

Non Linear Spherical Tank Control using IMC Tuning Method

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Abstract

Controlling the nonlinear tank is very difficult. Because nonlinear tank have variation in area of cross section. The aim of this paper is to implement optimum controller for a spherical tank. The objective of the controller is to maintain the level inside the process tank in a desired value. The real time implementation of the process is designed and implemented in MATLAB using data acquisition module. The identified mathematical model is in the form of first order plus delay time process (FOPDT).[1] The controller design is compared with different controller tuning methods. The best controlling methods is determined based on no overshoot, better set point tracking, faster settling time and lower performance indices.[1].

Keywords: PID, First order plus delay time process, MATLAB

I. INTRODUCTION

In many industries chemical process have many challenging problems during their nonlinear dynamic behavior. Because of this nonlinearity process industries are need traditional control techniques to control tank level. These nonlinear tanks are having variation in area of cross section.

The process industries require the liquids to be pumped, stored in tanks and then pumped to another tank. Many times the liquid will be processed by chemical or mixing treatment in the tanks, but always the level of the fluid in the tanks must be controlled. A level that is too high may upset the reaction equilibrium, cause damage to the equipment or result spillage of valuable or hazardous material. If the level is too low, it may have bad consequences for the sequential operations. Hence, control of liquid level is an important and common in process industries. [2]

Spherical tanks used in process industries, namely hydrometallurgical industries, food processing industries, concrete mixing industries, sewage water treatment industries and wastewater treatment industries for many applications. Their shape contributes to better drainage of solid mixtures, slurries and viscous liquids at the bottom of the tank. So control of spherical tank is a challenging problem due to its non-linearity and constantly changing cross section. [2]

Conventional controllers are widely used in industries. Because this controllers have robustness and them familiar operation. The most basic and pervasive controller algorithm used in the feedback control is proportional integral derivative controller algorithm. PID controller is widely used to controlling method to control most of industrial automation process because of its simplicity and efficiency. [3] In this paper, we propose IMC based controller for controlling the liquid level in a spherical tank. The basis for IMC method is a first order plus time delay model. Here IMC method is have process reaction curve better than other controller tuning methods.

II. GENERAL CLOSED LOOP BLOCK DIAGRAM

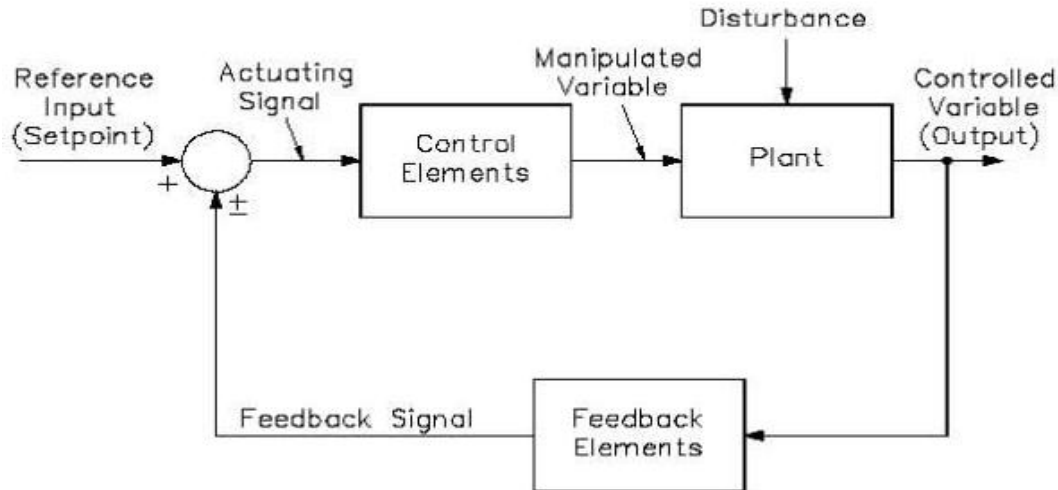


Fig. 1: Closed Loop Block Diagram

Here we are going to control plant output. So output value of the process is measured using sensors and that is given to comparator. The set point value also given to the comparator. Then the output of the comparator is given to controller. Then the controller output is given to final control element. The final control element takes the suitable control action.

