FUZZY GAIN SCHEDULED PI CONTROLLER FOR A TWO TANK INTERACTING CONICAL TANK SYSTEM

J.Merlin(1), Dr.K.Prabhu(2)

(1) *M.E Control and Instrumentation, Kongu Engineering College, Erode.*

(2) *Associate Professor, Department of EIE, Kongu Engineering College, Erode.*

Abstract—*This Paper presents the mathematical modeling of two tank conical interacting system is designed. The transfer function of TTICTS parameters and Proportional Integral (PI) controller parameters are obtained for implementing Gain Scheduled Adaptive Controller (GSAC) for TTICTS. The Ziegler-Nichols method is used to obtain the optimal PI control settings. Then the tuning is done by using GSAC. The step response is obtained for both conventional PI&GSAC method. The response of GSAC shows less overshoot and quick settling time.*

Keywords—Nonlinear process, Adaptive control, Gain scheduled Adaptive control, Ziegler-Nichols method, Two Tank Conical Interacting System.

1. INTRODUTION

The control of fluid level in tanks and stream between the tanks is a fundamental issue in process ventures. The procedure require the fluids to be pumped, put away in tanks and the pumped to another tank. Ordinarily the fluid will be prepared by synthetic or blending treatment in the tanks, yet dependably the level of the liquid in the tanks must be controlled. The level is too high which may upset the reaction equilibria and cause damage to the equipment, or result in spillage of hazardous material. If the level is too low, it may have bad consequences for the sequential operations. Hence, control of liquid level is very important and common task in process industries.

Conical tank finds wide application in process industries like waste water treatment industries, sewage water treatment industries, concrete mixing industries, food processing industries and hydrometallurgical industries due to their shape leads to better drainage of solid mixtures, slurries and viscous liquid at the bottom of the tank. The control of the cone shaped tank exhibits a testing issue because of its non-linearity and always showing signs of change cross sectional territory through and through of the tank.

Conventional PID Controllers are widely used in industries since they are simple, robust & familiar to the field Operator. Practical systems are not precisely linear but may be as represented as linearized models around a nominal operating point. The controller Parameters are tuned at that point does not reflect the real time system characteristics due to variation in process parameters. The solution is controller parameters have to be done adjusted. Many researchers have done work on the conical tank process and adaptive control.

Anandanatarajan et al. [1] have proposed the performance of PI controller at various operating regions in the conical tank. Bing Chen et al. [2] design of a nonlinear system has proposed the adaptive fuzzy control for a class of nonlinear systems with nonstrict-feedback structure by using fuzzy logic systems.

Jaya et al. [3] proposed the need of a new fuzzy gain scheduled PI controller for a two tank conical tank interacting process. It is then followed by the development of a fuzzy gain scheduling scheme by PI controller for the process. Marshina et al. [4] proposed the controller. Mohini Narendra Naik et al [5] have proposed the adaptive fuzzy control for a class of nonlinear systems with non-strict-feedback structure by using fuzzy logic systems.

Nagamani et al. [6] proposed a method for the new fuzzy gain scheduled PI controller (FGSPI controller) for a two tank conical interacting level system. It is then followed by the development of a fuzzy gain scheduling scheme by PI controller for the process. Fuzzy gain scheduling scheme by PI controller for the process. Fuzzy rules and reasoning are utilized to tune the PI controller parameters. Although several methods have been developed, in most of them, either some assumption is made or the nonlinear characteristics are linearised and then controller is designed.

The paper is organized as follows: In section II, the process and hardware set-up are described. In section III, simulation studies and implementation of conventional controllers are discussed. In section IV, adaptive control through Gain Scheduling method is discussed. Finally results and conclusions are discussed in section V.

2 PROCESS DESCRIPTIONS:

The TICTS is a benchmark problem due to its non-linearity property. TICTS consist of two identical conical tanks(TANK1 and TANK2) , two independent pumps that deliver the liquid flows F_{IN1} and F_{IN2} to TANK1 and TANK2 through the two control valves CV_1 and CV_2 respectively. These two tanks are interconnected at 31 cm of the tanks through manual control valves MV_{12}. MV_1 and MV_2 with valve coefficients β_1 and β_2 are the outlet valves for Tank1 and Tank2 respectively.

