IMPLEMENTATION OF MODEL BASED CONTROLLER FOR A NON LINEAR LEVEL PROCESS

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ABSTRACT:

Control of nonlinear process is a complicated task in industrial environment. The non linear process chosen in this paper is spherical tank liquid level system. In this paper process model is identified in real time and the controller is designed using MATLAB simulink. This paper compares the tuning of PID controller using Internal Model Control (IMC) with the traditional methods. Different tuning methods are tried to obtain the controller settings out of which the best controller is highlighted with the aid of time domain specifications. The ability of the designed model based controller is compared with other controllers in terms of set point tracking and simulation results are shown.

Index terms:

PID controller, non-linear process, internal model control

1. INTRODUCTION

Control of a level in a spherical tank is important, because the change in area l inside the tank leads to nonlinearity. In spite of the enormous attention towards modern control techniques have sparked among researchers during the last few decades, PID controllers are still widely used in many control applications. The PID Controllers are popular because of its simplicity and reliability. To implement a PID controller, three parameters (the proportional gain, *Kp*; the integral gain, *Ki*; the derivative gain, *Kd*) must be determined properly. Various techniques have been developed to determine PID controller parameter settings for single input single output (SISO) systems[9]. Among them well-known approaches are the Ziegler-Nichols (Z-N) method [1], the Cohen-Coon method [2], Astrom and Hagglund [3] , internal-model-control (IMC) based PID method for first order plus dead time process [4]. Ziegler and Nichols proposed rules for tuning PID controllers based on the transient response characteristics of a given plant [1]. The Internal Model Control (IMC) is applied based on the predictive output of the process model. Model based identification of PID controller parameter settings increases the process consistency and quality. In the process control area, there has been some work along these lines, including the IMC Proportional-Integral (PI)/PID tuning by Rivera et al[5] and Morari and Zafirion introduced the IMC for process control systems [6].The internal model control tuning helps to overcome the problem of oscillatory response and set point tracking.

In this work the process dynamics are modeled from a step response analysis by changing the inflow rate of fluid. For the developed model an IMC based PID control structure is designed and its performance measure is based on rise time, settling time and various performance indices are compared with conventional PID controller. In section 2, we have discussed in detail about the development of the mathematical model for the non linear spherical tank level process. In section 3 process model and dead time identification is discussed. The tuning method of conventional techniques and the explanation of the IMC based PID and its implementation is discussed in section 4. The comparative studies and results are given in Section 5. The conclusions arrived, based on the results in section 6.

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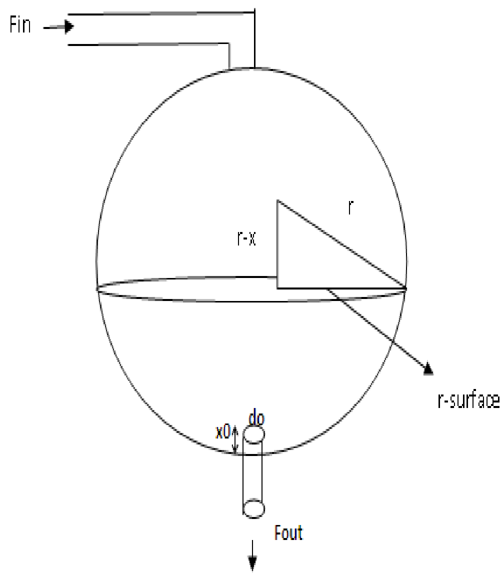
2. MATHEMATICAL MODELING:



In the above figure [7], Fin is the inflow rate of inlet liquid and X is height of the liquid level which is varying with respect to time. Let r be the radius of tank and d0 is the diameter of pipe (m) and initial height is considered as xo.

r- Surface = radius of the surface of the fluid varies according to the level (height) of fluid in the tank.

