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Design of Controllers using Soft Computing Techniques for Conical Tank System

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Abstract- Conical tanks find wide range of applications in process industries. In this work the mathematical modeling of a conical tank system is obtained and the system is linearised using piecewise linearization. There is a rapid growth in the use of fuzzy logic controllers for plants those are complex and ill-defined is high due to its efficiency. The Zeigler Nicholas (Z-N) tuned PI controller, Fuzzy Adaptive PI(FAPI), Model Reference based Fuzzy Adaptive PI Control(MRFAPI) is implemented in simulation. The simulation is designed in MATLAB platform.

***Index Terms*- Conical tank system, Mathematical modeling, Piecewise linearization ,PI tunning, Fuzzy Adaptive PI, Model Reference based Fuzzy Adaptive PI**

I.INTRODUCTION

Most industries exhibit processes that are mostly nonlinear in nature. Designing of a controller for a nonlinear system is a major problem, due to their nonlinear dynamic behavior, uncertain and time varying parameters, constraints on manipulated variable, interaction between manipulated and controlled variables, unmeasured and frequent disturbances [1]. Conical tanks with gravity discharge flows are used widely as an inexpensive to feed slurries and liquids with solid particles to unit operations. Conical tank prevents the accumulation of solid particles at the bottom of the tank. Control of liquid level seems tedious because of its nonlinearity and varying cross sectional area. The primary task of the controller is to maintain the process at the desired operating conditions and to achieve the optimum performance when facing various types of disturbances. There is a rapid growth in the use of fuzzy logic controllers for plants those are complex and ill-defined is high due to its efficiency. In most applications of fuzzy logic controllers, the rule base of the fuzzy controller is constructed from expert knowledge; the need may arise to tune the controller parameters if the plant dynamics change.In an attempt to overcome this problem, researchers have introduced adaptive control techniques. In such techniques, the functional approximation capability and on-line learning ability of fuzzy based variable PI systems are exploited.

Therefore designing controller to achieve the required performance is required, because if level of the tank not maintained it leads dangerous situations and also wastage of valuable products. Conical tank system is one such nonlinear system which requires proper tunning.

The proportional integral (PI) and proportional integral derivative (PID) controllers are widely used in many industrial control systems for several decades since Ziegler and Nichols proposed their first PID tuning method[4]. This is because the PID controller structure is simple and its principle is easier to understand than most other advanced controllers. The most basic and pervasive control algorithm used in feedback control is PID control algorithm.

However, the presence of nonlinear effects limits their performances. Fuzzy controllers are successful when applied to nonlinear system, because of their knowledge based nonlinear structural characteristics. Conical tanks find wide application in process industries and its level control is important, because the change in shape gives rise to the nonlinearity. The Fuzzy Logic Controller is well suited for the level control of conical tank system for which conventional controller is not giving satisfactory result[2]. Control algorithms based on fuzzy logic have been implemented in many processes. The application of such control techniques has been motivated by the following reasons: 1) improved robustness over the conventional linear control algorithms;2) simplified control design for difficult system models; 3) simplified implementation.

II. BLOCK DIAGRAM

The level of the conical tank should be maintained at a desired value. So, the controller is designed for the non-linear system and implemented using MATLAB software. The automatic process control block diagram is shown in the Fig.1.

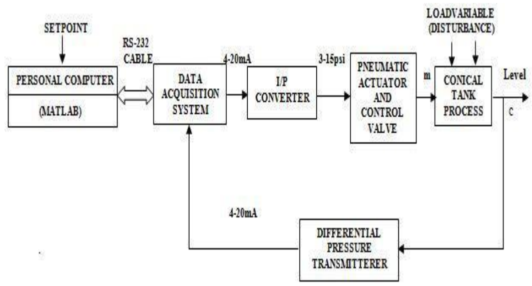

Fig.1.Block diagram of conical tank system

III. CONICAL TANK

The conical tank system which exhibits the property of non-linearity is considered here. The photograph of the conical tank system is shown in the Fig.2 with its components.

