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# Design and Implementation of a Controller for a Non Linear Spherical Process

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***Abstract-*** **Chemical processes present have many challenging control problems due to various significant features like non-linear dynamic behavior, uncertainty and time varying parameters and so on. Our interest is built around the non-linearity of systems. Because of the inherent non-linearity, most of the chemical process industries are in need of traditional/standard control techniques. The fluid level control problem is commonly associated with storage tanks and blending & reaction vessels in the process industries. Control of process parameters is one of the important problems in process industry. The process considered for modelling is spherical tank liquid level system. Control of liquid level in a spherical tank is nonlinear due to the variation in the area of cross section of the level system with change in shape. System identification of this nonlinear process is done using black box model, which is identified to be nonlinear and approximated to be a First Order Plus Dead Time (FOPDT) model. The controller is designed with the PID based level controller to control the fluid level in spherical tank. Few standard tuning methods like Liptak tuning method, Parr tuning method, Borresen and Grindal tuning method, Camacho tuning method and Tan tuning method have been done and the performance are compared based on ISE (Integral Square Error),IAE (Integral Absolute Error), maximum peak overshoot ($M_p$) and settling time ($t_s$). The best tuning method is determined using simulation and implemented to tune the controller so that the better performance can be obtained in real time process tank. The real time implementation of the process is designed and implemented in MATLAB software tool using V-MAT data acquisition module. All these are carried out for the particular operating region of the process tank.**

***Keywords- FOPDT; ISE; IAE; Maximum Peak Overshoot and Settling Time.***

## I. INTRODUCTION

In process industries, the contribution of Proportional + Integral + Derivative (PID) takes up a major part, since it provides robust, optimal performance and also its simple structure. The PID algorithm is the most widely used in the industrial process control systems of the whole world. It is a robust easily understood algorithm that can provide good control performance despite the varied dynamic characteristics of process plants. Since the creation of PID controllers, roughly sixty years ago, several PID tuning methods were and are being proposed. These methods can be classified in empirical (e.g., Ziegler-Nicholas), analytical (e.g., direct synthesis), or based on some kind of optimization (e.g., ITAE optimization criterion). But all of them have at least one gap or a deficiency. Usually, they work for only some special conditions producing an unsatisfactory result for some classes of plant behaviour.

A common tuning method is normally model-based, or in some cases, based in some measured characteristics of the system (such as: ultimate gain '$K_u$' and period '$P_u$'), but in all of them only one operating region is considered. It is well known that the industrial processes are nonlinear at some extension. In spite of the intrinsic process nonlinearities, usually the dynamic behaviour can be satisfactory approximated by a linear model at each operating point. Therefore, if the process works in several operating points, a set of linear models can be constructed to represent the system behaviour. Even if the process is linear, during the identification procedure, usually more than one linear model is identified, or an uncertain bound is given for the identified parameters, what again produce a set of linear model.

The aim of the paper is to control the level of the non-linear process in industries. The fluid level control problem is commonly associated with storage tanks, blending and reaction vessels in the process industries. Control of liquid level in the spherical tank is non-linear due to the variation in the area of cross section of the tank with height. A single operating region is considered and tuned to get a settled and steady performance of the tank. For that particular region the method that has minimum peak overshoot and with better performance criteria is identified.The objective is to control the fluid level (*h*) through varying the inlet flow (*Fin*). This system is related to storage tanks, however it is not so common in the process industries. Cylindrical tanks are normally used but the spherical ones have a more nonlinear behaviour, and because that they are more difficult to control.

This project is carried out for performance behavior of the spherical tank system for various tuning methods with a comparative study of its performance analysis.

## II. MATHEMATICAL MODELING

Any system, if has to be analyzed, must be mathematically modeled, i.e. the mathematical equations describing the system must be derived so as to aid in studying the system, its features, predicting the dynamic behavior and for many other purposes.

The mathematical modeling of our system is as follows:

The modelling of liquid level in a spherical vessel as shown in Fig.1 is a minor modification of a classical exercise in process modelling.Consider a spherical tank of radius R. The water flows in at a rate $F_{in}$ & flows out at a rate $F_{out}$.

Through a material balance of the system, the outlet flow ($F_{out}$) is dependent of the fluid level considering turbulent flow.