Fig 1 Experimental set up of TTICTS

TABLE -1: Operating Parameters of TTICTS

Parameter	Description	Value
R	Top radius of the conical tank	17.35 cm
H	Maximum height of TANK1 & TANK 2	60 cm
F_{IN1} & F_{IN2}	Maximum Inflow to TANK1 & TANK 2	129cm³/s
β_1	Valve co-efficient of MV_1	35cm³/s
β_2	Valve co-efficient of MV_2	78.2cm²/s
β_{12}	Valve co-efficient of MV_{12}	19.69cm²/s

2.1 Representation of model

A model is a mathematical representation of a system. Two Tanks conical interacting system is considered as measured variable and F_{IN1} are considered as manipulated variables. The mathematical model of two tank conical interacting system is given by the equations.

$$\frac{dh_1}{dt} = \frac{F_{IN1} - \beta_1\sqrt{h_1} - sign(h_1 - h_2)\beta_{12}\sqrt{|h_1 - h_2|}}{\pi \frac{R^2 h_1^2}{H^2}}$$

$$\frac{dh_2}{dt} = \frac{F_{IN2} - \beta_2\sqrt{h_2} + sign(h_1 - h_2)\beta_{12}\sqrt{|h_1 - h_2}}{\pi \frac{R^2 h_2^2}{H^2}}$$

Where

F_{IN1} =Inflow rate of the TANK1 (cm^3/s)
F_{IN2} =Inflow rate of the TANK2 (cm^3/s)
h_1 =Liquid height in TANK1 (cm)
h_2 =Liquid height in TANK2 (cm)
R =Top radius of the tank (cm)
H =Total height of the tank (cm)
β_1 =Valve co-efficient of MV_1 (cm^2/s)
β_2 =Valve co-efficient of MV_2 (cm^2/s)
β_{12} =Valve coefficient of MV_{12} (cm^2/s)

3 CONVENTIONAL PI CONTROL

Conventional PI Controllers are widely used in industries and simple easy to understand the process initialization or operation. PI controllers are designed for linear system around six operating regions.

For each linearized region controller parameters are optimally tuned using Ziegler Nichols method. The process variable going through different operating region the respective controller parameters table shows different linearized region and controller parameters of TTICTS using Z-N method.

TABLE II Different Linearised Regions and Controller Parameters for TTICTS

Operating region	Flow rate (LPH)	Height (h_2)cm	Kp	K_i
Region 1	0-150	10	70.08	0.13
Region 2	150-250	20	80.4	0.11
Region 3	250-320	30	40.5	0.7
Region 4	320-390	35	150	0.14

The process variable is going through different operating region the respective controller parameters table II shows the different linearised regions and Controller Parameters for TTICTS.

4 GAIN SCHEDULING ALGORITHM

Gain scheduling is an approach to control of non linear system that uses a family of linear controller each of which provides satisfactory control for a different operating point of the system. It is a technique to increase the region of attraction to a range of possible operating points. One of the most popular adaptive control technique is gain scheduling technique. It facilities process control, the gain and time constants vary with the current value of the process variable.

4.1 Principle

This method consists of two loops. Inner loop composed of the process and the PI controller. Outer loop that adjusts the controller parameters based on the operating conditions.

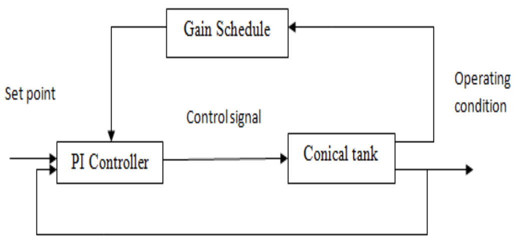

Fig- 3: Block diagram of GSAC for TTICTS

Gain scheduling can be regarded as mapping from process parameters controller parameters. The scheduling variable used in the process is area of TANK1 A (h_1).The scheduling variable has been determined at each operating condition, the controller parameters are calculated at each operating conditions by using some suitable set of equations. It relates process parameters and controller parameters. The controller is thus tuned for each operating condition.

