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Control Of Non Linear Spherical Tank Process With PI-PID Controllers – A Review

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ABSTRACT
This paper focuses on the review of control methods for spherical tank system and tuning of non-linear PI / PID controllers in real time. The control of liquid level in spherical tank is complicated with conventional controllers due to variation in the area of transverse section of the tank. Thus the proposed non-linear PI and PID controllers are simulated and compared with the conventional PI and PID controllers available in the literature for spherical tank system. The proposed controllers are tuned based on Cohen Coon tuning method from the open loop response of the experimental setup of spherical tank in real time. The results of the proposed control methods are presented and compared with the conventional PI and PID controllers. The performance of the proposed control methods are evaluated with time domain specifications. The proposed non-linear PI and PID controller provides better response than the conventional PI and PID controllers for the spherical tank system.
Keywords – Spherical tank, PI, PID controller, Cohen Coon tuning and Liquid level

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I. INTRODUCTION

The spherical tanks are predominantly used in chemical, petroleum refining, pulp and paper industries to store and dispense the liquids with respect to quantity. The walls of the spherical tank act as a membrane to agitate bending shear stresses acting on the tank. The spherical tank presents uncomplicated maintenance and efficient as compared with that of conventional cylindrical tanks and cylindrical tank with conical bottom. In those conventional tanks the wall stresses vary with direction to generate foam typically by agitation and hence presents inefficient washing. PID (Proportional-Integral-Derivative) control is underpinning control technology for process control engineers to control level of liquid. The control of liquid level in spherical tank is difficult due to their non linear dynamic behavior and time domain specifications such as peak overshoot, settling time, peak time and rise time. The controller calculates an error value as the difference between a desired set point and measured process variable to optimize the error. The controller output is computed by selecting Proportional gain (K_p), Derivative gain (K_d) and Integral gain (K_i) through appropriate tuning methods.

K.K. Tan [1] designed self-tuning of PID controller from the limit cycle oscillations are naturally induced by the preload relay is elaborated and robustness analysis are made by gain (K) with respect to time. G.Sivagurunathan [2] proposed fuzzy based self tuning PI controller gives reliable output than Internal Model Control (IMC) based PI controller at three different operating points. C.priya [3] developed particle swarm optimization (PSO) technique to control of spherical tank system and better closed loop step response are obtained for level process with PSO tuned controllers, comparatively to IMC-based PI controllers. D.Dinesh Kumar [4] designed non linear system using gain scheduled PI controller by conservation principle on Total mass balance by George Stephanopoulos and set point tracking case were obtained. K.Hari Krishna [5] proposed Model Reference Adaptive Controller (MRAC) by obtaining reference model transfer function to eliminate peak overshoot of the process. G.Sakthivel [6] designed fuzzy logic controller (FLC) shown membership function for change in controller output to abolish error in time domain specifications. K.Sundaravadivu [7] developed Fractional order PID (FOPID) is designed for liquid level system and compared with traditional integer order PID (IOPID) controller and error is reduced in (FOPID) by performance evaluation criteria by Integral Square Error (ISE). Praveena [8] designed level control of spherical tank system is implemented by conventional PID controller and soft computing controllers specifically fuzzy logic and neural controllers in labVIEW environmental tool. S.P.Selva raj [9] implemented constrained genetic algorithm based online PI Controller, at different operating regions and performed indices analyzed by Integral square error and Integral absolute error. Keasavan [10] designed the adaptive PID controller for conical tank by Programmable Logic Controller and online estimation of linear parameters like time constant and gain brings an exact model of the process.