Volume of a sphere is given by,

$$V = \frac{4}{3}\Pi R^3 \quad (1)$$

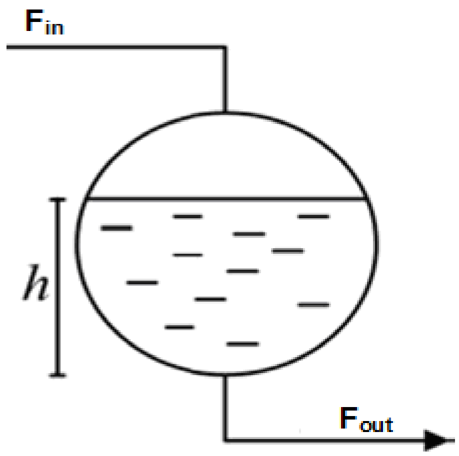



Fig 1 Spherical tank Representation

The first order differential equation of the system is given by,

$$F_{in} - F_{out} = \pi R^2 \left[1 - \frac{(R-h)^2}{R^2}\right]\frac{dh}{dt} \quad (2)$$

Where

h – Height of liquid level in the tank

R – Radius of the tank

$F_{in}$ – Inlet flow rate

$F_{out}$ – Outlet flow rate

By Mass Balance Equation

$$F_{in} – F_{out} = dV/dt \quad (3.3)$$

Applying steady state values & solving (1) & (3), for linearizing the non - linearity in the spherical tank, the system transfer function approximates to a first order plus dead time (FOPDT) equation.

$$\text{Transfer function} = \frac{K e^{-\theta_d s}}{\tau s+1}$$

Where

K = Process gain

τ = time constant

$\theta_d$ = dead time

### A. *System Identification*

Identification of the system refers to determining the system parameters like time constant ($\tau$), dead time ($\theta_d$) and process gain (K). There are many procedures available to identify a system. The most commonly opted method to determine the parameters is from the open loop response of the system with the process reaction curve. The process reaction curve is obtained from the step test procedure. For a spherical tank due to its non-linearity the system parameters will be varied for different operating regions due to variation in cross sectional area. Here the control action is carried out for single operating region.

Fig 2 Spherical tank setup

Specifications:

| | |
|---|---|
| Tank capacity | 125 liters |
| Rotameter | 100 – 1000 LPH |
| Level Transmitter | 0 – 700 mm Wc |
| Electro Pneumatic Positioner | 4 – 20 mA and 3 – 15 psi |
| Pneumatic Control Valves | 100 – 1000 LPH |
| Air Regulator | 18 $Kg/cm^2$ and 1 $Kg/cm^2$ |
| Pressure Gauge size | 2.5” |
| Centrifugal Pump Discharge | 1500 LPH |
| I/P Converter | 20 psi |

## III. CONTROLLER AND ITS TUNING

There are many controllers like P controller, PI controller, PID controller, I-PI controller, I-PID controller etc.. Among those PID controller has better performance with lower peak overshoot, faster settling time and with less oscillation.

Proportional integral derivative controller: The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating element.

By tuning the three constants in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. The PID controller is extremely simple, inherently stable when properly tuned and it is easy to tune to obtain better dynamics with reduced lags.

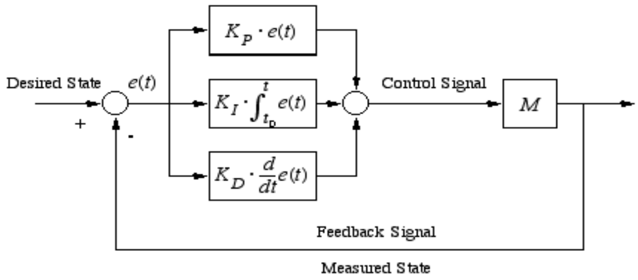



Fig 3 PID Controller

### A. TUNING METHODS

Process of tuning the controllers is an important topic to be studied. Tuning a control loop is the adjustment of its control parameters (gain/proportional band, integral gain/reset, derivative gain/rate) to the optimum values for the desired control response. There are many tuning methods proposed by various authors. A few among them and most popularly used methods (that are specified for a first order plus dead time system) are discussed here.

