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Research Article

Comparison of PID Controller Tuning Techniques for a FOPDT System

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Abstract

Control of liquid level in the process tank is important in process industries. A PID controller is otherwise called as three term control is taken up here for discussion and analysis. It has three constant parameters and they are proportional, integral and derivative values which depend upon the present error, aggregation of past errors and anticipation of future errors based on current rate of change of error respectively. It is highly used in chemical industries because of their success rate in practical applications, robustness and simplicity. In this work, various PID control tuning techniques are used designed. At first, the real time level process is identified as first order plus dead time model. To find the effective controller parameters settings, a conventional PID control tuning techniques and model based PID were analyzed and their simulation results were to be obtained. The effectiveness of various PID controller are highlighted with the aid of time domain and error criterion analysis. The best among the tuned controlled technique is emerged out as a good result of minimum rise time, setting time and is highlighted.

Keywords: *PID controller, Level Process, Internal Model Control (IMC).*

1. Introduction

In 1930s proportional - integral - derivative(PID) controller came into existence. It is being used even today since it provides generic and efficient solution for real world control problems. Hence it is widely accepted in major process industries. It makes things easier for the operator who has to look into control of the system. Different tuning methods are compared in this study. To achieve optimum performance following are essential,

1. Dynamic model ofthe system,
2. Desired performance of closed loop system on the basis of known physical parameters,
3. Adopting controller strategies for desired performance
4. Implementation of the controller using suitable platform,
5. Validation of controller performance (Mohammad Shahrokhi and AlirezaZomorrodi,2012)

The transfer function of PID controller is,

$$G(s) = K_c\,(1+\frac{1}{sT_i}+sT_D)= K_p+\frac{K_i}{s}+K_D \qquad (1)$$

Where, K_P is the proportional gain,
Ti is the integral time,
$T_D$is the derivative time.

The PID controller is very popularly used in the feedback network. It has good clarity and its easy to implement. A PID controller helps to bring down the difference between the process variable and the set point by outputting the response with the desired value. PID controller has zero steady state error, fast response, short rise time, no oscillations and higher stability. PID controllers are preferred over PI controllers because they reduce the overshoot and it also holds added advantage of employability for higher order systems. A PID controller propels a control signal that has a component proportional to the error of a system, accumulation of the error over time and the rate of change of the error with respect to time.

Mostly every system will have multiple and contradictory objectives to be achieved. For designing a controller by satisfying all the requirements we need algorithms so as to tackle the problems that may arise. The conventional tuning methods which works based on fixed parameters will result in lesser performance when system necessitates. In section 2, we will discuss about the process Setup of the system. (ii) Determination of Transfer function of the experimental setup. (iii) Design of basic PID controller.

In Section 3 ,we will discuss about the four tuning techniques-Ziegler-Nichols(ZN),Modified Ziegler Nichols (MZN), Chien Hrones Reswich (C-H-R),Internal Model Control (IMC) for designing the PID controllers. From the above specified tuning methods, the proportional band, integral time and derivative time can be calculated. By using those values one can determine the Proportional constant (Kc), Integral constant (Ki) and Derivative constant (Kd).Section 4 includes the PID values [Kc,Ki,Kd] of the four tuning methods and the Tuning method of Minimum Error Integral Criteria for determining the error values of ITAE, ISE, IAE, MSE. In Section 5 we will compare the time

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domain specifications and the performance index of different PID controllers mentioned above. The curves for those controllers will be plotted and from the above analysis, the best controller for the system is found.

2. Experimental setup of level measurement

The process setup consists of a tank, whose input is given from the pump and the flow rate is measured in the rotameter. The flow rate is controlled by the control valve and the level of the tank is sent to the level transmitter, which is stored in the computer. In this setup, the I/P converter is used to convert (4-20) mA to (3-15)psi .The specifications of the tank for level measurement are as follows. Tank has a transparent body and a cylindrical shape. A level transmitter is employed whose electronic range is (0-90)cm and output (4-20)mA. A centrifugal pump (0.5 HP) is present and also a control valve which is pneumatically actuated and it is air to close type valve. Current to pressure converter whose input range is 4-20 mA and output range is 3-15 psi. Along with these a pressure gauge is also present which has got a range of (0-30) psi.