II. EXPERIMENTAL SETUP

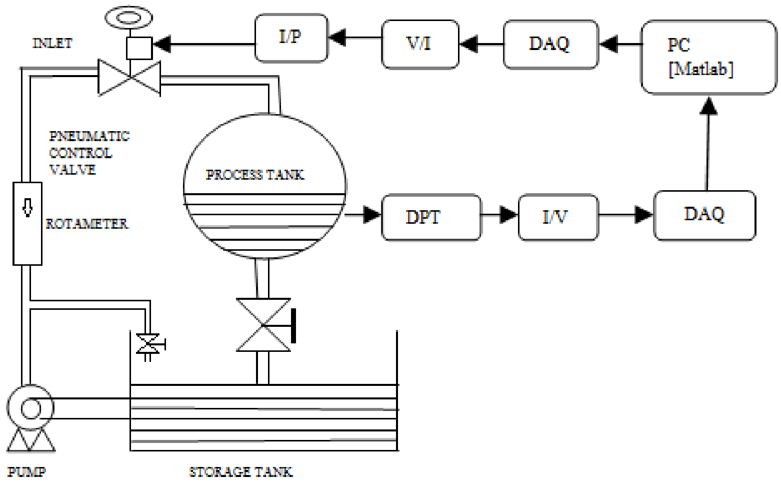

Figure 1 Block diagram of spherical tank setup

Experimental system of the non linear spherical tank is shown in figure 1. It's be made up of a Differential pressure transmitter (DPT), Current to voltage converter (I/V), Data Acquisition (DAQ), An installed Matlab simulink with PC, Voltage to Current converter (V/I), Current to Pressure converter (I/P), Pneumatic valve with actuator and pump. DPT acts as a feedback measurement device to measure the level of tank by difference between low side and high side pressure and it coverts 4-20mA. The converted current is passed to Current to Voltage converter (I/V) to produce a voltage is proportional to applied current. The voltage is interfaced with PC using DAQ to convert process variable to comparator. An error signal progress to take immediate control action based upon gain of controller. The controller output interfaced with computer using DAQ in the form of 0-5 V. The voltage output is converted in terms of current 4-20mA by (V/I) converter and subsequently converted to 3-15psi by (I/P) converter to get manipulated variable to actuate the electro pneumatic positioned control valve to opening and closing. Figure 2 causes to be visible the pressure pipe which is connected from air pressure compressor and level scaling is fixed with the tank to get better results.

Figure 2 Real time spherical tank systems

S.no	Technical description	Features
1	Spherical tank	Height – 50cm
2	DPT	4-20mA
3	I/V converter	0-5V
4	I/P converter	3-15psi
5	Rota meter	44-440 LPH
6	Control valve	3-15psi
7	Pump	2700 rpm

Table 1 Technical description

III. MATHEMATICAL MODELLING

Consider non linear dynamics described by the first order differential equation with dead time depicted by following transfer function [1].

$$\frac{dv}{dt} = Fin(t) - Fout(t) \qquad (1)$$

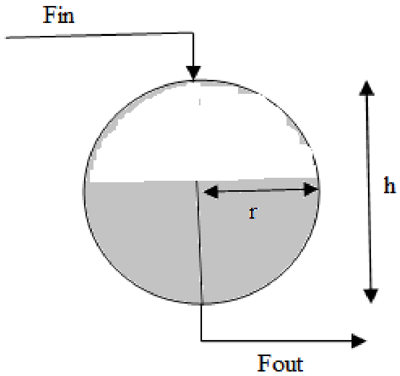

Figure 3 Schematic diagram of spherical tank system

$$V = \frac{4}{3}\pi h^3 \qquad (2)$$

Where
V = Volume of spherical tank
F_{in} = Volumetric flow rate of spherical tank
F_{out} = Volumetric flow rate for outlet flow rate
h = Height of the tank in (cm)
Apply steady state values to system response from the plant and substituting the equations (1) and (2) to bring the process as a linear.

$$\frac{H(S)}{Q(S)} = \frac{Rt}{\tau s+1} \qquad (3)$$

$$Rt = \frac{2hs}{Fout} \text{ And } \tau = 4\pi hs Rt$$

Where
h_s = height of the Tank at steady state
τ = Time constant
Rt = Process gain
Transfer function is obtained by black box modeling method.

IV. CONTROL SCHEMES

Paper [1] identified the transfer function by open loop response and it is controlled by PI controller to adjust the gain parameters like proportional gain (K_p), integral gain (T_i) by Ziegler Nichols tuning at three operating regions using Matlab tool.

Region (cm)	Model parameters		
	Rt	τ(sec)	τd (sec)
0-10	1.0619	76.729	11.99
0-20	2.25	381.704	11.02
25-30	4.037	1382.4	8.98

Table 2 Calculated values of K, τ and τd for different operating regions [1]

Region (cm)	Tuning parameters	
	K_p	T_i
0-10	5.479	0.1214
0-20	11.12	0.3062
25-30	27.227	0.909

Table 3 PI Tuning values for different regions [1]

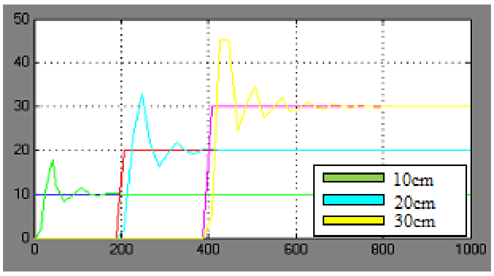

Figure 4 Servo response of PI controller at an operating point of 10, 20 and 30 cm level

Servo response of PI controller results in larger overshoot and slower settling time as shown in figure 4.

