Level Control of Nonlinear Hopper Tank Process in Pharmaceutical Industry using Ziegler Nicholas and Cohen Coon Tuning Techniques

Vinothkumar. C, Esakkiappan. C

Abstract: In this paper, the design and simulated results of conventional controllers on non linear hopper tank system are presented to attain a desired level of a process tank. The hopper tank non linear systems are used for this analysis which is also used in the field of Pharmaceutical, Petro chemical industries. Evacuation of products without wastage is possible due to non-linearity of hopper tank's cross sectional behavior of the process. The open loop performance are determined to obtain the desired level control with conventional PI, PID controllers for various tuning techniques like step response based Ziegler Nicholas and open loop Cohen coon tuning method. The major advantage of this method is simplicity. The relationship between these two tuning systems is reproduced by Matlab Simulink model & Compared the presentation of controllers with hopper process tank.

Keywords: Controller Tuning, First Order plus Dead Time, Hopper Tank System, Level Control, Nonlinear Process.

I. INTRODUCTION

In many process industries like Pharmaceutical industries, Petrochemical industries, Paper making Industries, etc., the main issue is to control the process parameters and to attain the desired Set point. It is necessary to control the process parameter like liquid level, pressure, temperature or flow, failing to do so many lead to serious shutdown process. So it is necessary to maintain the parameters of the process tank at particular set point. Most of the industries deal with non linear tanks like conical, spherical, hopper tanks [2]. The controlling of nonlinear nature of processing tank provides a challenging task in industries. It is expected to non-linearity and continually changing cross section. The main aim of this work is to control the level in a nonlinear tank process. The non-linear tank system taken up for controller design is a hopper shape process tank. Owing its shape in a hopper tank the raw resources can be disposed easily and quickly. It can able to store large quantity of process materials due the cylindrical shape at the top, which can be increased based on the requirements. It provides a fast and hygienic cleaning. The raw material may include solvents, slurries, viscous liquids and solids.To pass up the rusting and maintain the flow of the process evenly can be done by using a conical part available at the bottom of the system. The greater part of the pollution happening occur due to spillage, overcapacity of tank, reduced practice and poor treatment facilities can be avoided.

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The standard assignment of the controller configuration is to accomplish the perfect working conditions and to structure the controller to achieve its most great execution [5].

II. MATHEMATICAL MODELLING

The modelling of non-linear hopper process tank is the combination of cylindrical and conical Region. The cylindrical region is used for storage portion and conical region is used for liquid disposal portion. The mathematical representation of hopper tank is obtained with the following two suggestions.

- The tank Level is controlling variable.
- The input flow of hopper tank is manipulated variable.

The hopper tank process transfer function is obtained in terms of process gain K_s, time constant of process □ and delay time of process is t_d [5]. The figure 1 illustrates the schematic view of fabrication of Hopper tank process. The level of hopper tank can be measured by using piezoelectric type level sensor [16]

2.1 Modelling of Cylindrical Region

This portion of hopper tank is considered with Outlet flow rate directly proportional to square root of level [15] and hence its transfer function is given as,

$$G_{cyl}(s) = (h(s)) / (F_{in}(s)) = (k_s / (\tau s+1))*e^{(-t_d s)}$$

Where, A is constant in cylinder region. It is not varying based on the height h. But in Conical Region A is varied based on height h.

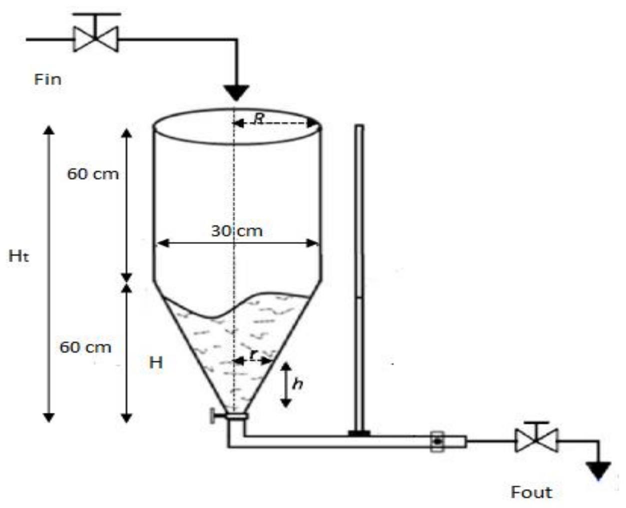

Figure 1. Schematic view of Hopper tank system

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2.2 Modelling of Conical Region [14]