4.2 Transfer function of TTCIS

The model of TANK1 can be represented as,

Rate of Accumulation=Inflow Rate- Outflow Rate.

$$\frac{dv}{dt} = F_{in} - F_{out}$$

Where,

$$V = \frac{\Pi}{3} r^2 h.$$

Since the ratio, $\frac{r}{h} = \frac{R}{H}$

Substitute equation we get,

$$V = \frac{\Pi}{3} \frac{R^2}{H^2} h^3$$

Diff.volume, we get,

$$\frac{dv}{dt} = \Pi \frac{R^2}{H^2} h^2 \frac{dh}{dt} = A \frac{dh}{dt}$$

For tank 1,

$$A_1 \frac{dh_1}{dt} = F_{in} - F_{min}$$

For tank 2,

$$A_1 \frac{dh_1}{dt} = F_{mid} - F_{out}$$

Equation is rewritten as,

$$\frac{dh_1}{dt} = \frac{F_{in} - \beta_1 \sqrt{(h_2 - h_1)}}{A_1}$$

Where,

$$A_1 = \Pi \frac{R^2}{H^2} h_1^2$$

$$A_2 = \Pi \frac{R^2}{H^2} h_2^2 \quad \partial h_1 = \frac{\partial h_1 + \frac{\beta_1 \partial h_1}{2\sqrt{h_{10} - h_{20}}}}{A(h_1)s + \frac{\beta_1 \partial h_1}{2\sqrt{h_{10} - h_{20}}}}$$

Let us assume,

$$C_1 = \frac{1}{2\sqrt{h_{10} - h_{20}}}, C_2 = \frac{1}{2\sqrt{h_{20}}}$$

$$R_1 = \frac{1}{\beta_1 C_1}, \quad R_2 = \frac{1}{\beta_2 C_2}$$

$$\tau_1 = A(h_1)R_1, \quad \tau_2 = A(h_2)R_2$$

Finally, the transfer function of Two Tank Conical Interacting System is given by,

$$\frac{\partial h_2}{\partial F_{IN1}} = \frac{R_2}{\tau_1 \tau_2 s^2 + [\tau_1 \tau_2 + A(h_1)R_2]s + 1}$$

4.3 RELATION BETWEEN TWO TANK CONICAL INTERACTING SYSTEM PARAMETERS AND PI PARAMETERS

The closed loop transfer function of unity feedback two tank conical interacting system with PI controller is derived as,

$$\frac{C(s)}{R(s)} = \frac{K_p R_2 [1 + \tau_i s]}{\tau_i \tau_1 \tau_2 s^3 + \tau_i (\tau_1 + \tau_2 + A(h_1) R_2) s^2 + (1 + k_p R_2) \tau_i s + k_p R_2}$$

The characteristics equation of above transfer function is,

$$\tau_i \tau_1 \tau_2 s^3 + \tau_i (\tau_1 + \tau_2 + A(h_1) R_2) s^2 + (1 + k_p R_2) \tau_i s + K_p R_2 = 0$$

The controller parameter can be written as,

$$K_p = \frac{A(h_1)(\tau_1 + \tau_2)}{\tau_1 \tau_2}$$

$$\tau_i = \tau_1 + \tau_2$$

From this,

$$K_i = \frac{1}{\tau_i}$$

The equations provide the relationship between two tank conical interacting system parameters and PI controller parameters. And the equations are used to implement Gain scheduling Adaptive Controller for TTICTS.

TABLE III Tuned Parameters of Gain Scheduled Algorithm.

