DESIGN OF MODEL REFERENCE ADAPTIVE CONTROLLER FOR CONICAL TANK SYSTEM

K.Indhumathi, D.Angeline Vijula, M.E., Ph.D
Sri Ramakrishna Engineering College, Coimbatore.

*Abstract-*The control of liquid level is mandatory in process industries. Many process industries use conical tanks because it prevents the accumulation of solid at the bottom of the tank. The Proportional-Integral (PI) controller is commonly used to control the level in process industries. The non-linearity and constantly changing cross section of the conical tank are the immense challenge in process control. In this paper it is proposed to obtain the mathematical modeling of a conical tank system and to design model reference adaptive controller (MRAC) for controlling the level in conical tank system. The controller is simulated using MATLAB/ SIMULINK environment and the results confirm the effectiveness of the proposed system than the conventional methods.

Index Terms- Conical tank system, Model reference adaptive controller. IMC tuned PI, Z-N tuned PI.

I. INTRODUCTION

The conical tank system is widely used in many process industries because it contributes better drainage of the liquids solid mixture, slurries. The level control of the conical tank is difficult because of its nonlinearity and constantly varying cross section. The PI and PID controllers are widely used in many industrial control systems because of its simple structure and robustness. Tuning of the PI controller is setting the proportional, integral constant. The most common classical controller tuning methods are the Ziegler Nichols (Z-N) and Cohen-Coon methods. Since it is easier than other methods. Internal model control (IMC) tuning offers an alternative tuning to increase the controller's overall performance.

In MRAC a reference model describes the system's performance. The adaptive controller is then designed to force the system (or plant) to behave like the reference model. Model output is compared to the actual output and the difference is used to adjust feedback controller parameters. Therefore this technique is convenient for controller design under the requirement of the system.

The section two presents the hardware description of the conical tank system. The section three explains the modeling of the system. The section four provides the PI controller design. Z-N tuning and IMC tuning is explained. The section five deals with the MRAC controller design. The results are obtained and the comparison is done in the section six. The section seven gives the conclusion and future enhancements.

II. HARDWARE DESCRIPTION

The conical tank is made up of stainless steel and is mounted vertically on the stand. The water enters into the tank from the top and leaves to the reservoir, which is placed at the bottom of the tank. The level of the water in the conical tank is quantified by means of the Differential Pressure Transmitter (DPT). The quantified level of water in the form of current in the range of (4-20) mA is sent to the DAQ in which ADC converts the analog data to digital data and feed
it to the PC. The PC acts as the controller and data logger. The controller considers the process variable as feedback signal and finds the manipulated variable as the output based on the predefined set point. The DAC module of the anipulated variable to analog form into 4-20 mA current signals. The I/P converter converts the current signal to pressure in the range of (3-15) psi, which regulates the flow of water into the conical tank based on the outflow rate of the tank. The block diagram of conical tank system is shown in Fig.1
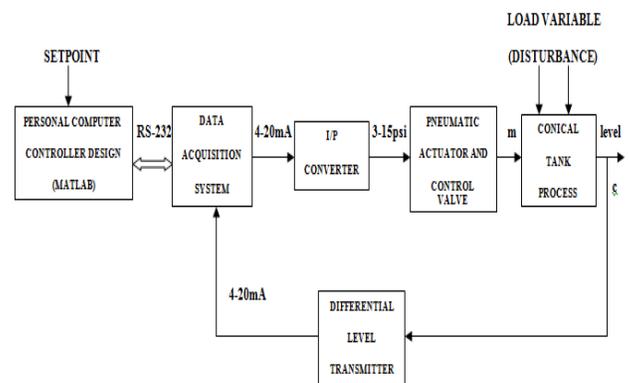

Fig.1. Block diagram of conical tank system

III. MODELING OF CONICAL TANK PROCESS

MATHEMATICAL MODELING
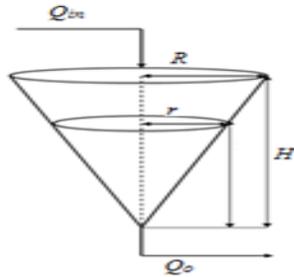
The cross section of the conical tank is shown in Fig.2.