The mass equilibrium equation of the conical portion of hopper tank system dynamics is

$$F_{in} - F_{out} = A_c . dh/dt$$

$$F_{in} - b\sqrt{h} = A_c . dh/dt$$

After Taking Linearization using partial differentiation, conical region transfer function is approximated to a first order transfer function which varies with respect to the height.

$$G_{con}(s) = (h(s)) / (F(s)) = [k_s / (□s+1)] *e^{(-t_d s)}$$

Where;

$K_s = 2\sqrt{h}/b$; $b = a\sqrt{2g}$; $T = 2A_c\sqrt{h}/b$

K_s-Process Gain

□ -Time constant

a- Bottom Outlet area

h- Nominal height of hopper tank

A_c-Nominal area of tank at h cm

b- Outlet discharge constant.

2.3 Design of Transfer Function with FOPDT

Based on the specification requirement in a pharmaceutical industry for the following design specifications are considered for Transfer function modelling of hopper tank system. The design specifications of hopper is as follows

H-Total height of conical portion =60 cm;

R-Radius of Cylindrical Portion =15 cm;

r_b - Bottom outlet hole radius=1.25 cm;

h- Nominal height of Hopper tank=60 cm;

Transfer function of FOPDT [3] with process step input response method at the nominal liquid level 60cm is,

$$G(s) = \frac{0.07126}{50.3781s + 1} e^{-11.12s}$$

III. CONTROLLER DESIGN USING TUNING TECHNIQUES

3.1 Ziegler Nicholas Controller Tuning Method

The issue of tuning parameters of controllers is the point at which the parameters characterizing the elements of the framework are unknown [1]. Ziegler Nicholas tuning method is the most common method, which is used to deal this problem. These unknown parameters can be gotten either from the mathematical model as well as experimentally [1,5]. The Ziegler Nicholas tuning method is a heuristic technique of tuning controllers. The ZN step reaction of the open-loop Transfer function is first acquired and this strategy depends on the assumption that the procedure can be reasonably characterized **by** first order plus a dead time (FOPDT) Transfer function [1], expressed as

$$G(s) = [K_s / (1 + □s)] *e^{(-t_d S)}$$

The hopper process tank response when it is empowered with a standard step input signal is accepted to have a comparable response as appeared in the Figure 2. The process parameters K_S, t_d and □ are obtained from fig. 2. Then the controller parameters of the PI and PID controllers can be obtained using ZN tuning rules as specified in Table 1.

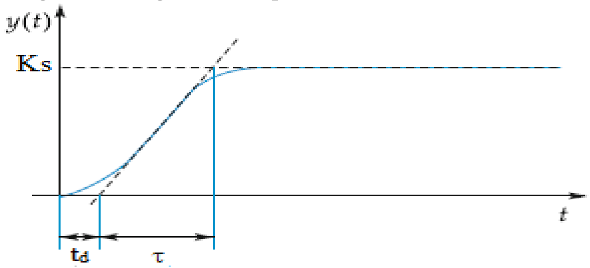

Figure 2. Typical Step Response of FOPDT for ZN Tuning Method [1]

Table-1: Ziegler Nicholas Tuning Rule based on Step Response Method [1, 4]

Controller	Kp	T_i	T_d
P	τ/ t_d	-	-
PI	$(0.9\tau)/ t_d$	$3.33t_d$	-
PID	$1.2(\tau/t_d)$	$2t_d$	$0.5\ t_d$

Table-2: Controller parameters using Ziegler Nicholas Tuning Rules

Controller	K_P	K_I	K_D
P	4.5306	-	-
PI	4.0775	0.11	-
PID	5.4367	0.2445	30.2281

3.2 Cohen Coon Method

The open loop Cohen-coon tuning rules are suited to a wider variety of process. This is used as an alternative tuning method to ZN tuning method, proposed by Cohen and coon. This tuning technique is similar to ZN step response tuning method and it develops the controller parameters K_S, t_d and □ from open loop step response. The rule applied in this method work fine only on processes having the delay time is less than 2 times of time constant. Cohen coon provides one of the few sets of open loop tuning rules that has rules for PI, PID controllers as mentioned in table.3.

