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Design of Intelligent Controllers for the Spherical Storage Vessels

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Abstract: **Non linear process control is a difficult task in process industries. Control of liquid level in a spherical tank is one among them. It is highly non linear due to variation in the area of cross section of level system with change in shape. This paper investigates the design of** PI **controller and Self Tuning Fuzzy PI Controller for a spherical tank system. The servo and regulatory responses of the controllers were obtained. The simulation results are obtained using MATLAB. From the simulation it is clear that Self tuning fuzzy PI based controller perform well in terms of peak over shoot, settling time, rise time compared to other conventional controllers.**

Keywords**: Process modeling, PI controller, Fuzzy Logic Controller, Sel tuning fuzzy PI controller.**

I. INTRODUCTION

Chemical process presents many challenging control problems due to their non linear dynamic behavior. Because of the inherent non linearity, most of the chemical process industries are in need of traditional control techniques. PI is regarded as the standard control structures of the classical control theory and fuzzy controllers have positioned themselves as counter part of classical PI controllers. PI controllers are designed for linear systems and they provide preferable cost/benefit ratio. However, the presence of non linear effects limits their performance. Fuzzy controllers are successful applied to non linear systems. Unlike conventional control, designing a FLC does not require precise knowledge of the system model. Spherical tanks are used in many process industries as storage of cryogenic liquids, fuels and other liquids and find wide application in gas plants. Control of a level in a spherical tank is important, because the change in shape gives rise to non linearity.

K Harikrishna [1] modeling of spherical tank and the non linearity of the spherical tank is analyzed. Dinesh kumar [2] has shown that the performance of the manual tuning PID is better than that of manual PI controller.

D Pradeep kannan [3] showed that improved performance of GAPID controller than conventional PID controller to control the liquid performance of spherical tank system. Servet soyguder et.al [4] has shown that performance of the self tuning PID type fuzzy adaptive controller is best among others in terms of both steady state error and settling time. R. Anandanatarajan [5] brought limitations of PI controller for conical tank process. K.K.Tan [6] design closed loop automatic tuning of PID controller for non linear systems shows simulation study of spherical tank system. S.Nithya et.al [7-8] design a model based controller for spherical tank process. P.Madhavasarma [9] showed that improved performance of IMCPID controller than conventional PID controller. S.Ramesh [10] has shown that performance of FMRLC provides a superior tracking performance than NNIMC and conventional PI mode.

In this paper, through simulation in Matlab by selecting appropriate fuzzy rules are designed to tune the parameters k_p *and* k_i of the PI controller. In this study, we propose two controllers conventional PI and Self Tuning Fuzzy PI controller for a liquid level process and analysis the result. We find the improvement in system performance over the conventional PI controller by the influence of the external disturbance. This paper is organized as follows: section II presents the System Discription. In section III and IV, the description of the PI Controller and Self Tuning Fuzzy PI controller is contained. Finally, section V presents the simulation results followed by the conclusion and the references.

II. SYSTEM DISCRIPTION

The spherical type of storage vessel is shown as in Fig.1 is preferred for storage of high pressure fluids. A sphere is very strong structure. The even distribution of stresses on the sphere surfaces, both internally and externally, generally means that there are no weak points. Spherical storage vessels have a smaller surface area per unit volume than any other shape of vessel. This means that the quantity of heat transferred from warmer surroundings to the liquid in the sphere, will be less than that for cylindrical or rectangular storage vessels.Consider a spherical tank as shown in Fig.1 of radius r. The water flows in a rate of F_{in} & flows out at a rate of F_{out}. Volume of sphere is given by,

$$V = \frac{4}{3}\pi h^3$$

The first order differential equation of the system is given by,

F_i– flow rate at inlet of the tank

F_O– flow rate at outlet of the tank

h– height of the liquid in tank

R –resistance of flow

$$F_o = \frac{h}{R}$$

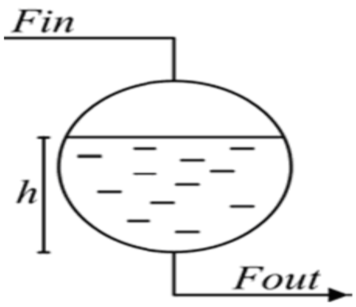

Fig.1. Spherical tank level process

A–cross sectional area of tank

$$A\frac{dh}{dt} = F_i - F_O = F_i - \frac{h}{R}$$

$$AR\,\frac{dh}{dt} + h = RF_i \qquad (1)$$

At steady state,

$$h_s = RF_{i,s} \qquad (2)$$

In terms of deviation variables from (1) &(2)

