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Enhanced Pid Control Strategy: Application To Spherical Tank System

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Abstract: This paper presents control of nonlinear system using Enhanced PID (EPID) controller. Spherical tank system is investigated as nonlinear system. The main aim is to control the liquid level in a spherical tank system for the variations in the area of cross section of tank with change in shape. The performance of the Enhanced PID controller is analysed and compared with conventional control Ziegler-Nichols PID controller (ZN-PID). The performance of the proposed controller is measured in terms of time domain specifications like overshoot, settling time, ISE(Integral Square Error) and IAE(Integral Absolute Error). The simulation results show that the proposed EPID controller provides consistent performance compared to ZN-PID controller.

Keywords—Spherical tank system; EPID controller; ZN-PID controller; settling time; ISE; IAE

I. INTRODUCTION

Most of the chemical industrial plants are nonlinear and come with a great deal of uncertainty. It is difficult to design a controller for nonlinear system. Even though various controllers have been developed to overcome these difficulties, PID controllers are widely used. The reasons for their popularity are simplicity, cost-effective and efficiency [1]. Marjan Golob et al (2003) design the linear PID controller with optimal parameters. The linear pole placement method is used to derive the controller parameters. The implementation of gain scheduling algorithm in the PID structure caused a better performance [2]. Arvanitis et al (2007) propose the tuning rules based on the exact satisfaction of gain and phase margin specifications. The tuning rules are given in the form of iterative algorithms, as well as in the form of accurate analytic approximations [3]. Jinhyunpark et al (1998) propose an enhanced PID controller for unstable processes. They suggested a simple control structure including inner feedback loop and the corresponding tuning relations to manipulate unstable processes more efficiently [4]. The most of the control techniques available are intelligent controllers. Intelligent controllers cannot be implemented easily. Conventional PID controllers are used due to simplicity of tuning rules [5].Aidan O'Dwyer (2006) suggested tuning rules and various tuning structures of PID controller for unstable, stable, integrating and double integrating process [6]. Te well known tuning method of PID controller is Ziegler-Nichols tuning rule [7]. Hajjaji et al (2001) develop the PID controller based on feedback linearization approach. The T_i parameter of PID is chosen in order to compensate a rapid dynamics, whereas the K_p and T_d parameters are determined in order to guarantee to the closed-loop system phase margin [8]. In this paper, new attempt is made to improve the time domain specifications. To prove the effectiveness of the proposed control strategy, spherical tank system is taken as an example. The spherical tank system is widely used in chemical industries because it is very simple to understand as a system and the control techniques that can be studied over many important classical and modern design methods. This paper is organized as follows. Section II shows the modelling of spherical tank system. Development of Enhanced PID controller is presented in Section III. The simulations results, comparative studies and performance measures of ZN-PID and EPID controller for control of liquid level in a spherical tank system are emphasized in Section IV. The conclusion of this paper is given in Section V.

II. MATHEMATICAL MODEL OF SPHERICAL TANK SYSTEM

Fig. 1. shows the nonlinear spherical tank system. The spherical tank system has a maximum height of 0.5meter and the maximum radius of 0.5 meter.

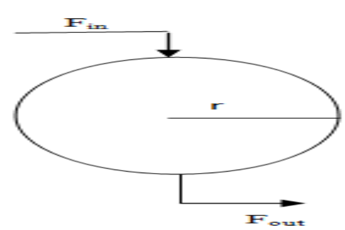

Fig. 1Spherical Tank system

Let, F_{in} (t) - inlet flow rate of the tank in in m^3/sec
F_{out} (t) – outlet flow rate of the tank in m^3/sec
h – height of the tank in m
r – radius of the tank in m (0.05 m)
x_0 – thickness of the pipe in m (0.04 m)
A – area of the tank in m^2
Using law of conservation of mass, the spherical plant equation is obtained as,

$$F_{in}(t) - F_{out}(t) = A(h_1)\frac{dh_1}{dt} \quad (1)$$

Applying the steady state condition values, the transfer function of the spherical tank system is obtained as,[9]

$$\frac{H(s)}{F(s)} = \frac{14.75}{25S + 1} \quad (2)$$

The above plant transfer function is a first order unstable system.

III.ENHANCED PID CONTROLLER

The pre-filter in addition with the PID controller is called as enhanced PID controller and it is shown in Fig. 2.

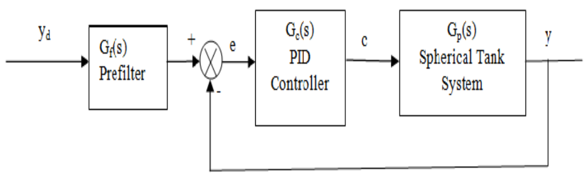

Fig. 2 Enhanced PID (EPID) controller

In the proposed EPID control structure shown in Fig. 2. , $G_p(s)$ is the plant model and $G_c(s)$ is the conventional PID controller tuned by Zigler-Nichols tuning method. Y is the actual output of the system and y_d is the desired output. To overcome the disturbance in stability condition at high frequencies the prefilter is used. The prefilter can be defined by a model $G_f(s) = \frac{a}{s+a}$.