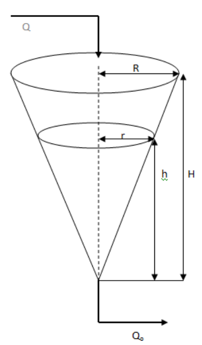

Fig.3.Conical Tank system

Q - Flow rate of the inlet stream in lph

Qo - Flow rate of the outlet stream in lph
R - Maximum radius of the conical tank in cm
r - Radius of the conical tank at steady state in cm
H - Maximum height of the conical tank in cm
h - Height of the conical tank at steady state in cm

Fig.2.Conical Tank Setup

A.MATHEMATICAL MODELLING

Table.1.Operating parameters of conical tank

Parameters	Description	Value
H	Height	60 cm
R	Top radius	17.6 cm
r	Bottom radius	2 cm
Q	Maximum flow rate	440 lph
K_v	Valve coefficient	15.48 cm3/sec

The mathematical modeling of the conical tank system is derived using the mass balance equation

Accumulation=Input–Output

$$\frac{dv}{dt} = F_{in} - F_0 \qquad (1)$$

Where F_{in}-inflow rate in lph
F_o-outflow rate in lph
V-Volume of the tank

The volume of the conical tank can be expressed as equation,

$$A\frac{dh}{dt} = F_{in} - F_0 \qquad (2)$$

Where A is the Area of the Tank

$$A = \pi r^2 \qquad (3)$$

$$\left(\pi r^2\right)\frac{dh}{dt} = F_{in} - F_0 \qquad (4)$$

Radius and height varied in every one of the tank.Tangent angle will be,

$$\tan\theta = \frac{r}{h} = \frac{R}{H} \qquad (5)$$

$$r = \frac{Rh}{H} \quad (6)$$

The Out flow rate F_0 depends on valve coefficient and gravitionalforce,

$$F_0 = k_v \sqrt{h} \quad (7)$$

$$A(h)\frac{dh}{dt} = F_{in} - k_v \sqrt{h} \quad (8)$$

$$hA(h)\frac{dh}{dt} = hF_{in} - k_v h \quad (9)$$

Applying laplase transform in equation (9),

$$hF_{in}(s) = hA(h)sh(s) - k_v h(s) \quad (10)$$

$$\frac{h(s)}{F_{in}(s)} = \frac{h}{hA(h).s + u} \quad (11)$$

$$\tau = \frac{hA(h).s}{u} \qquad k = h/u$$

$$\frac{h(s)}{F_{in}(s)} = \frac{k}{\tau s + 1} \quad (12)$$

B. PIECEWISE LINEARISATION

Using single transfer function for non linear system the output will be obtained exactly if the given set point is within the range of higher and lower limits which is calibrated before the process. Otherwise, if the range is out of the limits then there will be offset error in the output. For this reason, Piecewise linearization should be performed by considering different zones.

The transfer functions obtained for the three regions,

Zone I (0 to 15 cm)

$$G_1(s) = \frac{0.04619}{180.21s + 1} \quad (13)$$

Zone II (15.1 to 30.7 cm)

$$G_2(s) = \frac{0.11399}{3196.9s + 1} \quad (14)$$

Zone III (30.7 to 41.39 cm)

$$G_3(s) = \frac{0.11826}{3034.73s + 1}$$

IV. CONTROLLER DESIGN

A. PI CONTROLLER

The PI controller is commonly used to control the level in process industries. The PI controller consists of proportional and integral term. The PI gain values are calculated by using the Z-N open loop tunning algorithm.

Z-N OPEN LOOP TUNING

Z-N open loop tuning formula for PI controller is given in the equations

$$K_p = \frac{0.09\tau}{kt_d} \quad (16)$$

$$K_i = \frac{k_P}{\tau i} \quad (17)$$

Where $\tau_i = 3.33t_d$

Kp = proportional gain
Ki = Integral gain
τi= Integral time
td = delay time

The transfer function is obtained as

$$G_1(s) = \frac{0.04619}{180.21s + 1} \quad (18)$$

The calculated PI gain parameters can be given as

Kp= 5.624
Ki= 0.2424

B. FUZZY ADAPTIVE PI CONTROLLER

The structure of fuzzy adaptive PI controller is shown in Figure-1. It consists of two parts, one is the conventional PI controller and the other is fuzzy logic controller. Controllers based on the fuzzy logic give thelinguistic strategies control conversion from expert knowledge in automatic control strategies. The development of the control system based on Fuzzy logic involves the following steps:

a. Fuzzification strategy
b. Data base building
c. Rule base elaboration
d. Inference machine elaboration
e. Defuzification strategy