III. SPHERICAL TANK AND ITS DERIVATION

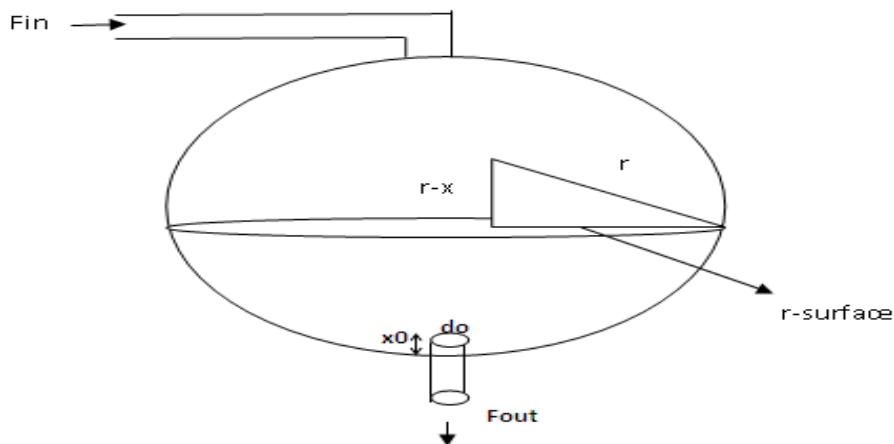


Fig. 2: Schematic diagram

Let us consider, $q_1(t)$ -flow rate of input to the tank in m^3/sec , $q_2(t)$ -flow rate of output of the tank in m^3/sec

- H - Spherical tank Height in meter.
- R - Tank radius in meter (0.5 meter).
- X0 - Thickness of the pipe in meter (0.04 meter).

By the law of conservation of mass, the non-linear equation obtained for the spherical tank is, $Q_1(t)-Q_2(t)=Ah_1 \cdot dh_1/dt$

Where $A=\pi \cdot r^2$ Radius on the surface of the fluid depends on the level (height) of fluid in the tank

$r=\sqrt{2rh_1-h_1^2}$ therefore

$$A=\pi (2rhx-hx^2) \text{ then } Q_2(t)=\sqrt{2g(h-x_0)}, a=\pi(x_0/2)^2$$

$$Q(s) = a\sqrt{2gH} (s)/2(\sqrt{h_0-x_0}) = \pi (2rhx-hx) 2SH(S)$$

By linearizing the non-linearity in spherical tank, we get

$$H(S)/Q(S) = 1/\pi(2rhx-hx^2)S + a\sqrt{2g}/2(\sqrt{hx-x_0})$$

By applying the steady state condition, the linearized transfer function of the plant obtained is,

$$\frac{Y(S)}{U(S)} = \frac{12}{53.6s+1} e^{-2.05s}$$

IV. ZIEGLER NICHOLS METHOD

This method was first proposed by Ziegler and Nichols at the year 1942. This method is based on trial and error technique. This method is mainly used at many factories. Because of its simplicity Controller parameters are determined from ultimate gain (K_u) and ultimate frequency (P_u) [3]

Table – 1
ZN Controller Parameters:

Controller	K_p	T_i	T_d
P	$0.5K_{cu}$	-	-
PI	$0.45K_{cu}$	$P_u/1.2$	-
PID	$0.6K_{cu}$	$P_u/2$	$P_u/8$

A. Disadvantage of this Method:

- Because of trial and error technique this method will need more time to determine controller parameters.
- We cannot use this method at open loop system.
- Some simple processes are not having ultimate gain such as first order and second order processes without dead time.