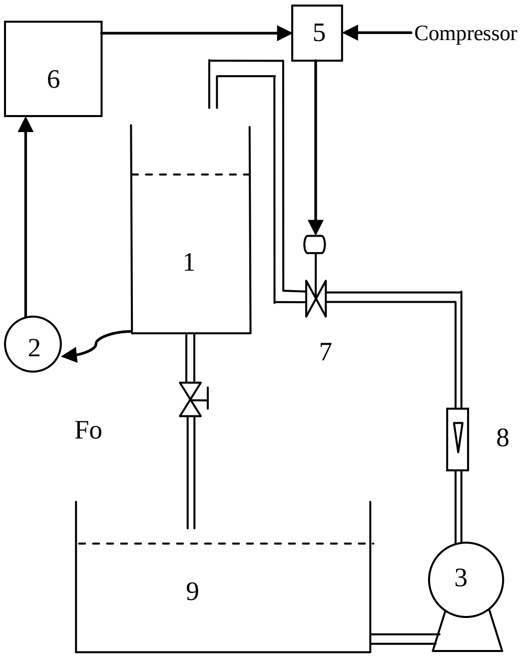

Fig.1. Piping and Instrument diagram of Experimental Setup

1	Process Tank
2	Level Transmitter
3	Pump
4	Reservoir
5	I to P convertor
6	Computer (controller)
7	Control Valve
8	Rotameter
9	Storage Tank
Fi, Fo	Inflow and Outflow

3. Determination of Transfer function

Controllers based on the model primarily require system model. White box model requires complete and correct knowledge of physical data of the system under consideration. But the data for the system described above is unknown. Hence, the system model is determined through system identification. We considered FOPTD model. The step response helps us to find the system parameters like steady state gain, time delay and the time constant of the process from which the model is obtained which is of general form as,

$$G(s) = \frac{k_p e^{-\tau_d(s)}}{\tau s+1} \quad (2)$$

Where,
$k_p$is steady state gain of system,
ts is time constant of system
$t_d$is dead time of system.

The transfer function is obtained by the following steps: Initially 50% inlet flow rate is fixed and the steady state is reached. After reaching the steady state, a step change was given by changing the inlet flow rate to 60%,which results in the open loop response curve with respect to time. From the response curve, the transfer function is obtained by 2 point method.

Hence, we get FOPDT model as,

Transfer function, $G(s) = \frac{1.24e^{-7.5s}}{85s+1}$ (3)

4. Tuning Methods

The two categories of PID tuning methods are :

i) Open loop method
ii) closed loop method

The open loop method refers to the tuning of controller when it is not in automated state and the system is said to be in open loop configuration. The closed loop method refers to tuning of controller when it is in automatic state and the system is said to be in closed loop configuration. The closed loop methods considered for simulation are:

1. Ziegler-Nichols method
2. Modified Ziegler-Nichols method
3. C-H-R method
4. IMC method

4.1. Ziegler-Nichols method

This trial and error method was suggested by Ziegler-nichols based on sustained oscillations. This method is very popular and used for tuning of PID controllers and it is otherwise called as online tuning method. Using ultimate gain and frequency (Ku and Pu) the controller parameters can be attained. A ¼ decay ratio is considered as design criterion for this method. This method can be employed even without the knowledge of process model. The proportional, integral and derivative values of Ziegler-Nichols method are K_C=11.4, K_I=1.0020 , K_D=32.4238.The response for this method has a rise time of 6.48 second and it attains the overshoot of 54.5% at 15.8 second and it settles at 50.4 second

4.2. Modified Ziegler-Nichols method

Modified Z-N control settings are preferred where there is large overshoot and undesirable oscillations. The proportional, integral and derivative values of Modified Ziegler-Nichols method with some overshoot are K_C=6.27,K_I=0.562,K_D=46.56.In this method, the response has a rise time of 8.23 second and it attains the overshoot of 31.9% at zeroth second and it settles at 88.5 second. The advantage of Modified Ziegler-Nichols over Ziegler-Nichols method is that it has lesser overshoot

4.3. C-H-R method

This method depend upon internal model principle, which states that control can be attained only if the control system encapsulates either implicitly or explicitly. The IMC approach has two important advantages are: a) It explicitly consider model uncertainty and (b) it allows the designer to trade-off control system performance against control system robustness to process changes and modelling errors. The proportional, integral and derivative values of Internal Model Control are KC=3.60,KI=0.0405,KD=2.601.In this method, the response has a rise time of 29.8 second and it attains zero overshoot at time greater than 200 seconds and it settles at 51.6 second. IMC settles earlier than Ziegler-Nichol's method.

