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COMPARISON OF TUNING METHODS OF PID CONTROLLER

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ABSTRACT

The basic objective of this paper is to find a better solution to nonlinear conical tank level process by the tuning of PID controllers. Since conical tank system is predominantly used nowadays in several industries to control of liquid level one of the important parameters and it needs to be controlled. The tuning here has been done using Ziegler Nicholas method (Z-N), Modified Z-N, IMC (InternalModelControl) and TL (Tyreus-Luyben) and CHR (Chien, Hrones, Reswick) methods to linearize the process and to make it attain high stability using these techniques. Also the supremacy of the chosen controller is tested for the various time integral performance criteria like ISE (Integral of the Square error), IAE (Integral of the absolute value of the error), ITAE (Integral of the time-weighted absolute error), and MSE (Mean square error). The above comparison has been done for Single Input Single Output System (SISO) for the conical tank model.

KEYWORDS: PID Controller, Tuning Methods, Error Criterions and Nonlinear Process

INTRODUCTION

Liquid level control one of the indispensable requirements in many industries, where the liquid level is the parameter to be controlled. This has a wide variety of applications in various fields. In order to control such a process conventional methods adapt the tuning of PID controllers, using the computed values of kp-proportional gain ki integral gain and kd derivative gain. There are several methods to tune PID controllers such as Ziegler-Nichols method, Cohen Coon method, IMC etc. [1]

A Proportional Integral Derivative controller (PID) is a generic control loop feedback mechanism widely used in industrial control systems. It is robust due to its strategy to give bounded errors. It was an essential element of early governors and it became the standard tool when process control emerged in the 1940s. In process control today, more than 95% of the control loops are of PID type, most loops are actually PI control.PID controllers can these days be found in all areas where control is needed. [8, 9, 10]. A PID controller calculates an "error "value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs. [6]

Once the set point has been changed, it is compared with the actual output to generate an error signal that is given to the PID controller to make the output achieve its set point. [3]

The PID parameters used in the calculation must be tuned according to the nature of the system. Tuning a controller means setting the best possible values for proportional, integral and derivative components that increase the systems final stability, and considering the performance specifications like margin of stability, transient response and bandwidth. The performance indices are minimized by choosing the appropriate gain. [6, 10]

The responses of the controlled variable to the unit change of the set-point variable and to the unit step disturbance are called “set-point response” and “disturbance response,” respectively. They have been traditionally used as measures of the performance in tuning the PID controllers. [8]

The model of the process under study is very important for its tuning as the accuracy of the tuned controller parameters is greatly dependent upon the degree of accuracy of the system model with that of the real system. As per the fundamentals, it is possible to approximate the actual input-output mathematical model of a very-high order, complex, dynamic process with a simple model consisting of a first or second order process combined with a dead-time element. [6, 11] Generally in a process it is better if tuning is done for a closed loop process since plant model is not known in many cases. [12]

Thus, a common practice followed in industries for the purpose of control, design and process analysis is to model the dynamics of the process near the operating point by simpler models such as First Order Process with Time Delay (FOPTD). [6]

The selection of good control algorithm depends upon the performance comparison of different possible control techniques and selecting the best for the desired condition. To achieve the above for the dynamically changing process the controller parameter should perfectly match with the parameter. [4]

Determination of Transfer Function

Process identification of this non-linear process is done using black box modeling. The process dynamics of the conical tank are analyzed in six zones so as to obtain effective models for the operating ranges. We are defining 6 operating zones here. The first zone is between 12 to 20cm [2], second zone is between 21 to 22, third zone is between 22 to 27, fourth zone is between 27 to 32, fifth zone is between 31 to 35, and the final zone i.e. the sixth zone is set between 34 to 38. For fixed input water flow rate and output water flow rate of the conical tank, the tank is allowed to fill with water from (0-43) cm. At each sample time the data from differential pressure transmitter i.e. between (4-20) mA is being collected and fed to the system through the serial port RS- 232 using ADAM’s interfacing module. The data obtained from ADAM module are in terms of time and voltage, so it is converted in terms of time and height (level). The calculated height (level) is obtained using process reaction curve method (PRC) and SK method. For a change in step function the PRC method produces a response, from the response parameters like dead time (τd), the time taken for the response to change (τ), and the ultimate value that the response reaches at steady state, τ = 63.2 % of the maximum value are measured. Sudareshan Krishnaswamy Method (SK) has proposed a simple method for fitting the dynamic response of systems in terms of first order plus time delay transfer functions. The method is based on computing the times t1 and t2 at which the 35.3% and 85.3% of the system response is obtained. After computing the t1 and t2 times, the time delay and process time constant can be obtained from the following equations:

$$\tau = 0.67(t2-t1)$$

$$\tau d = 1.3\ t1 - 0.29\ t2$$

Since the ISE values obtained from SK method prove to be minimal that method is used to calculate the transfer function, which is used by us for comparison of tuning methods for the PID Controller of this process.