Paper [2] a real time implementation of spherical tank system is done by PI controller and Fuzzy logic controller. By comparing two controllers fuzzy logic controller out performs in terms of overshoot, settling time, set point tracking. It also provides less integral square error which is better than digital PI controller.

Region (cm)	Model parameters		
	Rt	τ(sec)	τd (sec)
30	4.5	440	120
45	6	1200	130
65	2.75	1050	150

Table 4 Calculated values of K, τ and τd for different operating regions [2]

Region (cm)	Tuning parameters	
	K_p	T_i
30	0.7330	0.0018
45	1.3846	0.0032
65	2.2900	0.0046

Table 5 PI Tuning values for different regions [2]

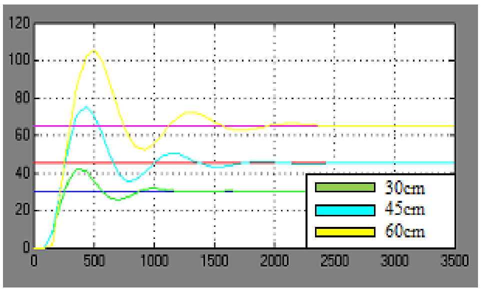

Figure 5 Servo response of PI controller at an operating point of 30, 45 and 65cm level

The operating regions of the tank considered in this work are larger because of the large size of the spherical tank, when comparing to other review papers. It is inferred from figure 5 that the servo response of PI controller presents larger overshoot and slower settling time.

Paper [3] describes the first order plus dead time model is acquired based upon the process reaction curve. Transfer function is identified using open loop response. PI controller parameters are tuned by Ziegler Nichols method and the tuning parameters are K_p=36 and T_i=138. The given transfer function [3] is obtained at 25cm as shown in equation 4.

$$Gp(s) = \frac{0.28e^{-39}}{500s + 1} \qquad (4)$$

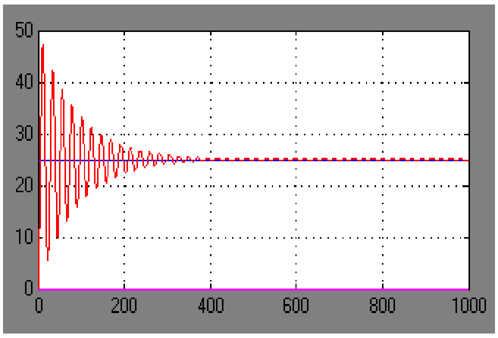

Figure 6 Servo response of PI controller

Servo response of PI controller is simulated by Matlab software results steady state error and oscillatory response as shown in figure 6.

After evaluating the papers real time spherical tank open loop response is obtained for three different operating regions. The technical description and features of tank is shown in Table 1.