$$AR\frac{dh'}{dt} + h' = RF_i{}' \qquad (3)$$

Where

$$h' = h - h_s$$

$$F_i{}' = F_i - F_{i,s}$$

τ_p =AR = time constant of the process

K_p= R = steady state gain of the process

Transfer function is

$$G(s) = \frac{h(s)'}{F_i'(s)} = \frac{K_P}{\tau_P s+1} \qquad (4)$$

$$G(s) = \frac{H(s)}{Q(s)} = \frac{R_t}{\tau s+1} \qquad (5)$$

$$R_t = \frac{2h_s}{F_o}$$

Where

h_s = Height of the tank at steady state

$\tau = 4\pi h_s R_t$

Time constant = storage capacity x resistance to flow.

Applying the steady state condition values, the linearized plant transfer function is given by,

$$\frac{y(s)}{u(s)} = \frac{.59}{s+.004}$$

III. PI CONTROLLER

In process industries, PI controller is used to improve both the steady state as well as the transient response of a process plant. In a closed loop control system, the controller continuously adjusts the final control element until the difference between reference input and process output is zero.

After identifying the transfer function model the PI controller has designed for a spherical tank system to maintain the level at desired set point. Fig.2 shows the structure of the corresponding PI controller. Use Zeigel Nichols open loop tuning method to obtain the gain parameter of the system. Obtained gain parameter is as K_p= 1and K_i= 1

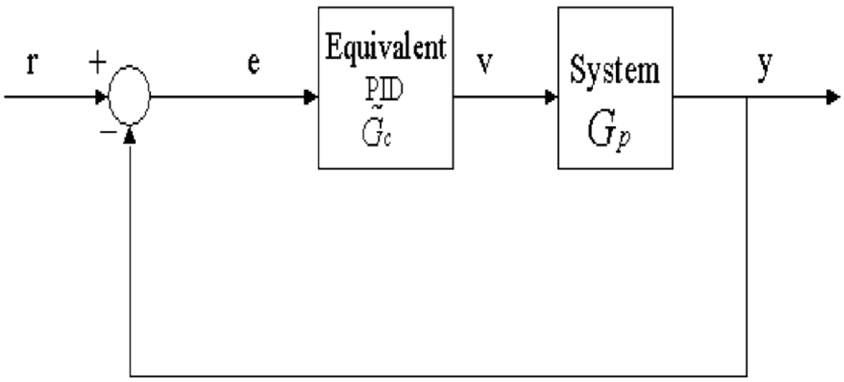

Fig. 2: PI controller

IV. SELF TUNING FUZZY LOGIC CONTROLLER

The performance specifications of the systems such as rise time, overshoot, settling time and error steady state can be improved by tuning parameters k_p and k_i of the PI controller. By developing self tuning fuzzy controllers, these parameters can be modified online, according to the changes in the process condition without much intervention of an operator.

Lotfi Zadeh, the father of fuzzy logic is extend two valued logic, defined by the binary pair {0,1}, to the whole continuous interval [0, 1]. Fuzzy controllers use heuristic information in developing design the control of nonlinear dynamic system. A fuzzy control system is shown in Fig. 3. FLS is consist fuzzifier, rules, inference engine and output processor (defuzzifier) and that are interconnected. The fuzzifier converts the crisp value into Fuzzy Sets. It is needed to activate rules that are in terms of linguistic variables. The rules are the heart of an FLS. The rules are expressed as a collection of IF-THEN statements. The IF-part of a rule represents antecedent and the THEN part represents consequent. The fuzzified inputs activate the inference engine and the rule base to produce a Fuzzy Set output. The commonly used inferential procedure is minimum and maximum implication method. Defuzzification is necessary to obtain the crisp number as the output.