Operating region	Flow rate (LPH)	Height (h_2)cm	Kp	K_i
Region 1	0-150	10	26.12	0.129
Region 2	150-250	20	397.9	0.72
Region 3	250-320	30	128.4	0.018
Region 4	320-390	35	724.0	0.44

In TTICTS the scheduling variable A (h_1) was calculated from the measurement of each of h_1.Using this A (h_1) the table III shows the tuned parameters of gain scheduled algorithm.

5 RESULTS AND DISCUSSION

The controller responses of conventional PI controller in operating region of two tank interacting conical tank system are simulated.

For operating region1 of the set point=10cm

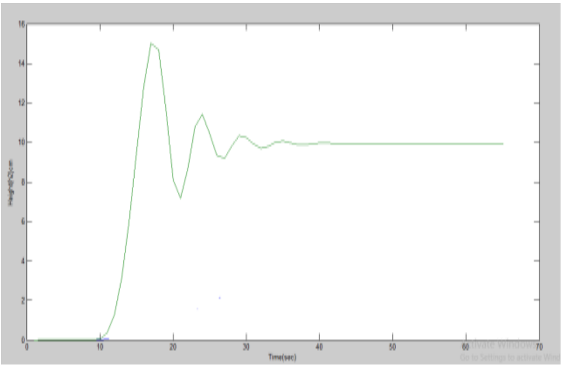

Fig -3: Response of Two Tank Interacting Conical Tank System for PI Controller

From the Fig 3 it can be seen that if set point is given as 10cm for two tank interacting conical tank system with PI Controller, the Settling time(sec)=28.5,Rise time(sec)=5.76,Overshoot(%)=6.5%.

The controller responses of gain scheduled PI controller in operating region of TTICTS are simulated.

For the operating region 1 of the set point=10cm,

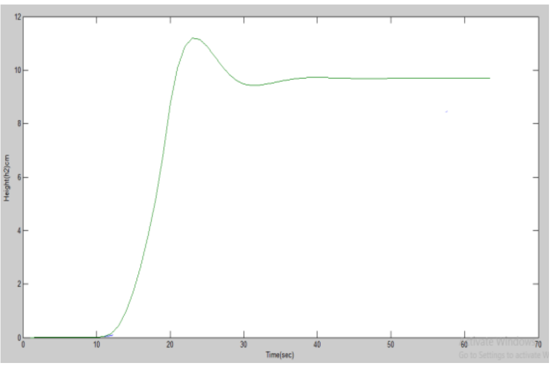

Fig- 4: Response of two tank conical interacting system with Gain scheduled PI Controller

From the Fig 4 it can be seen that if set point is given as 10 cm for two tank interacting conical tank system with Gain scheduled PI Controller, the Settling time (sec)=3.65,Risetime(sec)=4.43,Overshot(%)=5.5%

5.1 OBSERVATION:

Table IV shows comparison results for PI controller and Gain scheduled PI controller

Operating region	PI controller	Gain scheduled PI controller
1(set point= 10cm)	Rise time(sec)=5.76 Settling time(sec)=28.5 Overshoot(%)=6.5	Rise time(sec)=4.43 Settling time(sec)=3.65 Overshoot(%)=5.5
2(set point= 20cm)	Rise time(sec)=9.75 Settling time(sec)=30.2 Overshoot(%)=11.6	Rise time(sec)=7.61 Settling time(sec)=24.2 Overshoot(%)=9.54
3(set point= 30cm)	Rise time(sec)=5.76 Settling time(sec)=10.75 Overshoot(%)=11.2	Rise time(sec)=3.54 Settling time(sec)=7.54 Overshoot(%)=8.46
4(setpoint=35 cm)	Rise time(sec)=6.79 Settling time(sec)=30.2 Overshoot(%)=8.5	Rise time(sec)=0.41 Settling time(sec)=2.05 Overshoot(%)=5.95

The table IV shows the settling time was very much reduced when compared with conventional PI control scheme. In case of Gain scheduling adaptive algorithm, the response for the process parameter variation fast without any steady state error. This was achieved, in Gain scheduling adaptive algorithm by measuring h1 and required set point thereby updating controller parameter. This leads to better transients and steady state response.