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Table-3: Cohen Coon Open Loop Tuning Rules

Controller	Kp	T_i	T_d
P	[1/K] [τ/td][1+(td/3τ)]	—	—
PI	[1/K][τ/td][0.9+td/12τ]	td*[(30+3td/τ)/(9+20td/τ)]	—
PID	[1/K][τ/td][1.33+td/4τ]	td*[(32+6td/τ)/(13+8td/τ)]	td*[4/(11+2td/τ)]

Table-4: Parameters of Controllers using CC Tuning technique

Controllers	K_P	K_I	K_D
P	68.25	--	--
PI	58.38	2.2975	
PID	88.27	3.5173	343.20

IV. SIMULATED RESULTS AND PERFORMANCE ANALYSIS

The controller techniques are implemented for the desired transfer function to attain a desired set point value. The set point value considered is 50cm. The servo and Regulatory responses are obtained on ZN method and the CC methods were compared and their simulated response is publicized in figure 3 and figure 4.

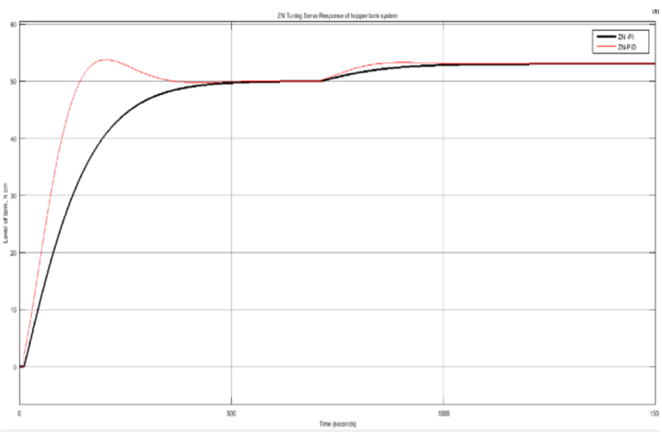

Figure 3. Servo Response of hopper tank with ZN method at set point as 50 cm

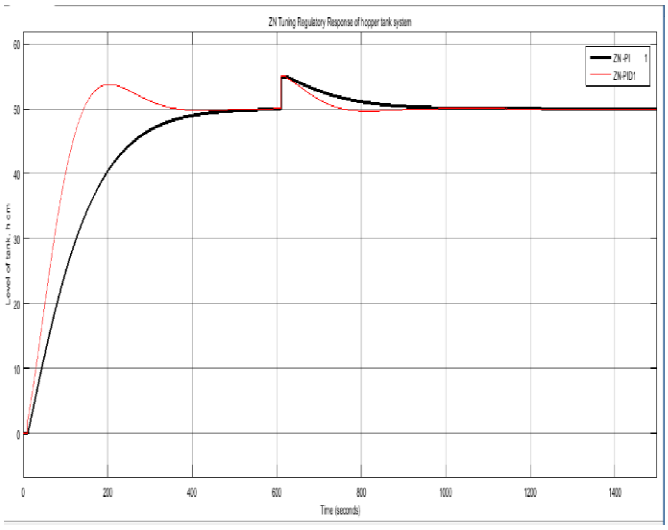

Figure 3a. Regulator Response of Hopper tank with ZN method at set point as 50 cm

