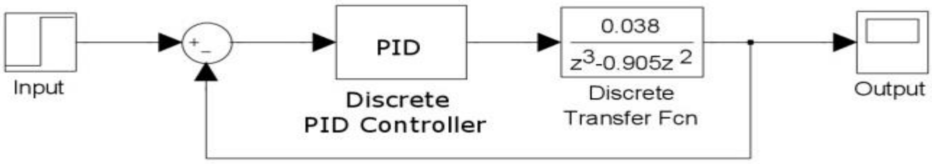

Figure 3: Model of Discrete PID Controller

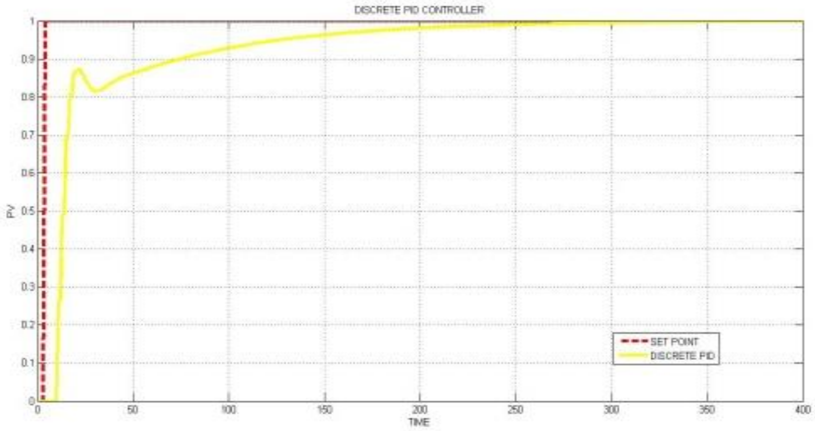

Figure 4: Response of Discrete PID Controller

4. DEADBEAT ALGORITHM

The deadbeat algorithm that requires the closed loop response to have finite setting time, minimum rise time and zero steady state error is referred to as a deadbeat algorithm specification that satisfies these criteria is [1].

$$K(z) = Z^{-n} \quad (3)$$

The n is user friendly, n value will be assumed based on our choice because the D(z) in the form of ration function. Dead beat controllers are often used in process control due to their good dynamic properties. They are a classical feedback controller where the control gains are set using a table based on the plant system order and normalized natural frequency. The deadbeat response has the following characteristics are Zero steady-state error, Minimum rise time, Minimum settling time, Less than 2% overshoot/undershoot, Very high control signal output.

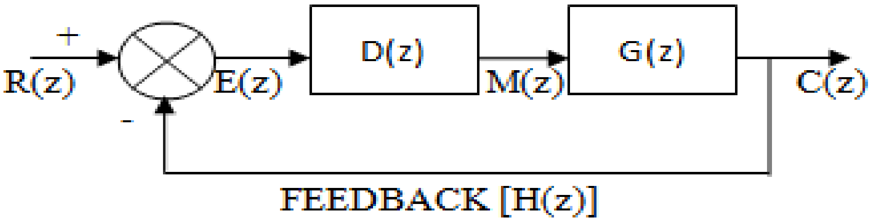

Figure 5: Closed loop system for Digital Controller

R (z) → Set point, D (z) → Controller, G (z) → Plant, E (z) → Error signal, M (z) → Manipulated variable (control signal), H (z) → Feedback signal, C (z) → Output, Error signal [E (z)] = Set point [R (z)] - Feedback [H (z)]

Discrete transfer function is ratio of Z - transform of output and Z - transform input.

The general close loop transfer function from Figure 1

The general close loop transfer function from Figure 1

$$\frac{C(z)}{R(z)} = \frac{D(z)G(z)}{1 + D(z)G(z)} \quad (4)$$

Assume

$$K(z) = \frac{C(z)}{R(z)} \quad (5)$$

K(z) → ratio of output and input

Substitute the value of equation (2) in equation (1), then to find the D(z)

$$D(z) = \frac{K(z)}{G(z)[1 - K(z)]} \quad (6)$$

Discrete transfer function G(z) is z-transform of zero order holder and open loop transfer function

$G(z) = z\{G_{zoh}.G(s)\}$ (7)