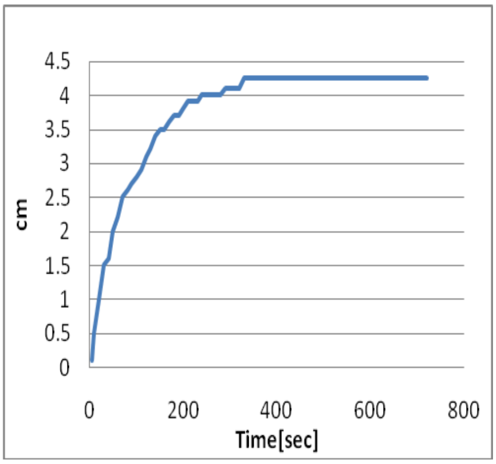

Figure 7 Open loop responses at an operating point 12.5cm

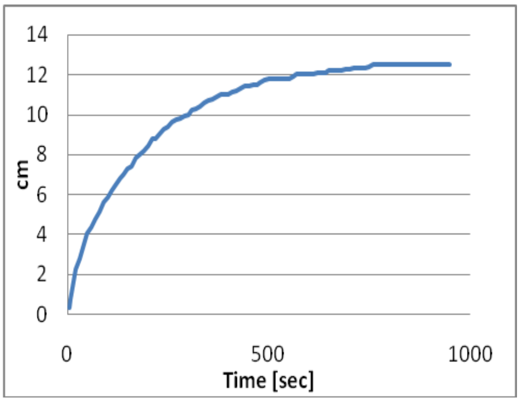

Figure 8 Open loop responses at an operating point 17.5cm

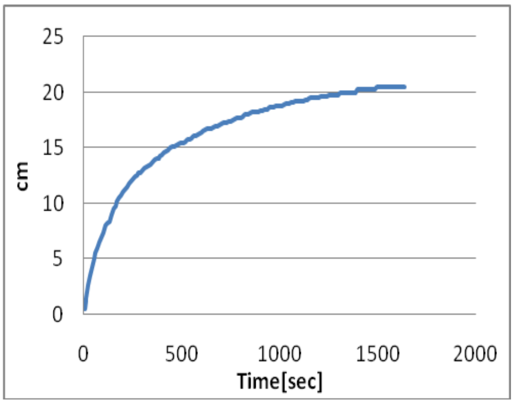

Figure 9 Open loop responses at an operating point 22.5cm

Open loop responses are obtained without any controllers, feedback loop and error detector. Hence height of the tank at steady state level (h_s) is measured for corresponding set point.

Region (cm)	Model parameters		
	Rt	τ(sec)	τd (sec)
12.5	1.627	86.84	0.20
17.5	4.789	751.873	0.15
22.5	7.854	2022	0.10

Table 6 Calculated values of K, τ and τd for different operating regions

As a result process variable (PV) does not reach the set point (SP) as shown in figure 7, 8 and 9. Mathematical modeling is done to convert real time plant into transfer function to analyze the performance in simulation tool. Process gain (Rt), delay time (td) and time constant (τ) calculated shown in Table 6. Delay time calculated by difference between process variable and controller output. PI and PID controllers will enhance to attain the set point based upon the gain of the controller. Gain is adjusted by tuning methods.

4. 1 Cohen Coon tuning

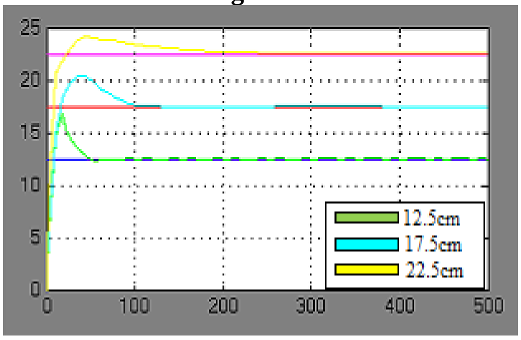

Figure 10 Servo response of PI controller at an operating point of 12.5, 17.5 and 22.5cm level

Region (cm)	Tuning parameters	
	K_p	T_i
12.5	6.602	0.660
17.5	14.70	0.498
22.5	28.681	0.3327

Table 7 PI Tuning values for different regions

Servo response of PI controller attained the set point with large over shoot, steady state error and quick settling time as shown in figure 10. The comparative study of time domain specifications performances of the proposed controllers with that of the methods in the literature and tabulated in Table 10. The simulation model for PI controller is shown in Figure 12 for different operating regions.

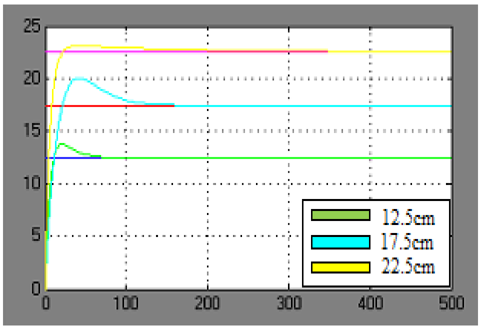

Figure 11 Servo response of PID controller at an operating point of 12.5, 17.5 and 22.5cm level

Region (cm)	Tuning parameters		
	K_p	T_i	T_d
12.5	9.9338	0.499	0.0739
17.5	13.86	0.374	0.0554
22.5	42.97	0.249	0.0369

Table 8 PID Tuning values for different regions

The controller gain like Proportional gain (K_p), Integral time (T_i) and Derivative time (T_d) are calculated by process variable reaction curve are tabulated in Table 8 and fine tuned by Cohen Coon tuning rules. The over shoot of the tank level is reduced and settling time is slower in lower operating regions in 12.5 and 17.5cm by comparing to PI controller as shown in figure 11.