Here we used self tuning fuzzy PI and PI controller, that is, the three parameters such as proportional gain (k_p) and integral gain (k_i) of controllers are tuned by using fuzzy tuner. The co-efficient of the classical controllers cannot be properly tuned for the non spherical type of storage vessel with unpredictable parameter variation, hence tune automatically the controller parameters such as k_p and k_i values by using self tuning fuzzy PI controller. The structure of the self tuning fuzzy PI controller is shown in Fig. 4.

The proposed controller structures consist of a simple upper level controller and a lower level classical controller. The upper level controller provides a mechanism to select the gain of a classical PI and the lower level deliver the solution to a particular situation. Here we use the control structure as a rule based Mamdani fuzzy controller. It is used in the upper level and conventional PI controller is selected for the lower level.

In fuzzy structure, there are two inputs to fuzzy inference: error $e(t)$ and change of error $de(t)$ and three outputs for each PI controller parameters respectively k_p and k_i. The steps for designing aimed controller for the spherical type of storage vessel are as follows:

a) Select the input and output parameters for the fuzzy controller. Here we choose the error signal and the change of error signal as the input parameters and output parameters for the fuzzy controller as the proportional and the integral gain.

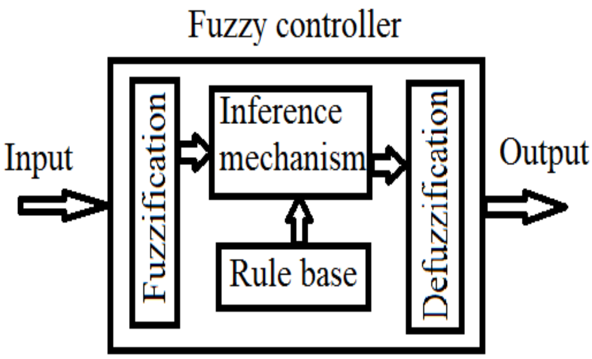

Fig. 3: A fuzzy control system

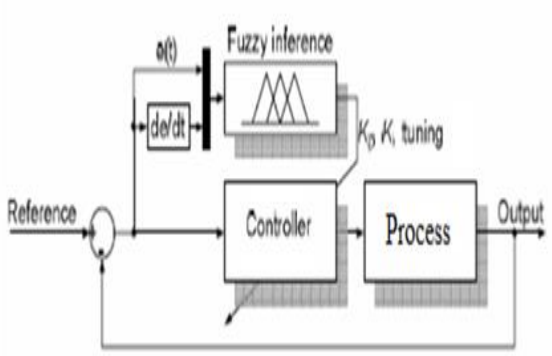

Fig. 4: The structure of the self tuning fuzzy PI controller

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b) Then divide the universe of discourse into FSs. Fig. 5 and 6 show the input membership functions for the error signal and change of error signal respectively. Here the universe of discourse is divided as Negative Large (NL), Negative Small (NS), Zero (Z), Positive Small (PS) and Positive Large (PL). Fig. 7 to 8 shows the output membership function for the proportional and the integral gains, whereas the universe of discourses is divided as Medium (M), Big (B) and Very Big (VB).

c) Write the rule base for the Self Tuning Fuzzy PI controller, based on experience and it is described in the below given Table 1 & 2 correspondingly.

d) Use the algorithm of the amied controller : Centroid defuzzification is the best technique to obtain the crisp output.

The degree of each membership function which was computed in the previous step of fuzzifications encountered by the subprogram called defuzzify and this after certain process it returns defuzzified output.