G_{zoh} → Zero order holder

$G_{zoh} = \frac{1-e^{-sT}}{s}$

Open loop transfer function is

$$G(s) = \frac{0.4}{10s + 1} e^{-2s}$$

The value of G_{zoh} and $G(z)$is substitute in equation (7)

$$G(z) = Z\left\{\frac{1 - e^{-sT}}{s} . \frac{0.4e^{-2s}}{10s + 1}\right\}$$

Assume the value of T = 1 sec

$$G(z) = 0.4(1 - z^{-1})z^{-2}\, Z\left\{\frac{0.1}{s(s + 0.1)}\right\} \quad (8)$$

Apply the Z-transform formula to get the G(z)

$$G(z) = \frac{0.038}{z^3 - 0.905z^2} \quad (9)$$

From equation (5)&(9) substitute (6) to find deadbeat controller parameter D(z)

$$D(z) = \frac{Z^3 - 0.905Z^2}{0.038Z^3 - 0.038} \quad (10)$$

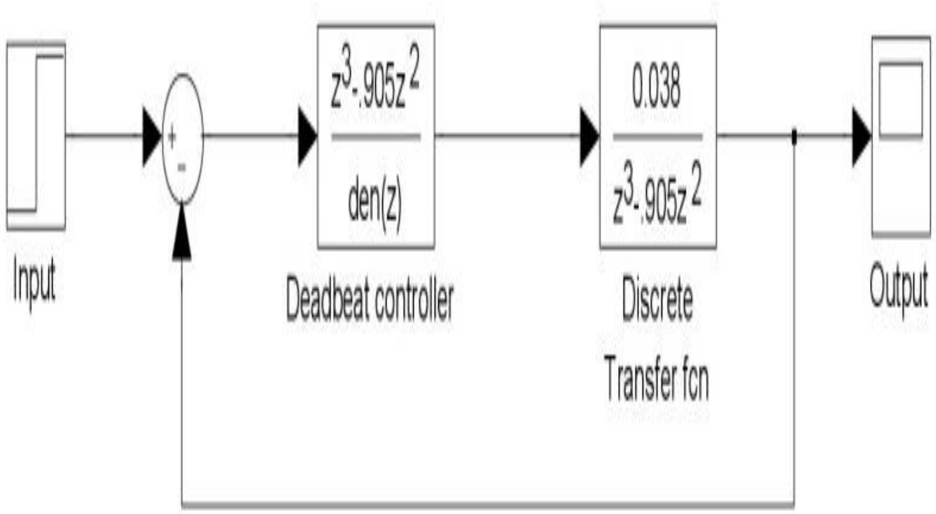

Figure 6: Model of Deadbeat Controller

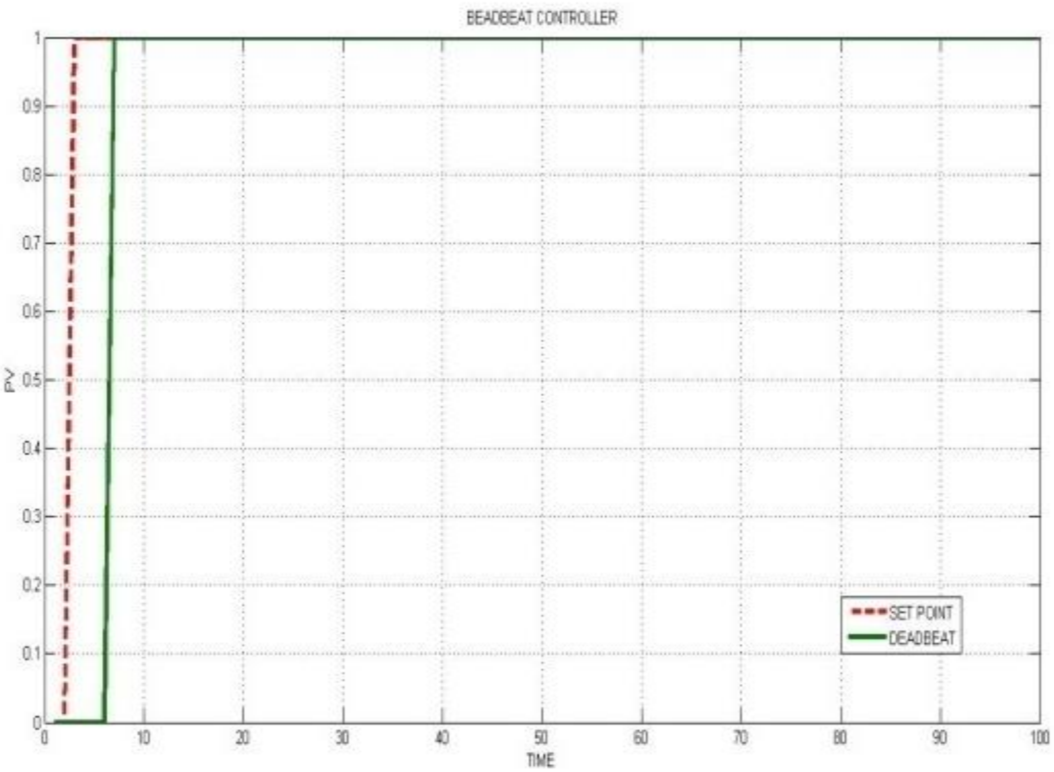

Figure 7: Response of Deadbeat Controller

5. DAHLIN'S ALGORITHM

Dahlin's controller is digital controller and also type of feedback controller. The Dahlin's controller is a special kind of controller, it suitable for first order system with a dead time.

$K(z) = Z\{G_{ZOH}(s).G(s)\}$ (11)

$$K(z) = z\{\frac{1-e^{-sT}}{s}.\frac{e^{-Ls}}{T_m s+1}\}$$

assume T_m =5 sce

$$K(z) = (1-z^{-1})z^{-L}\, Z\{\frac{0.2}{s(s+0.2)}\}$$

apply the Z-transform formula to get the K(z)

$$K(z) = \frac{(1-\alpha)Z^{-(L+1)}}{1-\alpha Z^{-1}} \quad (12)$$

$\alpha \rightarrow e^{\frac{-T}{Tm}}$

$T_m \rightarrow$ Time constant

L $\rightarrow$ delay time

discrete transfer function G(z) is z-transform of zero order holder and open loop transfer function

$G(z) = z\{G_{zoh}.G(s)\}$ (13)

$G_{zoh} \rightarrow$ Zero order holder

$G_{zoh} = \frac{1-e^{-sT}}{s}$

Open loop transfer function is

$$G(s) = \frac{0.4}{10s+1}e^{-2s}$$

