Design of Model Based Controller for a Non-Linear Process

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Abstract

Control of process parameters is one of the important role in process industry. The process considered here is conical tank liquid level system. Control of liquid level in a conical tank is a challenging issue due to the nonlinear variation in the area of cross section. Identification of the non-linear process is done using mathematical modeling and found to be first order plus dead time model. Then control schemes were used to obtain controller parameters Here initially Proportional plus integral (PI) controller based on Ziegler Nichols (ZN) method is designed and the results are compared with Internal model Control (IMC). Better controller performance and error can be minimized by using IMC than that of the ZN tuned PI controller. IMC gives better performance in tracking the set point and load changes with faster settling time and exhibit less overshoot.

Keywords: Conical Tank, ZN Tuning method, Non linear process, IMC, PI controller

1. INTRODUCTION

A conical tank is basically a nonlinear process due to the change in the area of cross section and the level rises or dropout with respect to its shape. PID controllers are commonly used in process industries as they are simple, robust and familiar to the field operator. Control of industrial processes is a challenging task for several reasons due to their nonlinear dynamic behavior, unpredictable and variation of parameters with time, changes in manipulated variable, changes between manipulated and controlled variables, unmeasured and continuous load disturbances, dead time on input and measurements. Due to the gravity discharge flow in conical tanks are mostly used in various process industries such as chemical industries, coal and mine industries, food and packaging areas, concrete mixing industries and wastewater treatment industries.

The process industries require the liquids to be transferred, stored in tanks and then passed to another tank. Many times the liquid will be used by chemical or mixing treatment in the tanks, but always the fluid level in the tanks must be controlled [7-9]. This is achieved by controlling the input flow into the tank. The process variable is the level in a tank and the manipulated variable is the inflow to the tank. The level control is a type of control method for common in process system. The level is to be maintained by the proper controller. The intention of the controller in the level control is to maintain a level at a given set point value and be able to accept new set point values dynamically.

A proportional-integral-derivative controller (PID) Controller [1,2] is a common feedback loop component used for control system. Here PID controller is implemented to track the set point and also to reject the disturbance occurs in the process. The proportional-integral (PI) and proportional integral- derivative (PID) controllers are widely used in many industrial control systems for several decades since Ziegler and Nichols [1] proposed their first PID tuning method. This is because the PID controller is quite simple and its principle is easier to understand than most other advanced controllers. The research has been going on in tuning the PID controllers for different process based on dead time and the different Order Process with Dead Time [7,10,11].

Tuning a controller is the adjustment of process parameters. The proposed method can adjust the controller parameters in response to changes and disturbances in plant by referring to the reference model that specifies properties of the desired control system. The well -known basic tuning approaches are the Ziegler-Nichols (Z-N) method and the Cohen-Coon method. Some researchers use a model based PID control scheme [10], PID controller parameters are identified from the process model.

In this paper, the fact discussed about the control aspects of conical tank using Internal Model based Controller [IMC] PI tuning settings . The IMC gives better performance in tracking the set point and load changes with faster settling time and exhibit less overshoot with no oscillation. Optimization is a powerful tool for design of controllers. Real time systems are not precisely linear but may be represented as linearized models around a nominal operating point. In this work the process model is determined by using system identification technique[8]. The conventional controller tuning is accomplished using Zeigler Nichols based PI controller settings and the performance is compared with IMC based PID controller in time domain specification. The rest of the section deals with the system identification in section 2, tuning method in section 3 and comparative analysis in section 4. Conclusion is come out based on the comparative analysis results from section 4.

2. SYSTEM IDENTIFICATION

2.1 Modeling

A mathematical model is a description of a process using mathematical concepts. The method of introducing a mathematical model is termed as mathematical modelling. It is used to explain the identified system and to study the effects of various parameters, and to make detections about the process behavior. Mathematical models can take many forms, including variable systems, statistical models, differential equations, etc. In this paper the proposed system includes the conical tank process whose area is variable throughout the height[9]. The mathematical model of the conical tank is determined by the following assumptions. Level as the control variable. Inflow to the tank as the changing variable. This is possible by controlling the input flow of the conical tank. Inflow rate of the tank (F_{in}) is regulated using the valve and the input flow through the conical tank .At each height of the conical tank the diameter may vary. This is due to the non linear behavior 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. Operating parameters are tabulated in table 1.

Table-1: Operating Parameters

Parameter	Description
F_{in}	Inflow rate of the tank
F_{out}	Outflow rate of the tank
h	Total height of the conical tank (0.8m)
R	Top radius of the conical tank (18cm)

Mass balance equation is given by,

Input – Output = Rate of Accumulation

$$Fin-Fout=Adh/dt \quad (1)$$

Outflow rate of the tank,

$$F_{out} = \beta\sqrt{h} \quad (2)$$

By substituting the values and considering cross sectional area of the tank at any level h.