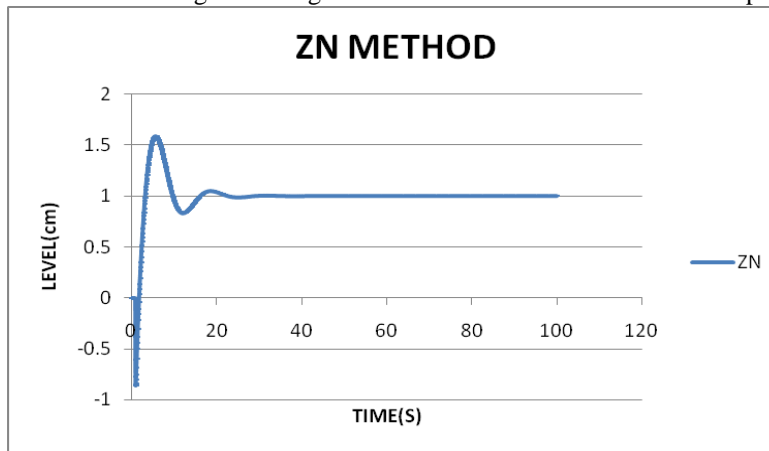


Fig. 3: ZN Tuning Chart

B. Basic Matlab Simulink Model:

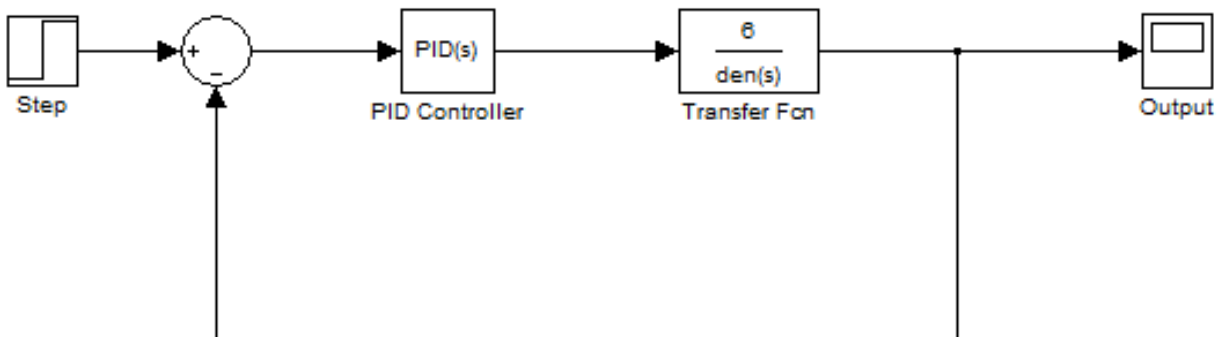


Fig. 4: Matlab Simulink Model

V. COHEN-COON METHOD

Open loop response parameters are used in this process. This method is also based on approximating the process as first order plus dead time model. This method is used when big delay was found in real time process.

Table – 2
CC Controller Parameter

Controller	K_p	T_i	T_d
PID	$(1/k)(\tau/\tau_d)(4/3+\tau_d/\tau)$	$\tau_d((32+6(\tau_d/\tau))/(13+8(\tau_d/\tau)))$	$\tau_d((4)/(11+2(\tau_d/\tau)))$

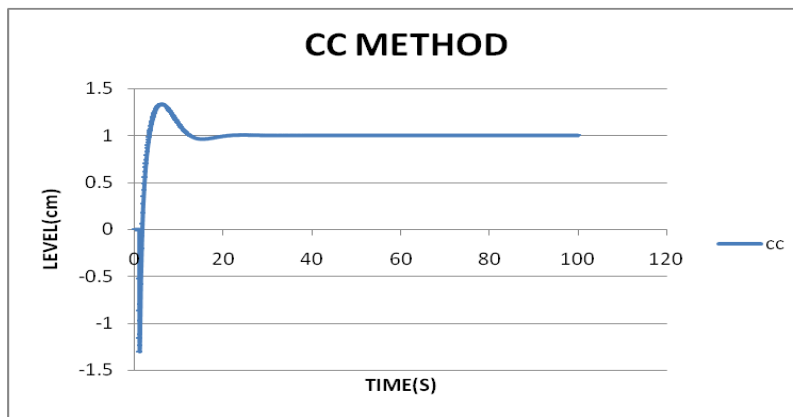


Fig. 5: Chart 2: CC Tuning Chart

VI. TYREUS-LUY BEN METHOD

This method is similar to Ziegler-Nichols method. But it has different final controller settings. Here controller parameters are determined by ultimate gain(K_u) and ultimate frequency(P_u). This method is implemented only for PI and PID controllers [3]

