# MODEL PREDICTIVE CONTROL DESIGN FOR CONICAL TANK SYSTEM

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***ABSTRACT*—Conical tanks are widely used in the process industries because of its shape thatcontributes better drainage for solid mixtures, slurries and viscous liquids. Level control of conical tank is a challenging task due to its nonlinear shape and constantly varying cross-section. The main objective of this paper is to design Model Predictive Control for conical tank system to maintain the desired set point. In this paper Model predictive control (MPC) is designed and the results are compared withPI controller that is designed using the Internal Model Control (IMC) based tuning method.MPC is expected to have better closed loop performance and robustness compared to PI controller.**

***Keywords-Conical Tank, Internal Model Control, Model Predictive Control,Nonlinear Process.***

## I. INTRODUCTION

Industrial control systems have galore features as such as nonlinear, time delay, and time invariant etc., these features causes difficulties in obtaining the exact model. The cone is a well-known system, which is having high non linearity, due to the variation of the area with respect to height. Thus automatic control of such nonlinear process is a challenging task. To recover the nonlinearity problem dynamics, those systems should be analyzed properly. Areas whichimplements the conical tank is petro chemical industries, waste water treatment industries because conical tank system provides better drainage for solid mixtures, slurries and viscous fluids. The proposed work's objective is to implement MPC design which uses model of the process to calculate the controller setting, but the structure of the model has not been explicitly involved in the controller design.

The section two deals with the experimental setup of the conical tank system. The section three explains the mathematical modelling of the system. The section four deals with the PI controller that is designed using the IMC based tuning method. The servo and regulatory response is obtained for the conical tank. MPC is explained in the section five. The results are obtained and the comparison is done in the section six. The section seven gives the conclusion.

## II. EXPERIMENTAL SETUP

The controller is designed for the nonlinear system and implemented using MATLAB software. The automatic process control block diagram is shown in the fig.1.The operating variables that are included in the conical system are as listed below. The controlling variable is inflow rate of the tank. The controlled variable is level of the conical tank. Probes are used to sense the level in the process tank and fed into the signal conditioning unit which makes the required signal for further processing.

The process is interfaced with the personal computer using DAQ card. The personal computer acts as a controller. The output from the personal computer is fed to the drive circuit. The drive circuit consist of power electronic device, SCR. Then the control action is taken by the final control element.

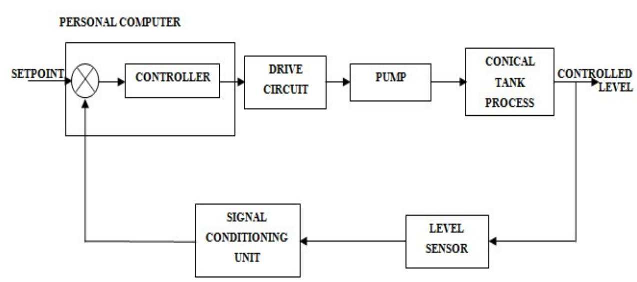


**Fig 1: Block diagram of conical tank system**

Specification of conical tank system

| | |
|---|---|
| Height, H | : 70cm |
| Steady state value, h | : 10cm |
| Bottom radius, r | : 2cm |
| Top radius, R | : 17.6cm |
| Material | : Stainless steel |

## III. MATHEMATICALMODELLING

The level of the tank can be maintained by adjusting the inflow rate of the tank. Nonlinear process model gives improper response. The area of the tank is constantly varying and hence linearization of the system is required. The process considered here is the conical tank system as shown in fig. 2.

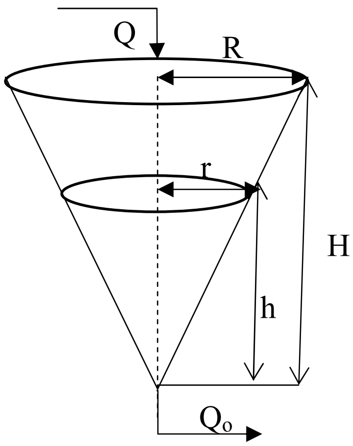


**Fig 2: Conical tank**

Q Flow rate of the inlet stream
$Q_o$ Flow rate of the outlet stream
R Maximum radius of the conical tank
R Radius of the conical tank at steady state
H Maximum height of the conical tank
H Height of the conical tank at steady state

The mathematical modelling of the system should be obtained using the process parameters. According to mass balance equation, Accumulation = Input- Output

$$A\frac{dh}{dt} = Q - Q_o. \quad (1)$$

$$\text{Area, } A = \pi r^2 = \pi\left(\frac{Rh}{H}\right)^2 \quad (2)$$

sothat the tank model becomes

$$\frac{dh}{dt} = \frac{\alpha Q}{h^2} - \beta h^{-3/2} \quad (3)$$

where α and β are parameters defined by,

$$\alpha = \frac{1}{\pi\left(\frac{H}{R}\right)^2} \quad (4)$$

$$\beta = c\alpha \quad (5)$$

This process model has two types of nonlinear functions: $Qh^{-2}$ and $h^{-3/2}$. These two functions have to be linearized. Linearization is the process by which a nonlinear system is approximated to a linear process model.

The most popular technique for obtaining the linear approximation is based on Taylor series expansions of the nonlinear aspects of the process model.

The linearization of (h, Q) $=Qh^{-2}$ proceeds as follows,

$$f(h, Q) = f(h_s, Q_s) + \frac{\partial(h - h_s)}{\partial h} + \frac{\partial(Q - Q_s)}{\partial Q} + \text{higher order terms}$$

ignore the higher order terms,

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

Under steady state condition, $Q_s = \beta h_s^{-1/2}$ .Now introduce the variables y= $(h-h_s)$ and u=$(Q-Q_s)$.