Fig.2.Conical tank

where

Q_{in} - inflow rate in lph

Q_o- outflow rate in lph

R- Maximum radius of the tank in cm

H- Maximum height of the tank in cm

r- radius of the tank tank at steady state in cm

h- height of the tank tank at steady state in cm

According to mass balance equation

Accumulation =Input-Output

$$\frac{dv}{dt} = Q_{in} - Q_0 \tag{1}$$

The volume of the conical tank can be expressed as equation (2)

$$A\frac{dh}{dt} = Q_{in} - Q_0 \tag{2}$$

Where A is the Area of the Tank

$$A = \pi r^2 \tag{3}$$

So the height of the tank is,

$$\frac{dh}{dt} = \alpha Q_{in} h^{-2} - \beta h^{-\frac{3}{2}} \tag{4}$$

Where

$$k_v \alpha = \beta$$

Above equation (4) is Non linear form,

Linearisation is done using Taylor series method

Linearisation of $Q_{in}h^{-2}$ is,

$$f(h,Q) = f(h_s - Q_s) + \frac{\partial f(h - h_s)}{\partial h} + \frac{\partial f(Q - Q_s)}{\partial Q} \tag{5}$$

Linearisation of $\beta h^{-\frac{3}{2}}$ is,

$$h^{-\frac{3}{2}} = h_s^{-\frac{3}{2}} - \frac{3}{2} h_s^{-\frac{5}{2}} (h - h_s) \tag{6}$$

Now applying steady state values y= (h-h_s) and u=(Q-Q_s).

The approximate linear model obtained as,

$$\tau \frac{dy}{dt} + y = kU \tag{7}$$

$$\tau = \frac{2h_s^{\frac{5}{2}}}{3\beta} \tag{8}$$

$$k = \frac{2\alpha h_s^{\frac{5}{2}}}{\beta} \tag{9}$$

Above equation implies that the conical tank system is first order system.

The steady state height h_s=20 cm is considered. Corresponding gain and time constant values are calculated.

The transfer function is expressed in equation (10)

$$G(s) = \frac{0.578}{62.5s + 1} \tag{10}$$

Using the above Transfer function set point will not be reached exactly. Offset error will be present in the system. So, instead of analytical modeling Block box modeling is done.

IV.   BLOCK BOX MODELING

lock box modeling is used to obtain the parameters of the transfer function of the FOPDT model by letting the response of the actual system and that of the model to meet at two points, which describe the two parameters τ and t_d.

The loop is made open and a step increment (230 lph) is given in inflow rate then readings are noted till the system reaches the steady state value. The experimental data are approximated to a First Order Plus Dead Time (FOPDT) model to obtain the open loop parameters of the conical tank process. The response is shown in Fig.3
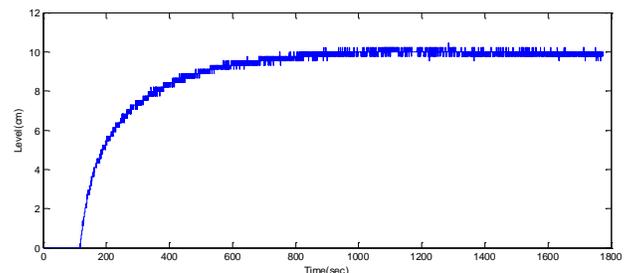

Fig.3. Open loop response of conical tank system

The transfer function is approximated using process reaction curve method expressed by equation (11).

$$G(s) = \frac{0.04e^{-98s}}{157s + 1} \tag{11}$$

V. PI CONTROLLER DESIGN

The PI controller consists of proportional and integral term. The proportional term changes the controller output proportional to the current error value. Large values of proportional term make the system unstable. The Integral term changes the controller output based on the past values of error. So, the controller attempts to minimize the error by adjusting the controller output.

The most common classical controller tuning methods are the Z-N and Cohen-Coon methods. The Z-N method can be used for both closed and open loop systems, while Cohen-Coon is typically used for open loop systems.

VI. ZIEGLER NICHOLS TUNING

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

$$K_p = \frac{0.09\tau}{kt_d} \tag{12}$$

$$K_I = \frac{Kp}{\tau_I} \tag{13}$$

The calculated PI gain parameters are,
K_p= 36.04
K_I= 0.11

VII. INTERNAL MODEL CONTROL TUNING

Internal model control tuning also referred as Lambda tuning method offers a robust alternative tuning aiming for speed. Lambda tuning is a form of internal model control (IMC) that endows a PI controller with the ability to generate smooth, non-oscillatory control efforts when responding to changes in the set point.