6 CONCLUSION

The conventional PI controller and gain scheduled PI controller for every operating region is designed and applied to two tank conical interacting tank system. But under situations where the process parameters vary the conventional controllers does not provide satisfactory results. By proper PI controller tuning of gain scheduled PI controller provides the better results for every operating region. The future work can be extended to tune the controller parameters. It is based on switching conditions plant operating conditions selected the controller gain values. In order to improve the transient response with less overshoot and quick settling time, the Fuzzy based gain scheduled PI controller is used .

REFRENCES

[1]Anandanatarajan.R, "Limitations of a PI controller for a first order Non-linear process with dead time", ISA transcations,pp185-199,April 2014.

[2]Bing Chen,Xiaoping P.Liu,Shuzhi Sam Ge and Chong Lin, "Adaptive Fuzzy Control of a Class of Nonlinear systems by Fuzzy Approximation Approach", Institute of Electrical&

Electronic Engineers (IEEE Transcations). Vol:20, No.6,pp. 1012-1021,Dec-2012.

[3] Jaya.D, "Fuzzy gain scheduled PI controller for a Two Tank Conical Interacting Level System" International Journal of Engineering and Technology (IJET), Vol:6,No. 6, Jan 2015.

[4]Marshiana.D & Thirusakthimurugan.p, "Design of Zieger Nichols Tuning Controller for a Non-linear system", International Conference on Computing and Control Engineering (ICCCE 2012),12&13 April,2012.

[5]Mohini Narendra & Nicole Monterio,"Design and simulation of gain scheduled Adaptive Controller using PI Controller for Conical Tank process", International Journal for Innovative Research in Science & Technology(IJIRST) Vol:2,Issue 04 | September 2015.

[6]Nagamani G.,Swathi Lakshmi &Mahalakshmi, "Design of Fuzzy gain scheduled PI controller for a Nonlinear SISO Process", International Conference Engineering and Technology(ICET),Jan 2015.

[7]RaviV.R, & Thayagarajan.T,"Adaptive decentralized PI controller for two conical tank interacting level system", Journal for Science and Engineering,vol:39,Issue12,pp 8433-8451,Dec-2014.

[8]Ravi.V.R & Thayagarajan.T," Application of adaptive controller technique to Interacting Non-Linear system", Institute of Electrical & Electronics Engineers (IEEE),vol:45,No:28,2011.

[9]RaviV.R & Thayagarajan.T,"A Decentralized PID controller for Interacting Non-Linear systems', Emerging Trends in Electrical and Computer Technology (ICETECT)", International Conference, pp.297-301,2011.

[10]Sowmya.P & Srivignesh.N,"A Fuzzy Control Scheme for Nonlinear process", International Conference On Advanced Engineering Science and Management (ICAESMT), May 2012.

[11]Sukanya R, & Sivanandam Venkatesh, "Design of Controllers based on MPC for a Conical Tank System", International Conference On Advanced Engineering Science and Management (ICAESMT),June 2015.

[12]Warier & Sivanandam Venkatesh,"Design of controllers based on MPC for a conical Tank System", International Conference on Advances In Engineering, Science and Management (ICAESM),2012.

[13]Yue Fu & Tianyou Chai,"Self-Tuning Control With a Filter and a Neural Compensator for a Class of Nonlinear Systems", Institute of Electrical& Electronics Engineers(IEEE Transactions),Vol:24,No:5,pp.837-843,May 2013.

[14]Yajun Zhang & Tianyou Chai,"Self-Tuning Control With a Filter and a Neural Compensator for a Class of Nonlinear system",Institute of Electrical & Electronics Engineers (IEEE Transcations),Vol-18,No:6,pp.1070-1082,June 2010.

[15]Zhang Huaguang and Lilong Cai,"Nonlinear Adaptive Control using the Integral and its application to CSTR Systems", Institute of Electrical & Electronics Engineers (IEEE Transcations),Vol-32,No:3,pp.367-372,June 2014.