G_f (s) is a first order low pass filter with cut off frequency a rad/sec. cut off frequency 'a' is computed as 0.9 rad/sec based on the bode response of the spherical tank system.

IV.SIMULATION RESULTS

To analyse the performance of the Enhanced PID (EPID) controller simulations are carried out in MATLAB. To illustrate the performance enhancement, the proposed EPID controller is compared with conventional ZN-PID controller. The performance is measured in terms of time domain specifications like overshoot, settling time, ISE and IAE.

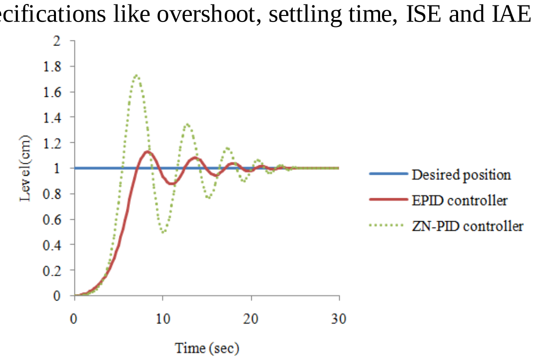

Fig. 3 Performance of EPID and ZN-PID Controller at the operating point of 1 cm

From the Fig. 3. , it is clear that, the EPID controller is forced to follow the set point with minimum settling time and less overshoot. The performance measures are tabulated in Table 1 for the operating point of 1 cm.

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Table 1

Result of process with EPID and ZN-PID controllers at the operating of 1 cm

Controller	Settling time	Overshoot	ISE	IAE
EPID	23 sec	10%	21.75	23.86
ZN-PID	25 sec	70%	17.86	32.71

The ensure the robustness of the EPID controller, the same analysis are carried out with different operating points such as 2 cm, 2.5 cm, 3.5 cm and 3 cm. Closed loop response of the system at different set points are shown in Fig. 4. The set point tracking responses show that EPID controller provide the robust response compared to ZN-PID controller.

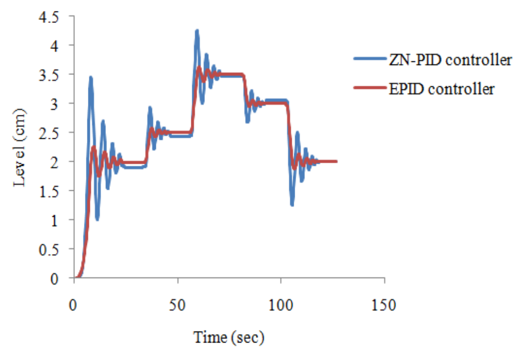

Fig. 4 Set point tracking of the System With Controller

Closed loop response of the spherical tank system with EPID controller for the set point tracking of $\pm$ 5% and $\pm$ 1.0% at the operating point of 2 cm are shown in Fig. 5. and the performance measures are reported in Table 2. The developed controller provides fair simulation results for different operating points.

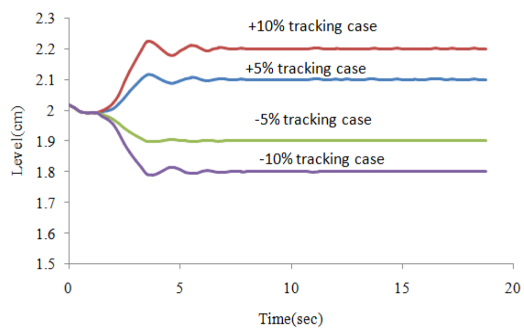

Fig. 5 servo response of the system with EPID controller at the operating point of 2 cm

Table 2

Performance measures

Region	ISE	IAE
2+5%	0.105	1.208
2+10%	0.395	2.317
2-5%	0.084	1.012
2-10%	0.354	2.122

The stability of the spherical tank system with EPID controller is analysed using Nyquist stability criterion. The Nyquist plot of the system is shown in Fig. 6. From the figure, the system is stable for the frequencies less than 1.36 rad/sec.

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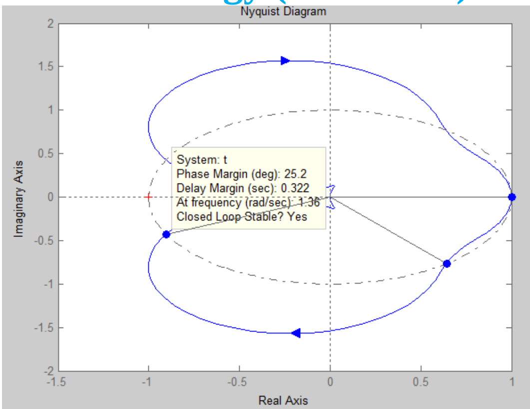

Fig. 6 Nyquist plot of spherical tank system

V. CONCLUSION

In this paper, enhanced PID controller is designed for nonlinear spherical tank system. A simulation study is carried out to test the performance of enhanced PID controller. The setpoint tracking has been done to test the performance of the controller and the controller performs successfully for the desired setpoint tracking. Comparison with the ZN-PID controller gives the effectiveness of enhanced PID controller for nonlinear system. Simulation results shows that enhanced PID controller is superior than ZN-PID controller. The stability of the system is analysed using Nyquist plot.

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