The IMC based tuning parameters for PI controller can be obtained by determining the controller equation. Otherwise directly the parameters can be calculated by using the formulae

$$K_p = \frac{\tau}{(\lambda + t_d)k} \tag{14}$$

$$K_I = \frac{K_p}{\tau_I} \tag{15}$$

Assuming λ =5 sec,

The calculated PI gain parameters are,
K_p= 38.106
K_I= 0.242

VIII. MODEL REFERENCE ADAPTIVE CONTROLLER

A tuning system of an adaptive control will sense these parametric variations and tune the controller parameters in order to compensate for it. The parametric variation may be due to the inherent non-linearity of the system such as conical tank. In a conical tank the cross section area varies as a function of level which in turn leads to parametric variations. The time constant and gain of the chosen process vary as a function of level.

In MRAC a reference model describes the system's performance. The adaptive controller is then designed to force the system (or plant) to behave like the reference model. Model output is compared to the actual output and the difference is used to adjust feedback controller parameters.

MRAC has two loops: an inner loop (or regulator loop) that is an ordinary control loop consisting of the plant and the regulator, and an outer (or adaptation) loop that adjusts the parameters of the regulator in such a way as to drive the error between the model output and plant output to zero. Block diagram of MRAC is shown in Fig.4.
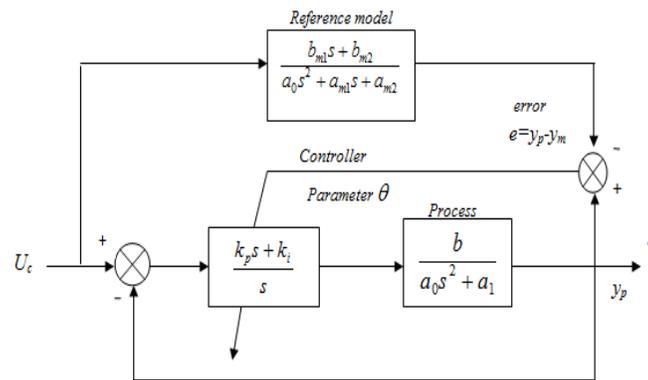

Fig.4. Block diagram of MRAC strategy
Tracking error is,

$$e = y_p - y_m \tag{16}$$

The cost function is,

$$J(\theta) = \frac{1}{2}(e^2\theta) \tag{17}$$

$$\frac{d\theta}{dt} = -\gamma\frac{\partial J}{\partial \theta} = -\gamma e\frac{\partial e}{\partial \theta} \tag{18}$$

where 'e' denotes the model error and 'θ' is the controller parameter vector.'γ' denotes the adaptation gain.

Instead of 'θ' the PI controller parameters K_P,K_I are considered.

So the K_p is,

$$k_p = \frac{1}{s}\left(-\gamma_p e\left(\frac{bs}{a_0 s^2 + \left(a_1 + b k_p\right)s + b k_i}\right)\left(U_c - Y_p\right)\right) \quad (19)$$

Similarly K_I Parameter is,

$$k_i = \frac{1}{s}\left(-\gamma_i e\left(\frac{b}{a_0 s^2 + \left(a_1 + b k_p\right)s + b k_i}\right)\left(U_c - Y_p\right)\right) \quad (20)$$

IX. SIMULATION RESULTS

The closed loop response is obtained for Z-N tuned PI. Both the servo and regulator operations are obtained. In the servo operation only set point tracking is done. In the regulator operation, the disturbances can be corrected automatically and desired level is obtained. The closed loop response of Z-N tuned PI is shown in Fig.5.
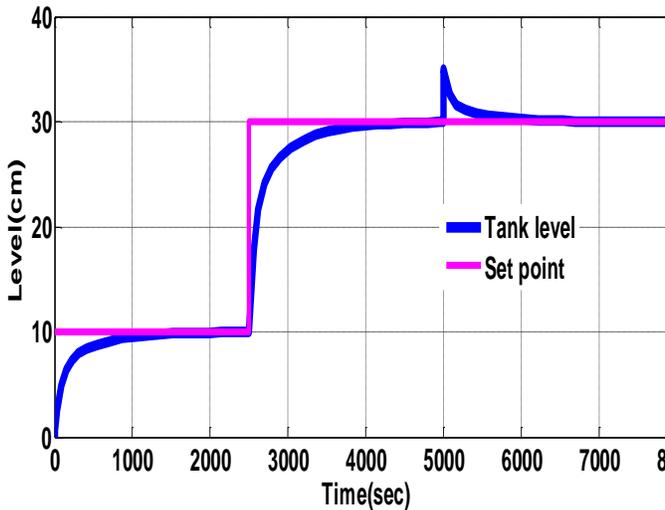