Table – 3

TL Controller Parameter:

Controller	K_p	T_i	T_d
PID	$K_u/3.2$	$2.2P_u$	$P_u/6.3$

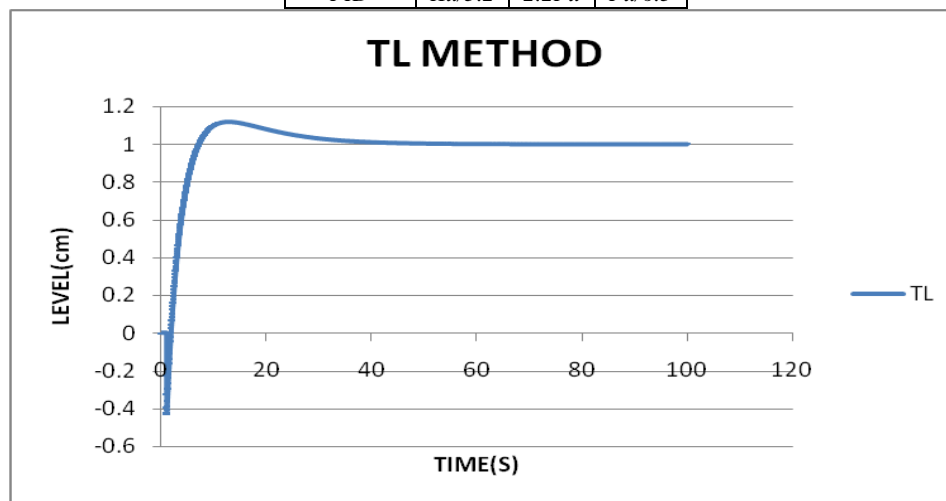


Fig. 6: Chart 3: TL Tuning Chart

VII. INTERNAL MODEL CONTROLLER

In this process model based control systems are used for good set point tracing and reject low disturbances. The internal model control philosophy relies on the internal model principle which states that if any control system contains within it, implicitly or explicitly, some representation of process to be controlled then a perfect control is easily achieved. If we develop control scheme exactly based on the process, we can control the process perfectly.

- Output = $G_c \cdot G_p \cdot$ Set-point (multiplication of all three parameters)
- G_c = controller of process
- G_p = actual process or plant
- G_p^* = model of the actual pro

A controller G_c is used to control the process G_p . Suppose G_p^* is the model of G_p then by setting:

- G_c = inverse of G_p^* (inverse of model of the actual process)

And if

- $G_p = G_p^*$ (the model is the exact representation of the actual process)

Now it is clear that for these two conditions the output will always be equal to the set point. It show that if we have complete knowledge about the process (as encapsulated in the process model) being controlled, we can achieve perfect control. [5]

In this ideal control performance is achieved without feedback. But feedback is necessary when we don't have knowledge about process. When there is open loop control is not present, IMC is able to compensate for disturbances and model uncertainty. If there is model uncertainty occurs, IMC will be detuned to assure stability.

A. IMC Basic Structure:

The distinguishing characteristic of IMC structure is the incorporation of the process model which is in parallel with the actual process or the plant. Also we consider that „*” is generally used to represent signals associated with the model.[5]