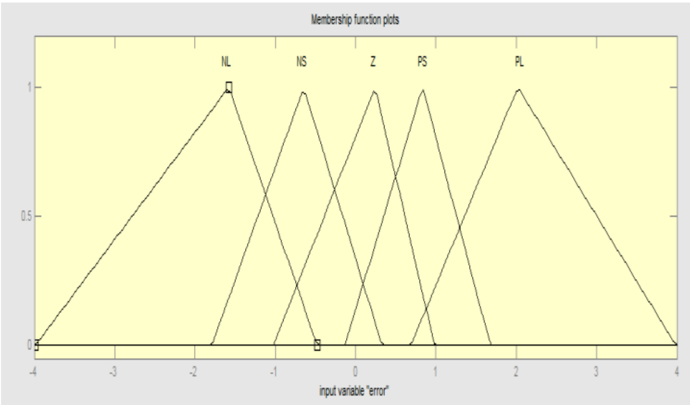

Fig. 5: Membership functions for the error signal

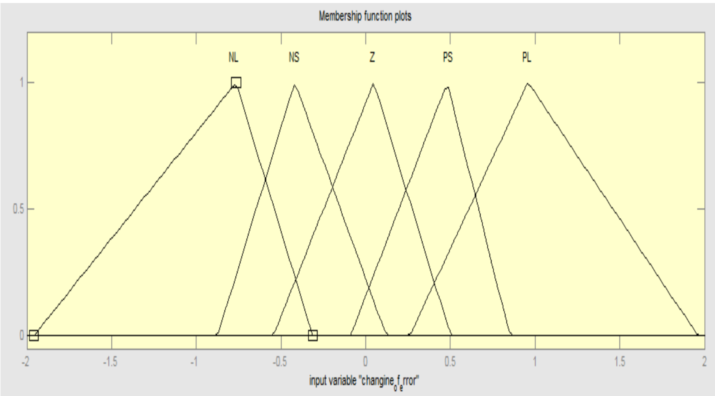

Fig. 6: Membership functions for the change of error signal

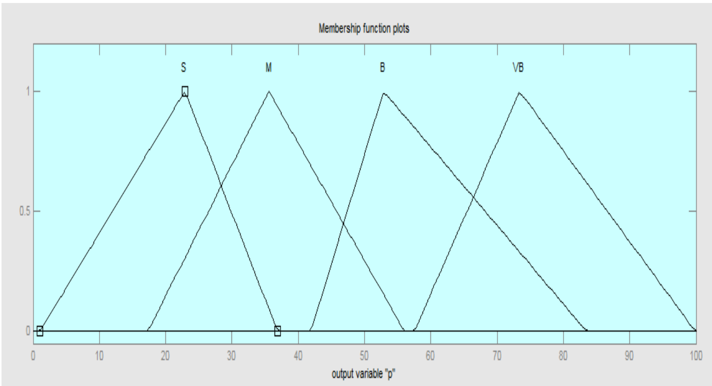

Fig. 7: Membership functions for the proportional gain

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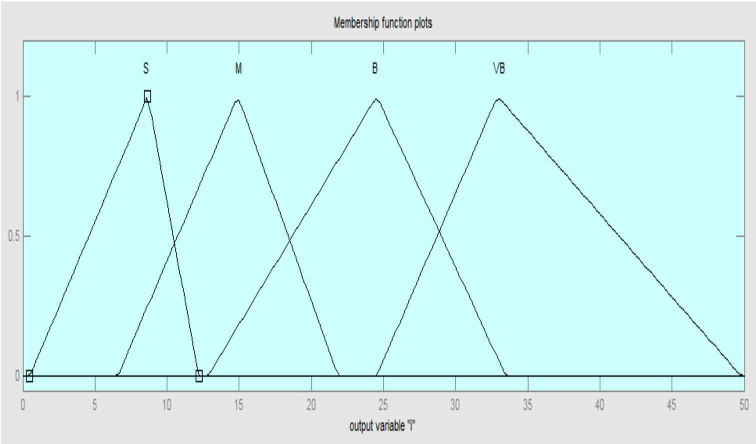

Fig. 8: Membership functions for the integral gain

TABLE 1: RULE BASE FOR THE PROPORTIONAL GAIN

e / Δe	NL	NS	Z	PS	PL
NL	M	S	S	S	M
NS	B	M	S	M	B
Z	VB	B	M	B	VB
PS	B	M	S	M	B
PL	M	S	S	S	M

TABLE 2: RULE BASE FOR THE INTEGRAL GAIN

e / Δe	NL	NS	Z	PS	PL
NL	B	M	S	M	B
NS	B	M	M	M	B
Z	VB	B	M	B	VB
PS	B	M	M	M	B
PL	B	M	S	M	B

V. RESULT AND DISCUSSION

The Self tuning fuzzy logic controller is designed and applied to the spherical tank system. The performance of the Self tuning fuzzy controller is compared with conventional PI controller using MATLAB/Simulink responses. The servo and regulatory responses of PI controller and Self tuning fuzzy PI controller are shown in Fig.9 and 10. It is observed that the level oscillates very much high for PI and whereas oscillation is very much less in Self tuning fuzzy PI controller. Also it is observed that in Self tuning fuzzy PI controller tracks the set point in less time compared to PI controller. Self tuning Fuzzy PI controller follows smooth tracking towards the given set point. The performances of controllers are also examined using ISE, IAE and ITAE and their values for Self tuning fuzzy PI controller is less compared to conventional PI controller in all the operating region. The performance indices in terms of ISE, IAE and ITAE for servo and regulatory response are also shown in Table 3 & 4.