Fig.5. Response of Z-N tuned PI controller

The Internal Model Control tuning is used to obtain the closed loop response. Both servo and regulator operations are obtained as shown in Fig.6.
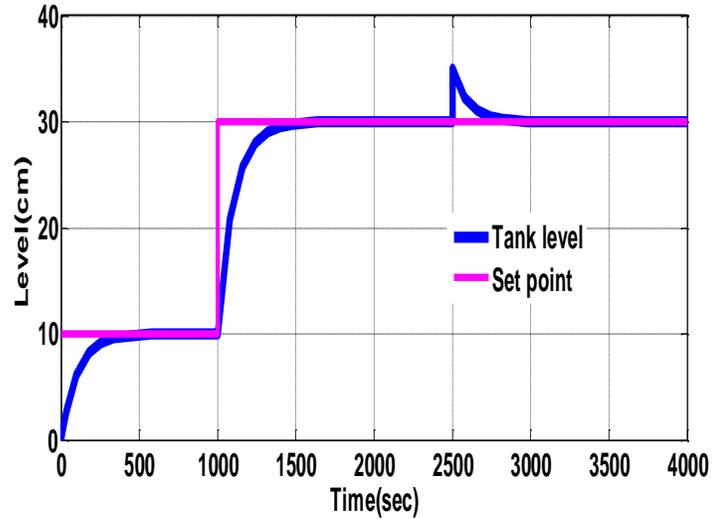

Fig.6 Response of IMC tuned PI controller

In MRAC a reference model describes the system's performance. Model output is compared to the actual output and the difference is used to adjust feedback controller parameters. The Servo and Regulatory response is shown in Fig.7
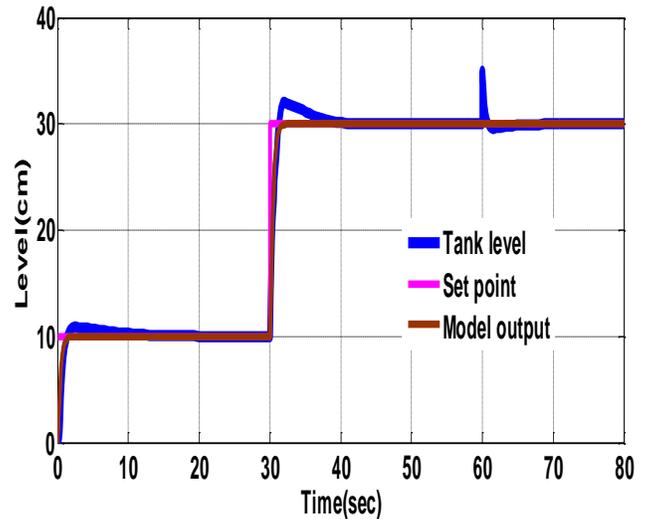

Fig.7 Response of MRAC

To Compare the Controller action various parameters such as rise time, peak time, peak overshoot and settling time are taken. Comparison of Z-N tuned PI, IMC tuned PI, MRAC for set point 10 cm is shown in Table I.

TABLE I: Quantitative Comparison of Z-N tuned PI, IMC tuned PI, Adaptive PI controller for setpiont=10cm

Controller	Settling Time(sec)	Rise Time(sec)	IAE

Z-N tuned PI Controller	2100	600	2273
IMC tuned PI Controller	600	400	1033
MRAC	20	5	12.57

Comparison of Z-N tuned PI,IMC tuned PI, MRAC for set point 30 cm is shown in Table II.

Table II: Quantitative Comparison of Z-N tuned PI, IMC tuned PI, Adaptive PI controller for setpoint=30cm

Controller	Settling Time(sec)	Rise Time(sec)	IAE
Z-N tuned PI Controller	2200	700	6818
IMC tuned PI Controller	1000	300	3099
MRAC	40	3	25.51

As shown in above tables in MRAC the Integral Absolute Error (IAE) is reduced when compared to the PI controller. The settling time is also reduced in MRAC which means it gives the faster response.

X. CONCLUSION AND FUTURE ENHANCEMENT

Conical tank system is highly nonlinear because of its variable cross section. The Conventional PI controller and Model Reference Adaptive Controller are implemented in simulation. MRAC gives the better performance.

PI controller and Model Reference Adaptive Controller are to be implemented for real time to control the Level of Conical Tank system. Adaptation Gain in MRAC is to be Optimized using Optimization Techniques.

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