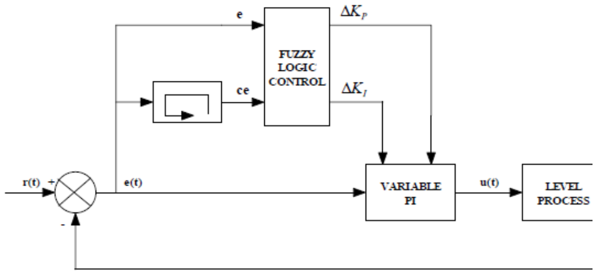

Fig.4.Block diagram of FAPI.

The objective is to find the fuzzy relations among KP, KI, error, and rate of change in error. The membership function used by fuzzy controller is triangular membership function. The fuzzy subsets are Negative Big, Negative small, Zero, Positive small, and Positive Big respectively termed as NB, NS, ZO, PS, PB. The control rules are framed to achieve the best performance of the fuzzy controller. These rules are given in the tables.

The controller is designed for ZONE I region for (0-15)cm

$$G_1(s) = \frac{0.04619}{180.21s+1} \quad (19)$$

Table.2.Fuzzy Rules for Kp

CE / E	NB	NS	ZO	PS	PB
NB	PB	PB	PS	ZO	ZO
NS	PS	PB	PS	ZO	NS
ZO	PS	PS	ZO	NS	NB
PS	PS	ZO	NS	NB	NB
PB	ZO	ZO	NB	NB	NB

Table.3.Fuzzy rules for Ki

CE / E	NB	NS	ZO	PS	PB
NB	PB	PB	PS	ZO	ZO
NS	PS	PB	PS	ZO	NS
ZO	PS	PS	ZO	NS	NB
PS	PS	ZO	NS	NB	NB
PB	ZO	ZO	NB	NB	NB

C. MODEL REFERENCE BASED FUZZY ADAPTIVE PI

The proposed model reference based fuzzy adaptive PI (MRFAPI) control uses an adaptive control structure is shown in figure 3. It consists of command inputs, reference model states, fuzzy logic control, variable PI control and the feedback of the output errors. In an ideal situation, the outputs of the system track the outputs of the known reference model. This proposed design methodology to adjust controller parameter using MRFAPI technique for solving the problem of conical tank non-linear process

The controller uses the error and the rate of change of error as its inputs and can meet desire of self-tuning parameters based on time-varying e and ce. There are many studies on determining the parameters of controllers and finding new values of controller parameters according to changing situations.

$$U(t) = \Delta KP(t) + \Delta KI(t)\, t0dt$$

Where Kp is proportional gain; Ki = Kp(T/Ti); T is sample-time; Ti is integral time parameter. Because the proposed fuzzy tuning PI controller aims to improve the control performance yielded by a PI controller, it keeps the simple structure of the PI controller and it is not necessary to modify any hardware parts of the original control system for implementation.

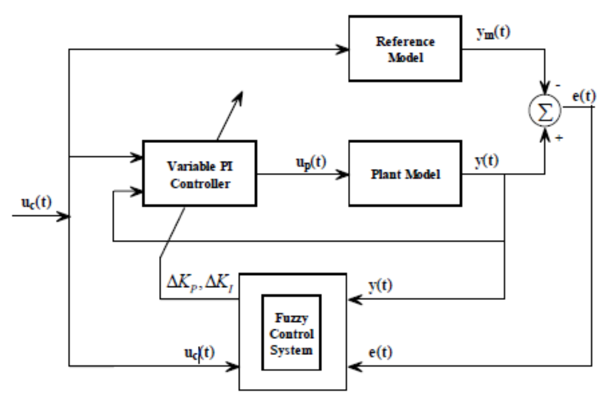

Fig.5.Blockdiagram of MRfAPI.