4.4. IMC method

This method that was proposed by Chien, Hrones and Reswich is a modification of open loop Ziegler and Nichols method (Astrom K,J, T. Haglund,1994).Two design methods were proposed for quickest response with 20% overshoot and another one without any overshoot. They made separate tuning strategies for set point tracking and load rejection. The proportional, integral and derivative values of Chien,Hrones and Reswich are K_C=8.6827,K_I=0.0729,K_D=30.6065.In this method, the response has a rise time of 10.4 second and it attains the zero overshoot at time greater than 400 second and it settles at 20.6 second. C-H-R method settles earlier than the three methods specified and also the overshoot is reduced.

5. Tuning method for minimum error integral area

As mentioned before, ¼ decay ratio results in undesirable oscillatory responses and also it takes only first two peaks into consideration. The alternative approach is to develop controller design relation based on a performance index that considers the entire closed loop response.(Smith,C.A., A.B. Copripio,1985)

Some of such indexes are as below:

5.1. Integral of the absolute value of the error (IAE)

Integration of absolute error over time without adding weight to the errors. Its response is slower than ISE but with less sustained oscillation.

$$\mathrm{IAE} = \int_0^T |e(t)|dt \quad (4)$$

5.2. Integral of the square value of the error (ISE)

In ISE square of the error is integrated over time. It eliminates the large errors quickly (because the square of a large error will be much bigger),but will tolerate small errors persisting for a long period of time. It produce fast responses, but with considerable, low amplitude, oscillation.

$$\mathrm{ISE} = \int_0^T |e^2(t)|dt \quad (5)$$

5.3. Integral of the time weighted absolute value of the error (ITAE)

In ITAE absolute error multiplied by time is integrated over time . It is to weight errors which exist after a long time much more heavily than those at the start of the response. Systems tuned by ITAE will settle much more quickly when compared to other two tuning methods. It produces system with sluggish initial response which avoids sustained oscillation.

$$\mathrm{ITAE} = \int_0^T t|e(t)|dt \quad (6)$$

5.4. Mean square error (MSE)

Mean Square Error is simple to use, natural to define energy of a signal, which possesses symmetry and differentiability. It is widely used in signal processing.

$$\mathrm{ITAE} = \int_0^T t|e^2(t)|dt \quad (7)$$

Table 5:PID values for different tuning methods

Tuning Methods	K_c	K_I	K_D
Ziegler-Nichol's	11.4	1.002	32.42388
Modified Ziegler-Nichol's	6.27	0.562	46.56
Internal Model Control	3.6	0.0405	2.601
Chien,Hrone,Reswich method	8.6827	0.0729	30.6065

6. Results and Comparison

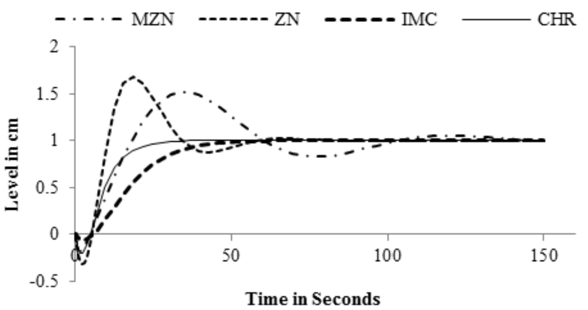

Fig.2 Comparison of Different Controllers Settings

Table 6: The Comparisons of different PID controllers tuning methods are plotted below

Tuning Method	Peak Overshoot	Rise Time	Settling Time	Peak Time
Z-N	68.9	4.037	80	18.69
Modified Z-N	51.2	10.65	140	34.09
CHR-20% overshoot	0	12.65	30	30
IMC	0	26	60	60

Table 7: The Comparison of different PID Controllers ITAE, IAE, ISE, MSE performance index are given below

Tuning Method	IAE	ITAE	ISE	MSE
Z-N	145.4971	2.3072 e+003	115.802	0.8292
Modified Z-N	2.0475 e+003	2.9392 e+003	1.9297 e+004	0.1083
CHR-20% Overshoot	86.3698	586.2215	77.4912	0.7568
IMC	662.1249	2.3602 e+003	1.4906 e+003	0.1378

Conclusion

The model is identified and control system for level process is analyzed using MATLAB platform. Proportional band, Derivative time and Integral time are fed to PID controller. Output is recorded and the results of various tuning methods depicts that Chien, Hrones and Reswich(CHR) tuned PID controller is better than other PID tuning techniques compared. The simulated responses for the model corroborated shows the effectiveness of CHR PID controller in terms of time domain specification. The performance index of CHR method PID controller is also better than other PID controllers compared her from the real time responses, the CHR method PID controller is suitable for this level process.

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