Zeigler Nicholas tuning method:

$kc = 0.6*ku$; $\tau_I = p_u/2$; $\tau_d = p_u/8$;

$kp = kc$; $ki = kp/\tau_I$ $kd = kp*\tau_d$;

Liptak tuning method:

$K_c = (0.85*\tau) / (K*\theta_d)$; $\tau_i = 1.6*\theta_d$; $\tau_d = 0.6*\theta_d$;

$K_p = K_c$; $K_i = K_p / \tau_i$; $K_d = K_p * \tau_d$;

Parr tuning method:

$K_c = (1.25*\tau) / (K*\theta_d)$; $\tau_i = 2.5*\theta_d$; $\tau_d = 0.4*\theta_d$;

$K_p = K_c$; $K_i = K_p/\tau_i$; $K_d = K_p*\tau_d$;

Borressen and Grindal tuning method:

$K_c = \tau / (K*\theta_d)$; $\tau_i = 3*\theta_d$; $\tau_d = 0.5*\theta_d$;

$K_p = K_c$; $K_i = K_p / \tau_i$; $K_d = K_p*\tau_d$;

Camacho tuning method:

$K_c = (1/K) * ((\tau + \theta_d) / (\tau*\theta_d))$; $\tau_i = (4\tau*\theta_d) / (\tau + \theta_d)$;

$\tau_d = (\tau * \theta_d) / (\tau + \theta_d)$; $K_p = K_c$;

$K_i = K_p / \tau_i$; $K_d = K_p * \tau_d$;

Tan tuning method:

$K_c = (0.6*\tau)/(k*\theta_d)$; $\tau_i = 0.58$; $\tau_d = 0.58$;

$K_p = K_c$; $K_i = K_p / \tau_i$; $K_d = K_p * \tau_d$;

## IV. SIMULATION RESULTS

Simulation refers to the process of predicting the response of a system to changes in load & disturbances. There are many types of software used to simulate results. One such software, commonly used, is MATLAB. We have used MATLAB for the simulation & design of controllers for the spherical tank system. The simulation block diagram of the control system is shown in fig 3.

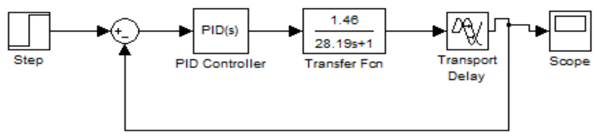



Fig 4 MATLAB Simulation block Diagram

The system can be worked on as per requirements and the response from the scope block can obtained. That response will give us a basic idea as to how the system will respond when implemented in real time. The tuning rules discussed in the previous chapter are simulated and the results are produced in this chapter. These results aid us in the comparative study of the tuning rules and choosing the best suited tuning rule for our level controller. Values of $K_p$, $K_i$ & $K_d$ are obtained by the formulae specified for each tuning technique.The controller parameters for those techniques were calculated & are given in the following table.

TABLE 1 CONTROLER PARAMETERS – PID CONTROLLER

| **Controllers** | **Tuning methods** | $K_p$ | $K_i$ | $K_d$ |
|---|---|---|---|---|
| Conventional | Ziegler Nicholas (ZN) | 34.318 | 29.883 | 9.853 |
| | Liptak | 28.2965 | 30.49 | 9.8471 |
| PID Controllers | Parr | 41.61 | 28.6965 | 9.464 |
| | Borresen and Grindal | 33.29 | 19.132 | 9.65 |
| | Camacho | 1.2051 | 0.5301 | 0.6844 |
| | Tan | 19.9740 | 34.4379 | 11.5849 |

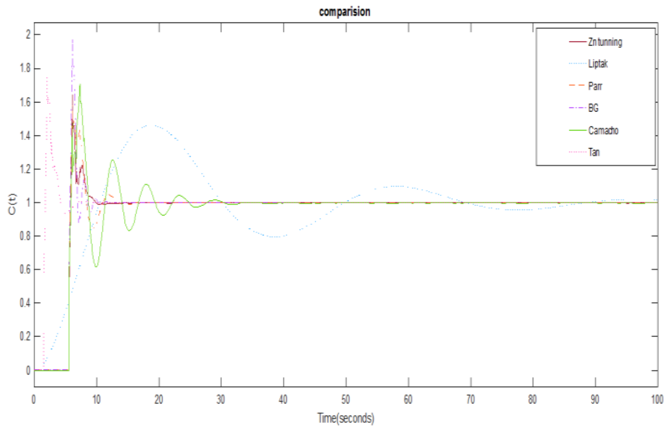



Fig 5 Combined Response of PID Controller Tuning Method

## V. PERFORMANCE ANALYSIS

The Performance analysis is carried out to choose, better method among the tuning methods opted. The analysis like settling time, ISE (Integral Square Error) and IAE (Integral absolute error) were taken and analyzed.