Cross sectional area of the tank, $A = \pi r^2$

$$A = \pi R^2 h^2 / H^2$$

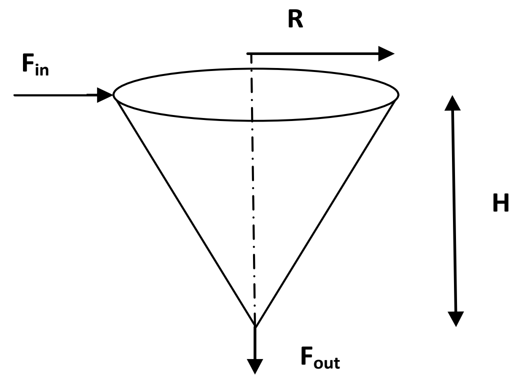

Fig-1: Schematic Diagram of Conical Tank

Mathematical model of the non linear tank is described by the set of differential equations. The differential equations describe the process in time domain. Transfer function of the system can obtain by converting the process from time domain to frequency domain. Transfer function of the conical tank is given by taking the partial differentiation of the linearized equation and its corresponding Laplace transform,

$$\frac{H(s)}{Fout(s)} = \frac{Ke^{-T_d s}}{\tau s+1} \quad (3)$$

Where, K is the process gain, Td is the dead time and τ is the time constant. The transfer function is first order plus dead time (FOPTD) process [8] and the appropriate tuning technique is used to stabilize the system. Based on performance the transfer function is given by,

$$G(S) = \frac{1.61}{(167s+1)} e^{-22.9s} \quad (4)$$

3. TUNING METHOD

In this work, a conventional controller tuning is performed using Zeigler Nichols based PI controller settings and the performance is compared with IMC based PID controller. PID controller algorithm involves three separate constant parameters are Kp, Ki, Kd. Over the last 50 years, few methods have been developed for setting the parameters of a PID controller. In this paper it is considered to proceed with Ziegler-Nichols and IMC tuning technique proposed for tuning controller parameters PI.

3.1. Ziegler and Nichols Tuning Method

Ziegler-Nichols closed-loop tuning method allows you to use the ultimate gain value, Ku, and the ultimate period of oscillation, Pu, to calculate Kp. To determine the critical gain and the critical period, the system is connected in a feedback loop with a proportional gain constant. It is also desirable to adjust the gain automatically. A reasonable

approach is to require that the oscillation is a given percentage of the admissible swing in the output signal. The PID controller is tuned form oscillatory response parameters[1]. The PI controller parameters are identified using tuning formula given in equation 5 and 6.

$$K_p = 0.45Ku \quad (5)$$

$$K_i = 1.2Kp/Pu \quad (6)$$

3.2 Internal Model Control (IMC)

It is a commonly used technique that provides a transparent mode for the design and tuning of various types of control. In process control applications, model based control systems are often used to track set points and reject disturbances. Designing a model-based controller usually requires a plant model, which is normally obtained from first principles. However, the parameters of the model are normally unknown and need to be estimated from experimental data. The basic PI controller parameters are proportional gain, Kp and integral gain Ki. Numerous methods were developed over last fifty years for setting the parameters of a PID controller. From the fig 2 d(s) is an unknown disturbance; R(s) is the reference input is introduced to both the process and its model [11], Qc= IMC controller, Gp= actual process or plant, Gp*= process or plant model, C(s) is the process output is compared with the output of the model. The controller parameters are calculated using the tuning formula is given by,

$K_P = \frac{2\tau+T_d}{(2\lambda+T_d)}$ and $T_i = \tau + \frac{T_d}{2}$.

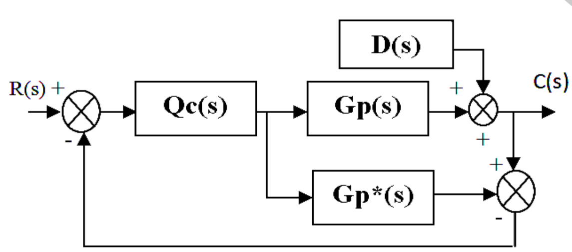

Fig-2: Closed loop structure of IMC

4. COMPARATIVE RESULTS

After the tuning process is done through conventional method and IMC based PI control techniques, analysis was done for their responses to a step input. The tuned parameters are tested and results are compared. Controller parameters are tabulated in table 2 and the response curves is plotted, shown in fig 3.

Table-2: Controller Parameters

Tuning Method	Kp	Ki
Z-N	4.43	0.0188
IMC	2.687	0.01497

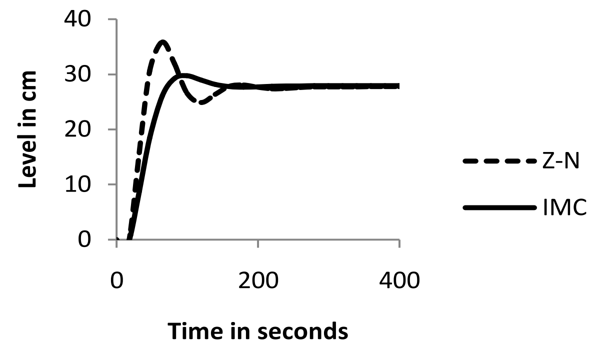

Fig-3: Closed response of the process model.

Table- 3: Comparison of Time Domain Specifications

Controller	Rise Time (sec)	Overshoot (%)	Settling Time (sec)
Z-N	44.3	28	360
IMC	75.05	6	210

The performance of the IMC based PI controller yield a better response the conventional design method by analyzing the time domain specifications like rise time, percentage over shoot and settling time values are tabulated in table 3.

5. CONCLUSION

This paper proposes a conventional PI controller tuning techniques and model based tuning approach for nonlinear conical tank process. By comparing the results the Internal Model Control based tuning provides the better results for the nonlinear process. From the simulation results, the response of the IMC was proved satisfactory in terms of rise time, percentage overshoot & settling time when compared with conventional techniques. From the system response, it is observed that the IMC tracks the set point with smooth transition and with less oscillation compared with Z-N method. The simulation results proven that the IMC control method is an easy-tuning and more effective way to enhance stability of time domain performance of the conical tank system.

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