The value of G_{zoh} and $G(z)$is substitute in equation(13)

$$G(z) = Z\left\{\frac{1-e^{-sT}}{s}.\frac{0.4e^{-2s}}{10s+1}\right\}$$

Assume the value of T = 1 sec

$$G(z) = 0.4(1-z^{-1})z^{-2}\, Z\left\{\frac{0.1}{s(s+0.1)}\right\} \quad (14)$$

Apply the Z-transform formula to get the G(z)

$$G(z) = \frac{0.038}{z^3-0.905z^2} \quad (15)$$

The T_m&L is user friendly, T_m&L value will be assumed based on our choice because the D(z) in the form of ration function. In this paper T_m=5&L=2.

From equation(12)&(15) substitute (6) to find dahlin controller parameter D(z)

$K(z) = Z\{G_{ZOH}(s).G(s)\}$ (11)

$$K(z) = z\{\frac{1 - e^{-sT}}{s}.\frac{e^{-Ls}}{T_m s + 1}\}$$

assume T_m =5 sce

$$K(z) = (1 - z^{-1})z^{-L} Z\{\frac{0.2}{s(s + 0.2)}\}$$

apply the Z-transform formula to get the K(z)

$$K(z) = \frac{(1 - \alpha)Z^{-(L+1)}}{1 - \alpha Z^{-1}} \quad (12)$$

$\alpha \rightarrow e^{\frac{-T}{T_m}}$

$T_m \rightarrow$ Time constant

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$G(z) = z\{G_{zoh}.G(s)\}$ (13)

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Open loop transfer function is

$$G(s) = \frac{0.4}{10s + 1} e^{-2s}$$

The value of G_{zoh} and $G(z)$is substitute in equation(13)

$$G(z) = Z\left\{\frac{1 - e^{-sT}}{s}.\frac{0.4e^{-2s}}{10s + 1}\right\}$$

Assume the value of T = 1 sec

$$G(z) = 0.4(1 - z^{-1})z^{-2} Z\left\{\frac{0.1}{s(s + 0.1)}\right\} \quad (14)$$

Apply the Z-transform formula to get the G(z)

$$G(z) = \frac{0.038}{z^3 - 0.905z^2} \quad (15)$$

The T_m&L is user friendly, T_m&L value will be assumed based on our choice because the D(z) in the form of ration function. In this paper T_m=5&L=2.