Based Law of conservation of mass,

Accumulation= mass input-mass output

$$\frac{d}{dt}(\rho \upsilon) = \rho qin - \rho qout \quad \ldots\ldots. (1)$$

$$\frac{d\rho}{dt}v + \frac{\rho dv}{dt} = \rho qin - \rho qout \quad \ldots.. (2)$$

As density of inlet water remains constant,
The above equation is simplified as

$$\frac{dv}{dt} = qin - qout \quad \ldots\ldots (3)$$

The dynamic model [7] of a spherical tank is given by,

$$\frac{\delta}{\delta t}\left(\int_0^{x1} A(x)\delta x\right) = Fin - a\sqrt{2g(x-x0)} \quad \ldots. (4)$$

Where A(x) is area of cross section of tank

$A(x) = \prod (2rx-x^2)$

'a' is area of cross section of pipe,

$a=\prod d_0^2/4$.

Rewrite equation (4) at time t+δt,
Then the equation becomes

$$A(X)\delta x = Fin\delta t - a\sqrt{2g(x-x0)}\delta t \ldots (5)$$

From equation (4) and (5)

$$\frac{\delta x}{\delta t} = \frac{Fin\delta t - \Pi\frac{do^2}{4}\sqrt{2g(x-x0)}}{\Pi(2rx-x^2)} \quad \ldots. (6)$$

$$\text{Lim}_{d\to 0} \quad \frac{\delta x}{\delta t} = \frac{dx}{dt}$$

$$\frac{dx}{dt} = \frac{Fin\delta t - \frac{\Pi^{d0}2}{4}\sqrt{2g(x-x_0)}}{\Pi(2rx-x^2)} \ldots\ldots (7)$$

3. Process identification:

Step test methods are most commonly used for system identification. A large number of graphical methods are available in literature and they have been used effectively in real time applications to obtain the model. At first, the inlet valve is at fully opened condition and outlet valve is set to a particular restriction. The open loop step response is obtained by varying the inflow rate, the experimental results are noted in terms of time and height or level. The models are identified by process reaction curve method (PRC) and Sunderasan Kumaraswamy (SK) method [4] method. For a change in step function the PRC method produces a response, from the response parameters like dead time (τ_d), 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 and Sunderasan Kumaraswamy (SK) method [4] is used to develop model from the obtained response. As per the structure FOPDT is given by,

$$Gp(s) = \frac{kpe^{-\theta s}}{\tau s+1} \ldots.. (8)$$

Where Kp is the process gain; τ is the first order time constant and θ is the delay time.

Using SK method the real time FOPDT model for this non linear level process is obtained as follows:

Step change: 0-100 lph

$$G(s) = \frac{0.276}{656.6s+1}e^{-49.1s} \ldots (9)$$

4 . CONTROLLER DESIGN:

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This paper implements three different controllers like Ziegler Nichols, Cohen-coon and internal model control to achieve the optimum response of the PID controller.

4.1Zn tuning:

Ziegler-Nichols tuning rule was the first such effort to provide a practical approach to tune a PID controller. In this method, a PID controller is tuned by firstly setting it to the P-only mode but adjusting the gain to make the control system in continuous oscillation. The corresponding gain value is referred to as the ultimate gain (Ku) and the oscillation period is termed as the ultimate period (Pu).Then the PID controller parameters are determined from Ku and Pu which are presented in first row of table(1).

The demerits of this technique are:

(I) It is time consuming because a trial and error procedure must be performed.

(ii) It forces the process into a condition of marginal stability that may lead to unstable operation or a hazardous situation due to set point changes or external disturbances.

(iii)This method is not applicable for Processes that are open loop unstable.

4.2 Cohen-coon method:

In this method the process reaction curve is obtained first by applying an open loop test and then the process dynamics is approximated by a first order plus dead time model. This method is used when big delays are found in real time process. One of the disadvantage of Cohen - Coon method is that the resulting closed loop system is often more oscillatory than the desired signal. The modeling parameters of Cohen -coon method are listed in table (1).

4.3 INTERNAL MODEL CONTROL:

The Internal Model Control (IMC) structure provides a suitable framework for satisfying objectives of non linear level process control. IMC was introduced by Garcia and Morari (1982), but a similar concept has been used previously and independently by a number of other researchers [9]. Using the IMC design procedure, controller complexity depends exclusively on two factors: the complexity of the model and the performance requirements stated by the designer.