Thus,

$$\text{Transfer function} = \frac{10.08e^{-4.68s}}{(294.8s+1)}$$

Modeling of Tank

A mathematical model is a description of a process using mathematical concepts. Mathematical modelling is used to explain the identified system and to study the effects of different components, and to make predictions about the process behaviour. Mathematical models can take many forms, including but not limited to dynamical systems, statistical models, differential equations, etc.

Here, the proposed system includes the conical tank process whose area is variable throughout the height.

The mathematical model of the conical tank is determined by the following assumptions:

- Level as the control variable
- Inflow to the tank as the manipulated variable. This can be achieved by controlling the input flow of the conical tank.

Inflow rate of the tank (Fin) is regulated using the valve and the input flow through the conical tank. At each height of the conical tank the radius may vary. This is due to the shape of the tank. The difference between the inflow and the out flow rate will be based on the cross section area of the tank and level of the tank with respect to time. The flow and the level of the tank can be regulated by proper modelling the tank. [1]

Operating Parameters are,

Fin - Inflow rate of the tank

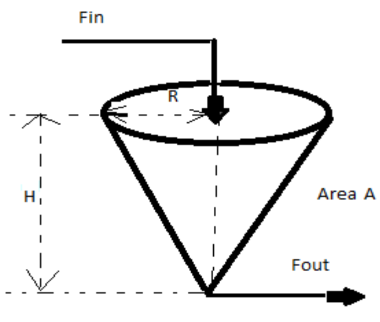
Fout - Outflow rate of the tank

H - Total height of the conical tank.

R - Top radius of the conical tank

h - Nominal level of the tank

r - Nominal radius of the tank



Schematic diagram of Conical Tank System

Figure 1

Tuning Methods

The PID controller tuning methods are classified into two main categories

- Closed loop methods
- Open loop methods

Closed loop tuning techniques refer to methods that tune the controller during automatic state in which the plant is operating in closed loop. The open loop techniques refer to methods that tune the controller when it is in manual state and the plant operates in open loop.[2]

The methods used here are:

Z-N Method

The Ziegler–Nichols tuning method (1942)ultimate-cycle tuning method, is a heuristic method of tuning a PID controller, which is a widely used tuning method. It was developed by John G. Ziegler and Nathaniel B. Nichols. It is performed by setting the *I* (integral) and *D* (derivative) gains to zero. The "P" (proportional) gain, Kp is then increased (from zero) until it reaches the ultimate gain Ku, at which the output of the control loop oscillates with a constant amplitude. Ku and the oscillation period Tu are used to set the P, I, and D gains depending on the type of controller used. [5]

Internal Model Control (IMC)

Morari and his co-workers have developed an important new control system strategy that is called Internal Model Control or IMC. The IMC approach has two important advantages:

- It explicitly takes into account model uncertainty
- It allows the designer to trade-off control system performance against control system robustness to process changes and modelling errors.

Tyreus-Luyben Method

This is a more conservative approach than Ziegler-Nicholas method and so it gives better performance with small values for dead time. But when the value of dead time is large it gives a sluggish performance. It considers ultimate gain Ku and frequency Pu for tuning the controller.

Modified Z-N Method

A version of Z-N method meant for the tuning of closed loop processes. The values for the parameters tuned are given below.

Chien, Hrones, Rewich Method

The Chien-Hrones-Reswick autotuning method focuses on setpoint response and disturbance response. This method provides formulas for 0% and 20% overshoot.

The proportional gain(Kc), derivative gain(Kd) and the integral gain (Ki) for different tuning methods are calculated from the formulae that is given in table [1], [2], [3], [4], [5] and the PID values are tabulated in table[6]

Table 6: PID Values

Tuning Methods	K_c	K_I	K_D
Ziegler-Nichol's	7.56	1.0444	13.6806
Modified Ziegler-Nichol's	4.158	0.5744	20.0653
Internal model control	4.594	0.0154	2.168
Chien, Hrone, Reswich method	5.9603	0.0144	13.1103
Tyreus luyben	3.9375	0.1236	9.0480

Tuning Method for Minimum Error Integral Area

In order to design the best controller for a system, the Time-Integral performance criteria, which are based on the entire response of the system unlike simple criteria that focuses on isolated criteria of the dynamic response, are used.