From equation(12)&(15) substitute (6) to find dahlin controller parameter D(z)

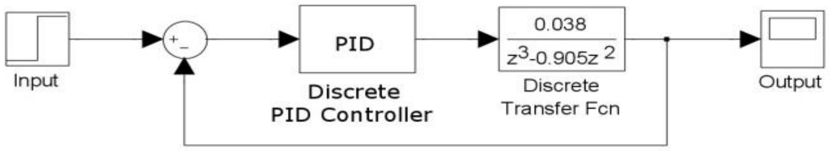

Figure 8: Model of Dahlin's Controller

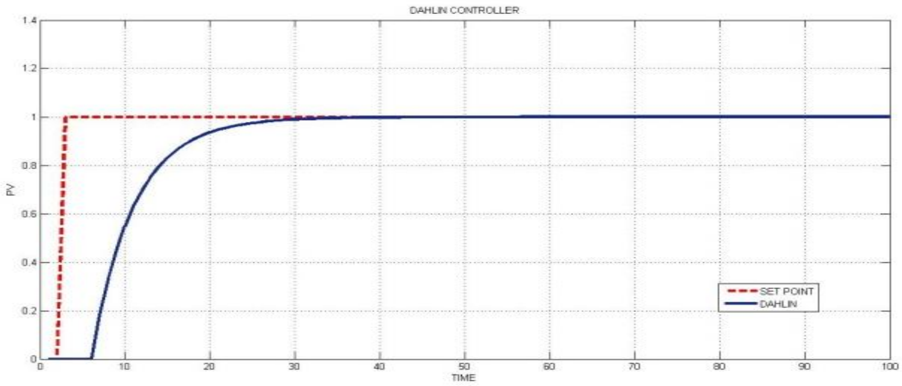

Figure 9: Response of Dahlin's Controller

6. RESULT AND DISCUSSIONS

The performance of the controllers is validated by comparing the time domain specifications. The error indices like Integral Absolute Error (IAE) and Integral Square Error (ISE) are also calculated and tabulated in Table 2 of the proposed system.

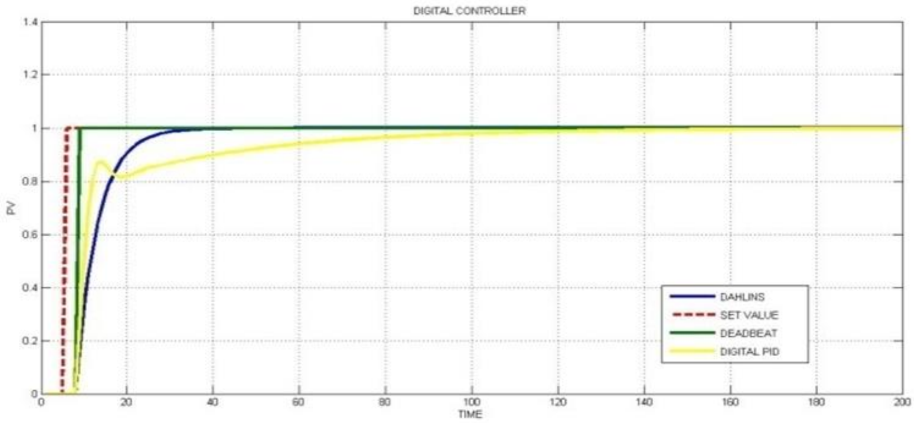

Figure 10: Response of the Digital controllers

6.1 PERFORMANCE ANALYSIS

PARAMETER	DISCRETE PID	DEADBEAT	DAHLIN'S
RISE TIME (sec)	10	8	12
DELAY TIME (sec)	9	8	11
SETTING TIME (sec)	160	8	40
ISE	4.696	3	5.049
IAE	12.45	3	7.608

Table 2. Comparative performance metrics of Discrete PID Controller, Deadbeat Controller and Dahlin's controller

ISE → Integral Square Error

IAE → Integral Absolute Error

From the Table it is clear that deadbeat Controller produces the better performances in real time compared to other controllers.

7. CONCLUSION

The controlling of pressure is mandatory in most of the industries. In this project, the discrete PID controller, dead beat controller, Dahlin's controllers are designed in such a way that the system is physically realizable. But due to the presence of rise time and settling time, the performance of the system is affected. To avoid that deadbeat Controller was designed and implemented using MATLAB simulation. From the Performance analysis deadbeat Controller gives better performance compared to other controllers.

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