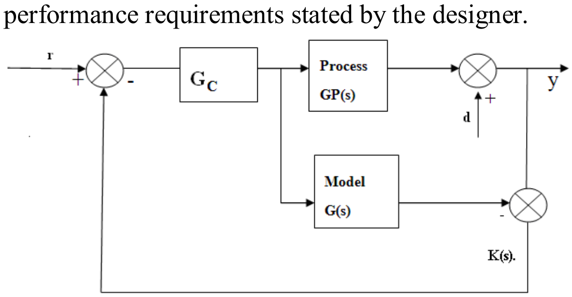

Figure (2) IMC structure

The IMC approach has two important advantages: (1) It explicitly takes into account model uncertainty and (2) It allows the designer to trade-off control system performance against control system robustness to process changes and modeling errors.

Inorder to use the PID Controller,the dead time is approximated using pade approximation method[8].

$$G(s) = \frac{k_p e^{-\tau_d (s)}}{\tau s+1} \qquad \text{...... (10)}$$

pade approximation for dead time is given by,

$$e^{-\tau_d (s)} = \frac{-0.5\tau_d s+1}{-0.5\tau_d s+1} \qquad \text{...... (11)}$$

Table(1) PID tuning formulas

Controller type	Gain(Kp)	Integral time(Ti)	Derivative Time(Td)
ZN	0.6Ku	0.5Tu	0.125Tu
CC	$\frac{1}{k}\frac{\tau}{\tau_d}\left[\frac{4}{3}+\frac{\tau_d}{4\tau}\right]$	$\tau_d\left[\frac{32+6\frac{\tau_d}{\tau}}{13+8\frac{\tau_d}{\tau}}\right]$	$\tau_d\left[\frac{4}{11+2\frac{\tau_d}{\tau}}\right]$
IMC	$\frac{1}{K}(\frac{2\tau/\theta+1}{2\tau c/\theta+1})$	$\theta/2+\tau$	$\frac{\tau}{2(\frac{\tau}{\theta})+1}$

5. Results:

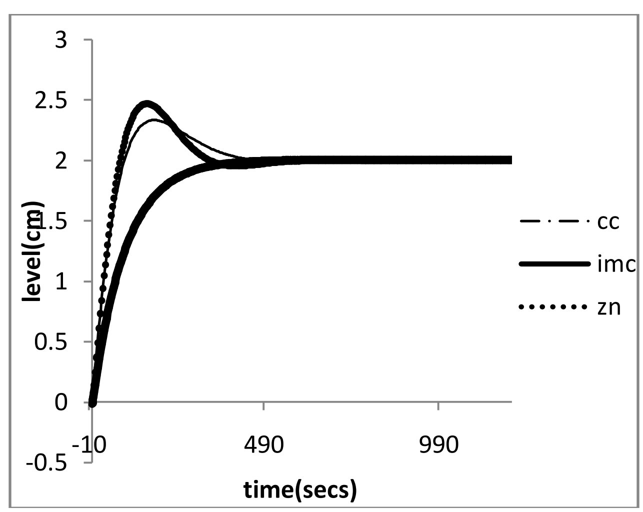

Figure 3) response of different controllers

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Table (2) controller parameters

S.No	parameters	ZN	CC	IMC
1	Kp	60.42	65.31	33.5
2	Ki	0.806	0.557	0.04
3	Kd	1131.6	1150.49	792.4

Table (3) comparison of time domain specifications

S.No	specifications	ZN	CC	IMC
1	Rise time(secs)	81	92	480
2	Settling time (secs)	620	500	500
3	Overshoot(cm)	0.47	0.335	0

Based on the results obtained above it is clear that the performance of Cohen-coon controller was better than Zn. IMC scheme provides better time delay compensation than other conventional tuning techniques. Moreover the effect of overshoot is very less in internal model control and it gives best closed loop performance as compared to conventional ZN and CC methods.

Conclusion:

IMC based PID structure proposed in this model ensures smooth and noiseless output. This controller performs well for set point tracking because it works on the basis of model parameters and filter parameter. From the simulation results and comparative analysis of time domain specifications it is proved that, this non linear level process is tuned effectively using IMC than Ziegler Nichols and Cohen-coon methods.

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