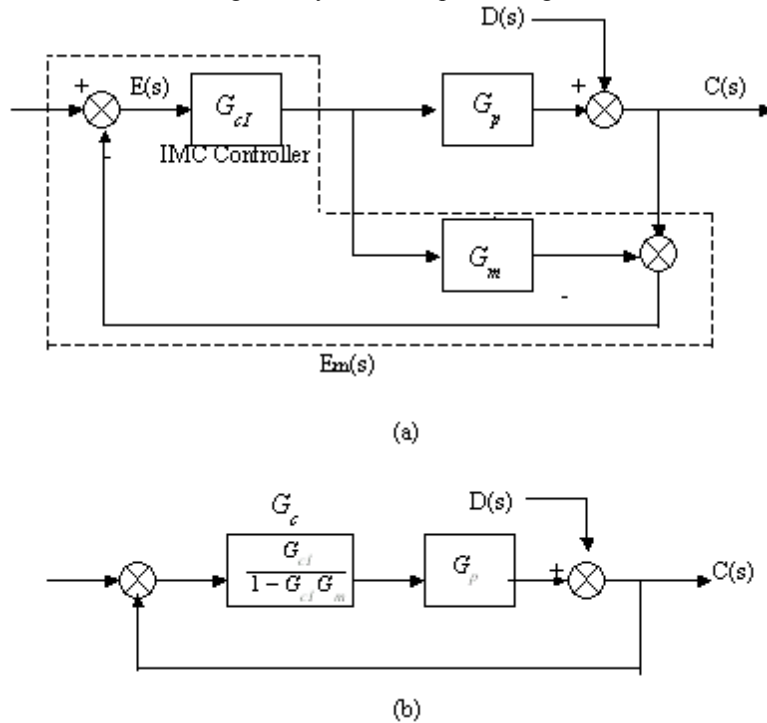


Fig. 7: Basic structure of IMC [1]

B. IMC Parameters:

The various parameters used in the IMC basic structure shown above are as follows:

- Qc= IMC controller
 - Gp= actual process or plant
 - Gp*= process or plant model
 - r= set point
 - R*= modified set point (corrects for model error and disturbances)
 - u= manipulated input (controller output)
 - d= disturbance
 - d*= estimated disturbance
 - y= measured process output
 - y*= process model output
 - Feedback signal:
 - $d^* = (G_p - G_{p^*})u + d$
 - Signal to the controller:
 - $R^* = r - d^* = r - (G_p - G_{p^*})u - d$
- Now we consider a limiting case

C. Perfect Model with No Disturbance:

We will say a model to be perfect if
 Process model is same as actual process
 i.e. $G_p = G_{p^*}$
 no disturbance means
 $d = 0$
 Thus we get a relationship between the set point r and the output y as
 $y = G_p \cdot Q_c \cdot r$

This relationship is same for as we got for open loop system design. Thus if the controller Q_c is stable and the process G_p is stable the closed loop system will be stable.

But in practical cases always the disturbances and the uncertainties do exist hence actual process or plant is always different from the model of the process. [5]

Table – 4
IMC Controller Parameter:

Controller	K_p	T_i	T_d	τ_f	Recommended λ / d ($\lambda > 0.2\tau$ always)
PID	$(2\tau+d)/2(\lambda+d)$	$\tau+(d/2)$	$\lambda d/(2\tau+d)$	$\lambda d/2(\lambda+d)$	>0.25

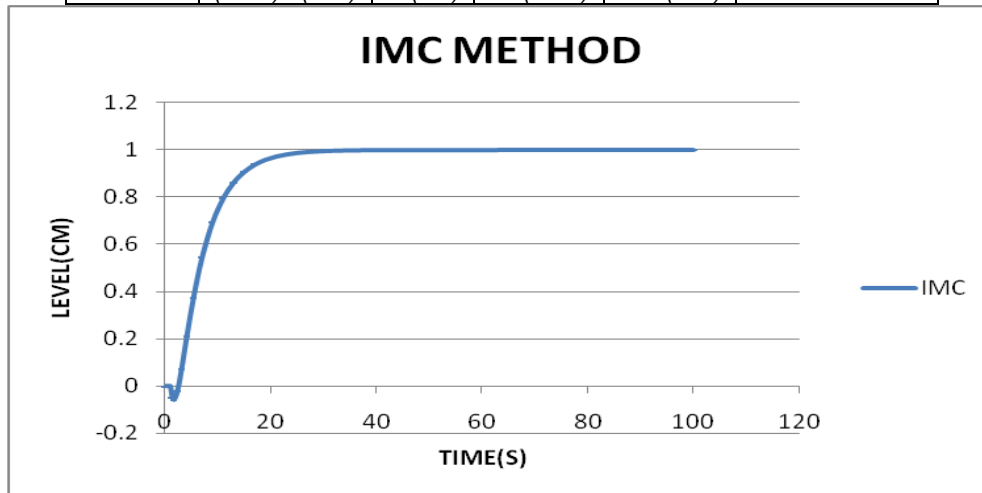


Fig. 8: Chart 4- IMC Tuning Chart

VIII. RESULTS AND COMPARISON TABLE

In this paper we are using ZN method, CC method, TLmethod, IMC method for finding best tuning method to control spherical tank. From the response curve we can find best controller. Let us see rise time, peak time, settling time for every tuning methods.