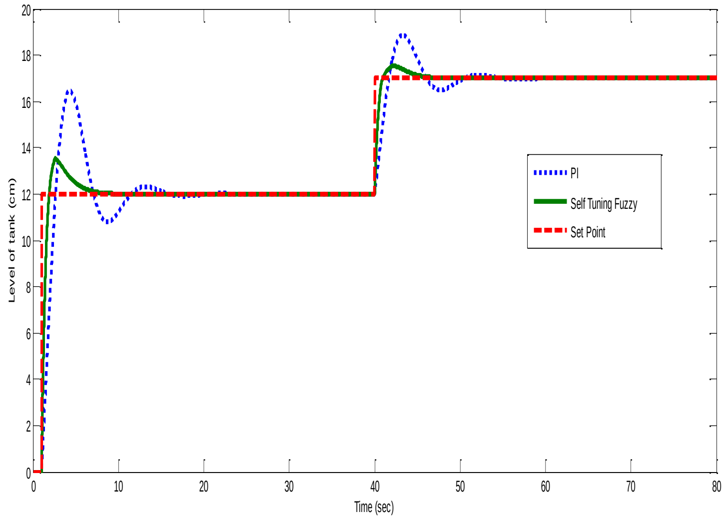

Fig. 9: PI & Self tuning fuzzy servo response

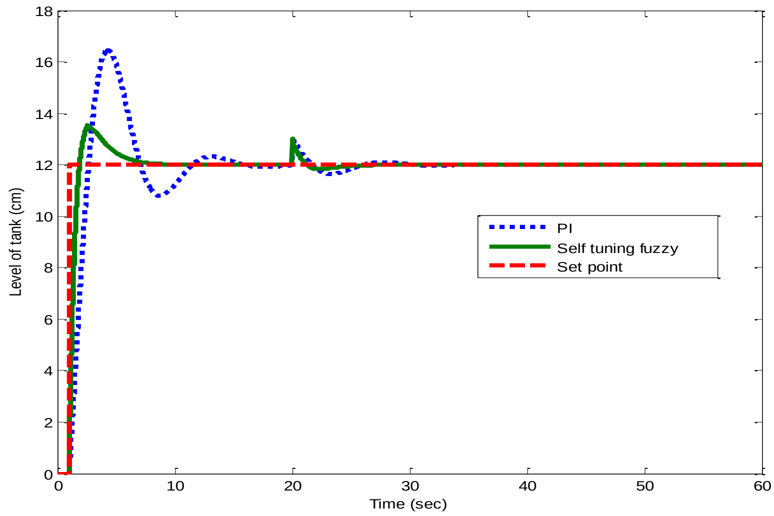

Fig. 10: PI & Self tuning fuzzy regulatory response

TABLE 3: PERFORMANCE COMPARISON (SERVO RESPONSE)

Controller	ISE	IAE	ITAE
PI	142.3	36.93	589.8
Self tuning fuzzy PI	35.7	10.82	152.1

TABLE 4: PERFORMANCE COMPARISON (REGULATORY RESPONSE)

Controller	ISE	IAE	ITAE
PI	122	28.11	165.3
Self tuning fuzzy PI	30.81	8.61	40.76

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VI. CONCLUSION

For non linear process a Self tuning fuzzy PI controller is designed. The performance is tested using MATLAB. The comparison of Self tuning fuzzy PI controller with conventional PI controller is done and the experimental results prove that the response is smooth for both servo and regulatory changes for Self tuning fuzzy PI controller compared to PI controller. It is concluded that Self tuning fuzzy PI controller is suited to maintain the level in spherical tank when compared to conventional PI controller.

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