The rules are given in the tables.

Table.3.Fuzzy rules for Kp

CE / E	NB	NS	ZO	PS	PB
NB	PB	PB	PS	ZO	ZO
NS	PS	PB	PS	ZO	NS
ZO	PS	PS	ZO	NS	NB
PS	PS	ZO	NS	NB	NB
PB	ZO	ZO	NB	NB	NB

Table.5.Fuzzy rules for Ki

CE / E	NB	NS	ZO	PS	PB
NB	PS	PS	ZO	NS	PS
NS	PS	PS	PS	NS	ZO
ZO	ZO	PS	PS	NS	ZO
PS	PB	PS	NS	PS	PB
PB	PB	PB	NS	PS	PB

The reference model transfer function is obtained as

$$G_{ref}(s) = \frac{1}{100s+1} \quad (20)$$

The plant transfer function obtained for this ZONE I include,

$$G_1(s) = \frac{0.04619}{180.21s+1} \quad (21)$$

V. SIMULATION RESULTS

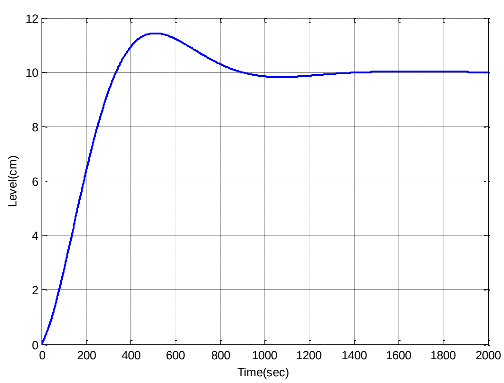

Fig.6.PI response for setpoint 10cm

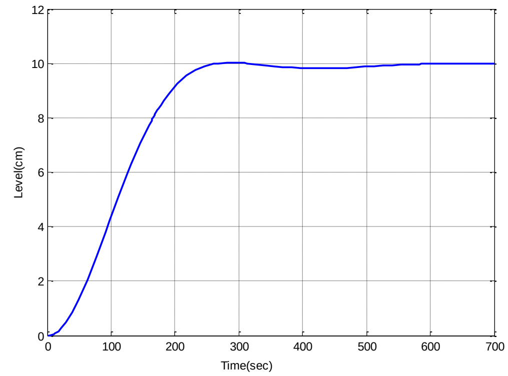

Fig.7.FAPI response for setpoint 10cm

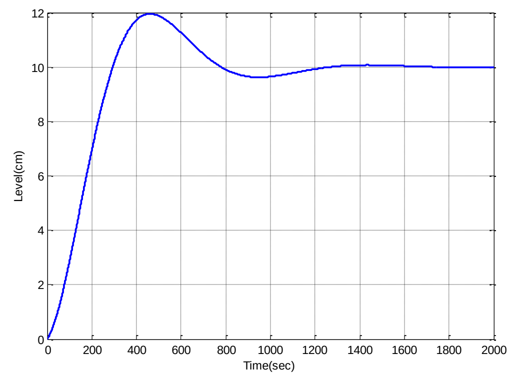

Fig.8.MRFAPI response for setpoint 10cm

Table.6.Comparison Results.

S.No	**Parameters**	**PI**	**FA PI**	**MRFA PI**
1	SettlingTime	1400	1300	600
2	Overshoot	2	1.6	0
2	IAE	2320	2178	1172

VI. CONCLUSION

The Conical tank system is highly nonlinear due to the varying cross sections. The Piecewise Linearisation is done to obtain the linearised transfer function for 3 Zones. Conventional PI controller,Fuzzy Adaptive PI controller and Model Reference based Fuzzy Adaptive PI are designed for ZONE I and verified using simulation.

The simulation results show that Fuzzy Adaptive PI controller is better than Conventional PI controller in terms of peak overshoot ,settling time and IAE. And the Model Reference based Fuzzy Adaptive PI is much better than the above controllers in terms of peak overshoot ,settling time and IAE.

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