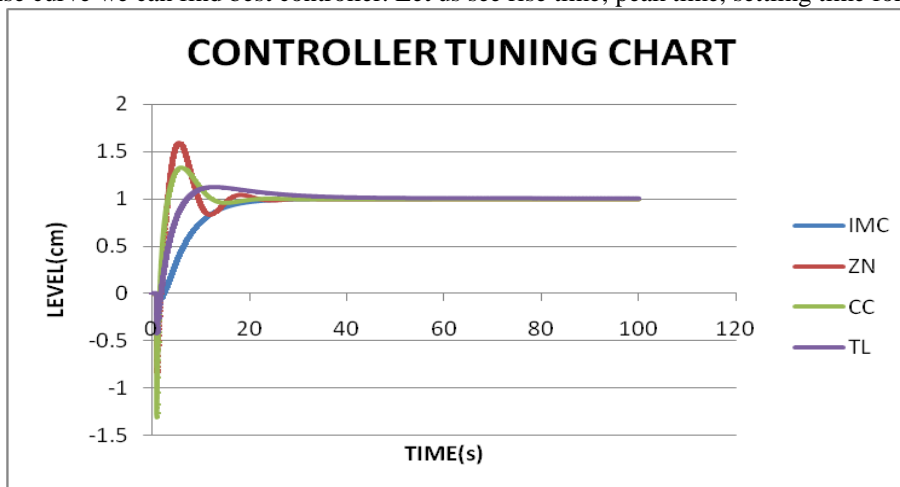


Fig. 9: Chart 5- Combined PID Tuning Chart

Table – 5
Comparison table

Name of the tuning method	Rise time	Peak time	Settling time	Overshoot
Ziegler Nichols	1.09	1.6	18.6	59.6
Cohen coon	1.22	1.33	10.2	33.4
Tyreus-Luyben	3.81	1.12	29.7	29.7
Internal model controller	20	-	25	

From the above tabulation we can find best controlling method from various controlling methods. Here INTERNAL MODEL CONTROLLER method has no peak overshoot and good settling time. IMC has good set point tracking.

IX. CONCLUSION

Optimum tuning parameters for controller are estimated by four tuning methods (Z-N method, C-C method, T-L method, IMC method) for spherical tank level process for Matlab/Simulink. Simulated results show that IMC controller results in quick response with no peak overshoot. Moreover, this method has good ability to adapt to tuning parameters for changes in process dynamics. To summarize, the IMC controller has been proved to be an efficient method in the spherical tank level control process. This method can be also used in a variety of nonlinear process control systems with large transportation lag processes. This paper will be extending in future to the evolutionary algorithms to determine optimum PID tuning parameters.

REFERENCES

- [1] J. G. Ziegler and N. B. Nichols, "Optimum settings for automatic controllers," Transactions of American Society of Mechanical Engineers, Vol. 64, 1942, pp. 759-768.
- [2] G. H. Cohen and G. A. Coon, "Theoretical investigation of retarded control," Transactions of American Society of Mechanical Engineers, Vol. 75, 1953, pp. 827-834.
- [3] Astrom, K J.; Hagglund .T,1984, "Automatic tuning of simple regulators with specifications on phase and amplitude margins", Automatic, 20,645-651.
- [4] Smith, O.J. (1957). Closer control of loops with dead time. Chem. Eng. Prog. 53, 217.
- [5] Horn, I.G., J.R. Arulandu, J. Gombas, J.G. VanAntwerp and R.D. Braatz (1996). Improved filter design in Internal Model Control. Ind. Eng. Chem. Res. 35(10), 3437-3441.