V. CONCLUSION

In this work 3 papers are reviewed and non-linear PI and PID controllers are proposed for spherical tank level process. In reviewed papers controller gain is adjusted by Ziegler Nichols tuning method and in this proposed controller gain is adjusted by Cohen Coon tuning method. The simulated process response is compared with reviewed papers and proposed work in terms of time domain specifications. The proposed PI controller gives better peak time in all regions and PID controller provides desirable overshoot, rise time and settling time for larger operating regions by future prediction of a derivative error. From the simulation results it is concluded that the proposed non-linear PI and PID controllers gives better results than the controllers proposed in reviewed papers.

Specifications	**Paper [1]**			**Paper [2]**			**Paper [3]**	**Proposed work**					
	PI			**PI**			**PI**	**PI**			**PID**		
Set point (cm)	10	20	30	30	45	65	25	12.5	17.5	22.5	12.5	17.5	22.5
Rise time (sec)	5	8	10	60	80	90	1	5	4.95	4	4.90	5.0	2.50
Peak time (Sec)	35	32	18	350	400	500	10	18	40	43	20	40	60
Settling time (sec)	180	190	400	1100	1600	2250	390	50	130	410	60	160	350
%Over shoot	80	40	46	40	62	60	84	30	15.42	7.77	13.6	14.28	4.44

Table 10 Comparative analysis and results of control schemes based upon time domain specifications

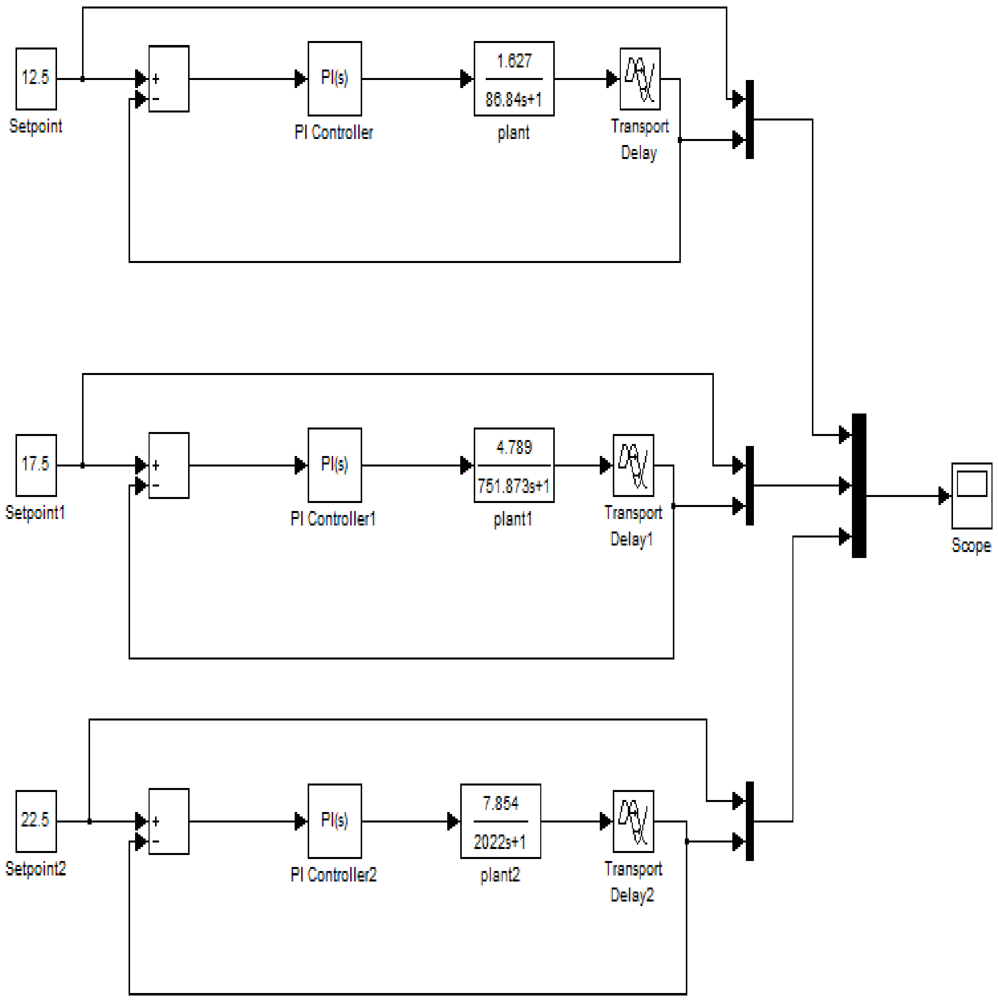

Figure 12 Simulation Model for PI controller

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