The formula for ISE and IAE are given below

Integral Square Error

$$ISE = \int (e(t))^2 dt \quad (4.1)$$

Integral Absolute Error

$$IAE = \int |e(t)| dt \quad (4.2)$$

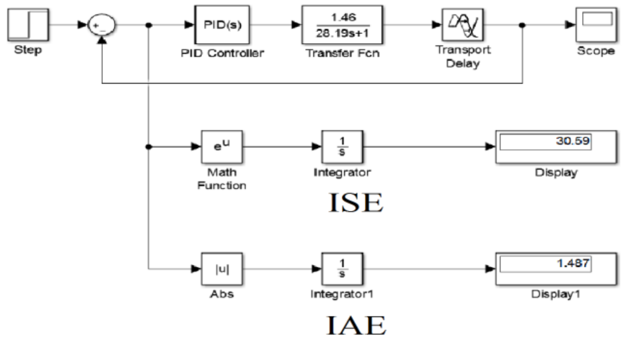



Fig 6 MATLAB Simulation block diagram for ISE & IAE

A. INFRENCE

From the above performance analysis it is inferred that **BORRESEN and GRINDAL PID Tuning,** which is better than the other tuning conventional PID controller in above stated operating condition (27 cm) in the spherical tank process. It is inferred from the above tabulation that BG is better in ISE, IAE than by other conventional PID tuning method.

## VI. REAL TIME IMPLEMENTATION RESULTS

The controller parameters were fed in to the controller interfaced with the spherical tank using RS232 cable and with data acquisition card (V-MAT).

The setpoint is defined by the user in the region of setpoint block which is given to the controller i.e. subsystem 1. The controller takes the action to the process via the data acquisition card. The level of the process is feedback to the process through the same card and it is given to the subsystem 2, this data will also be indicated in the display. Based on the process output the controller controls the opening of the control valve. The opening of the control valve will also be indicated in the display. From the output display the plot can also be visualized directly. The values are taken to the workspace of the MATLAB software tool.

The operating region taken is of 27cm of height of the spherical tank. So the set point given to the system is of 27, which is 53.8% of the total height of the tank. Till the process reaches the set value the control valve will be fully opened.

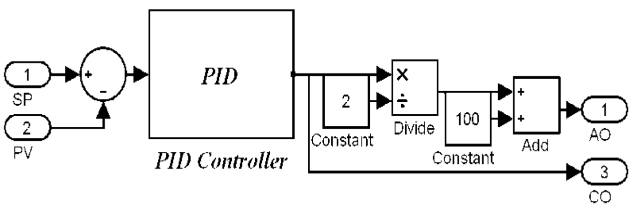
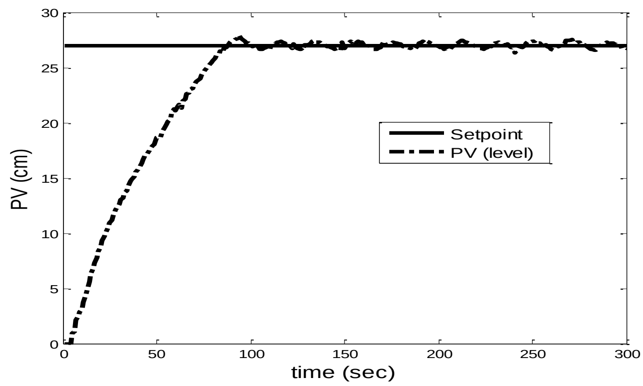



Fig 7 Real time block diagram for subsystem




| PERFORMANCE CRITERIA | ZN-PID | Liptak-PID | Parr-PID | BG-PID | Camacho-PID | Tan-PID |
|---|---|---|---|---|---|---|
| **IAE** | 1.487 | 1.849 | 1.438 | 1.305 | 15.58 | 3.577 |
| **ISE** | 30.5 | 30.6 | 40.62 | 30.0 | 155 | 100.8 |
| **Maximum peak overshoot (MP)** | 0.7767 | 0.6017 | 0.9723 | 0.6439 | 0.4599 | 0.7079 |
| **Settling Time (ST)** | 8.6 | 15.5 | 11 | 9.8 | 121 | 32 |

Fig 8 Real Time Response

Table 2 COMPARISON TABLE

## VII. CONCLUSION

Thus we designed level controller for the spherical tank system both through simulation & in real time setup. During the course of the project we were able to come to a conclusion as to which tuning method gives better performance in the control action. For this particular system, Borresen and Grindal tuning method, among PID Controller gave better responses when compared with the conventional PID controller.

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