Using this we can conclude that, the controller whose adjusted parameters are in such a way that they minimize the values of ISE, IAE, MSE, ITAE of the system's response, can be termed as the apt controller.

- ITAE (Integral Time Absolute Error) is preferred for errors which persists for long times, as the presence of larger time amplifies the effect of even small errors in the value of the integral.
  - ITAE=$_0\int^\infty t\ |e(t)|.dt$
- ISE(Integral Square Error) suppresses large errors since it includes square values and thus contributing more values to the integral
  - ISE= $_0\int^\infty e^2(t).dt$
- IAE(Integral Absolute Error) is better to eliminate smaller errors, since squaring of small numbers leads to even smaller numbers.
  - IAE= $_0\int^\infty | e(t) |.dt$
- MSE(Mean of the Squared Error)eliminates the positive/negative problem by squaring the errors. The result tends to place more emphasis on the larger errors and, therefore, gives a more conservative measure.
  - MSE=1/t $_0\int^\infty e^2(t)$.

RESULTS & COMPARISONS

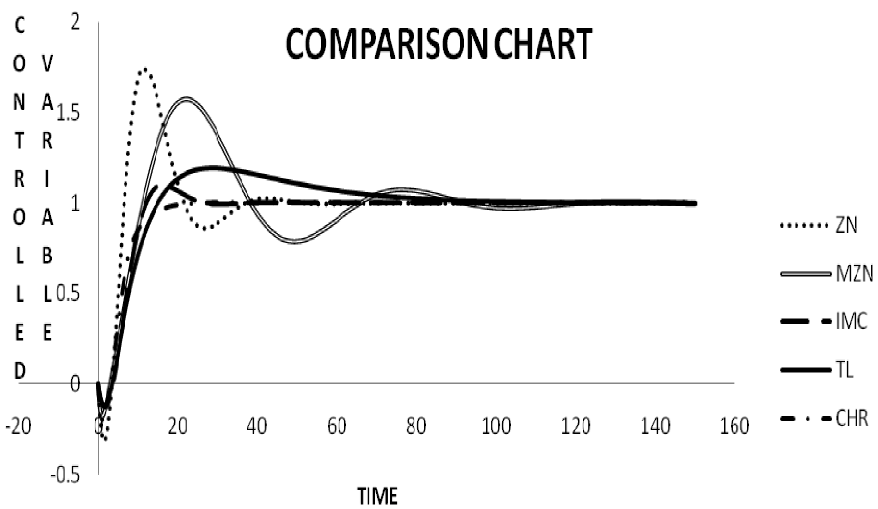


Figure 2

Table 7: Comparison of Time Domain Specifications

Tuning Method	Peak Overshoot	Rise Time	Settling Time	Peak Time
Z-N	72.39	2.5561	54	10.41
Modified Z-N	56.58	6.5288	120	23.7175
Chr-20% Overshoot	0	8.4344	30	8.344
IMC	10	6.1926	38.845	16.34
TL Method	19.3	8.5803	135	27.68

From the calculated PID values, the system response of five tuning methods is compared in terms of time domain specifications (peak overshoot, rise time, peak time, settling time) and the corresponding values are tabulated in Table [7].

Table 8: Comparison of Performance Index

Tuning Method	ITAE	IAE	ISE	MSE
Z-N	6.5823e+003	1.0914e+003	79.9111	0.2857
Modified Z-N	2.1362e+003	973.8048	55.6537	0.0771
CHR-20%Overshoot	175.7995	86.2051	54.9715	0.0487
IMC	435.3264	101.1716	62.8238	0.0635
TL Method	1.5670e+003	955.3523	54.1132	0.0601

In order to obtain the result the performance index of controller is compared with various other entities like the time domain specifications that include peak time, rise time, settling time, peak overshoot. The responses for the controller for various tuning methods has been plotted.

The Minimum Integral Error Criteria and the performance index are compared. Tabulation and comparison charts for time domain specifications that has been calculated are presented in Table [7] and Table [8].

CONCLUSIONS

Analysis of above specified five tuning methods time domain specifications and the performance index of the error criteria are shown in Table 7 and Table 8 respectively. From the comparison plot shown in **figure**, the best controller which has the characteristics of low peak time, low rise time, low settling time and low peak overshoot is found out.

The comparison of five tuning methods leads to the identification of the best controller tuning method- CHIEN, HRONES AND RESWICH(C-H-R METHOD). Based on analysis, Z-N method based PID controller is identified as the best choice.

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