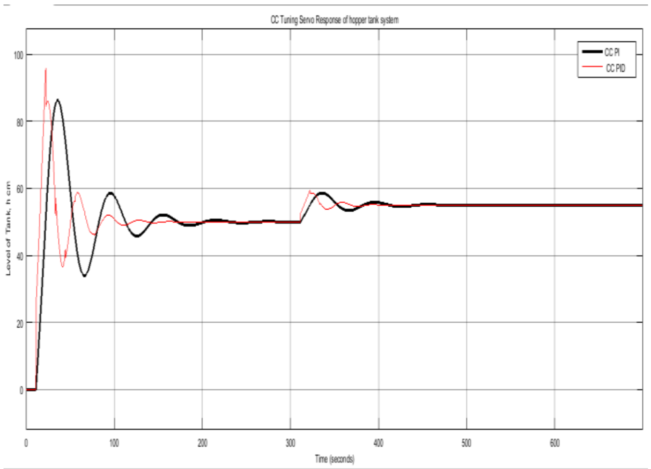

Figure 4. Servo Response of Hopper tank with CC method at set point as 50 cm

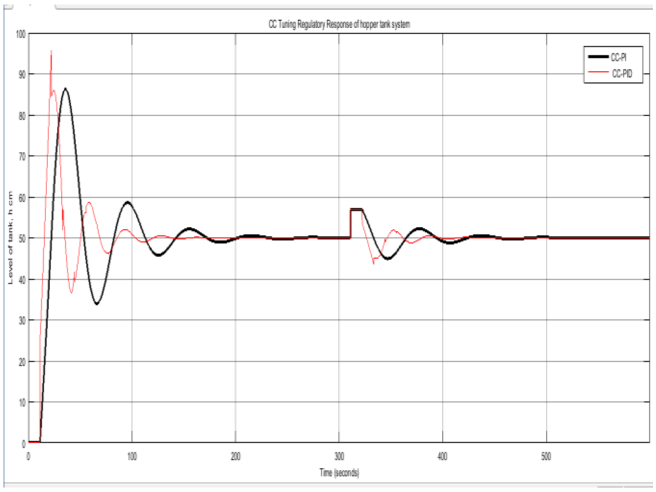

Figure 4a. Regulatory Response of Hopper tank with CC method at set point as 50 cm

The performance of these two tuning methods are compared based on the Time domain Analysis to maintain a faster setting time and the error is reduced using Time Integral performance analysis as shown in table 4.

Table-4: Comparison of Time Domain Analysis parameters on ZN & CC Method

Controllers	Time Domain Parameters	ZN Tuning Method	Cohen-Coon Tuning Method
PI	Rise Time (sec)	235	8.79
	Settling Time (sec)	405	189
	Overshoot (%)	0	72.5
	Maximum Peak Value	1	1.72
PID	Rise Time (sec)	99.40	3.45
	Settling Time (sec)	307	111
	Overshoot (%)	7.48	88.80
	Maximum Peak Value	1.07	1.89

4.1 Time Integral Performance Indices Analysis

The performance indexes are to optimize the performances of a closed loop non linear system by reducing the error and obtaining the best value. It is used for controller tuning and also for different optimization techniques [16]. Different performances indices are

- Integral Square Error

$$ISE = \int_0^\infty |e^2|\, dt$$

- Integral Absolute Error

$$IAE = \int_0^\infty |e|\, dt$$

- Integral Time Absolute Error

$$ITAE = \int_0^\infty t|e|\, dt$$

Table-5: Comparison of Time Integral Performance Criteria

Controllers	Performance Indices	Z-N Tuning Method	Cohen- Coon Tuning Method
PI	ISE	1.877e+05	6.277e+04
	IAE	6375	2171
	ITAE	6.539e+05	9.32e+04
PID	ISE	1.14e+05	4.477e+04
	IAE	3761	1381
	ITAE	2..55e+05	3.414e+04

V. CONCLUSION

The level control of hopper tank system in a Pharmaceutical industry is a major problem without the wastage of medicinal products. It is achieved by using Ziegler Nicholas method of controller tuning and Cohen Coon method of controller tuning techniques and results are simulated with conventional PI and PID controller. Comparison is made based on the time domain analysis parameters and time integral performance criterion. It was analyzed from the results that Cohen-coon PID & PI method of tuning gives better performance with faster settling time (111sec&189sec) compared with ZN PID&PI method of controller tuning (307sec &405sec). From performance indices analysis, it is observed that Cohen-coon method of controller tuning performs better than that of ZN controller tuning.

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