The approximate linear model is obtained as,

$$\frac{dy}{dt} + y = Ku \quad (7)$$

where the steady-state gain and time constant associated with this approximate linear model are given by,

$$K = \frac{2\alpha}{\beta} h_s^{1/2} = \frac{2}{c} h_s^{1/2} \quad (8)$$

And,

$$\tau = \frac{2}{\beta} h_s^{5/2} \quad (9)$$

Applying the values for all the parameters and taking Laplace transform, the conical tank transfer function is obtained. Once the transfer function is obtained, then the controller can be designed for the conical tank process. The system transfer function is obtained as follows,

$$G_m(s) = 3.\frac{184}{62.81s + 1} \quad (10)$$

## IV. INTERNAL MODEL CONTROL

The basic idea of IMC is to use a model of the open loop process transfer function in such a way that the selection of the specified closed loop response yields a physically realizable controller. The internal model principle states that control can be achieved only if the control system encapsulates, either implicitly or explicitly some representation of the process to be controlled. Process model is embedded in the controller. This method is very effective for utilizing process model as a feedback control. The basic structure of IMC is shown in the fig. 3. The process model is directly used and hence reduces the on-line computation.

Process model that receives the same manipulated variable signal as the actual process. Then the difference between the process output (actually measured) and the process model output (model predicted) is obtained to determine the model error. The disturbances entering into the system should be taken in consideration.

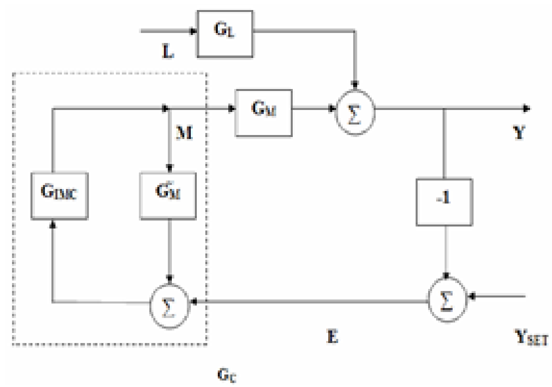


**Fig 3: Basic structure of Internal Model Control**

The IMC based tuning parameters for PI controller can be obtained by determining the controller equation.The IMC based PI parameter tuning formula can be given as,

$$G_f(s) = \frac{1}{\lambda s + 1} \quad (11)$$

$\lambda$ is taken as 50sec.

$$G_{PI}(s) = \frac{\tau p + 1}{k_p \lambda_s} \quad (12)$$

From equation 12 the $k_P$and $k_I$ parameter can be calculated as,

$$k_p = \frac{\tau p}{k_p \lambda_s} \quad (13)$$

$$k_I = \frac{1}{k_p \lambda_s} \quad (14)$$

From the equation 13 and 14, the $k_p$and $k_I$ parameter for different regions are calculated.

# V. MODEL PREDICTIVE CONTROL

MPC is a widely used means to deal with large multivariable constrained control issues in industry. The main aim of MPC is to minimize a performance criterion in the future that would possibly be subject to constraints on the manipulated inputs and outputs, where the future behaviour is computed according to a model of the plant. The model predictive control uses the models and current plant measurements to calculate future moves in the independent variables that will result in operation that honours all independent and dependent variable constraints. The MPC then sends this set of independent variable to the corresponding regulatory controller set-points to be implemented in the process.

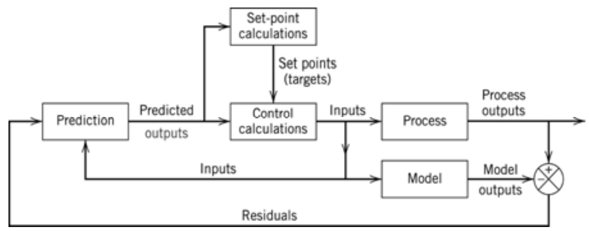


**Fig 4:Block diagram for model predictive control.**

A block diagram of a model predictive control system is shown in Fig. 4. A process model is used to predict the current values of the output variables. The residuals, the differences between the actual and predicted outputs, serve as the feedback signal to a prediction block. The predictions are used in two types ofMPC calculations that are performed at each samplinginstant: set-point calculations and control calculations. Inequality constraints on the input and output variables,such as upper and lower limits, can be includedin either type of calculation.

The step-response model of a stable, single-input, single-output process is shown in equation 15 and written as follows

$$y\,(k+1) = y0 + \sum_{i=1}^{N-1} s_i \Delta u(k - i + 1) + s_N u(k - N + 1) \quad (15)$$

where $y(k1)$ is the output variable at the $(k+1)$sampling instant, and $u(k\text{-}i+1)$ denotes the change in the manipulated input from one sampling instant to the next, $\Delta u(k\text{-}i+1) = u(k\text{-}i+1) + u(k+i)$. Both $y$ and $u$ are deviation variables. The model parameters are the $N$ step-response coefficients, $S_1$ to $S_N$. Model predictive control is based on predictions offuture outputs over a prediction horizon, $P$. This is why it is widely used in real time implementation.

# VI. SIMULATION RESULTS

The PI controller attempts to minimize the error by adjusting the controller output. The PI gain values are calculated by using IMC tuning algorithm. The closed loop response obtained for the setpoint = 10cm using PI controller and MPC is shown in the fig. 6.

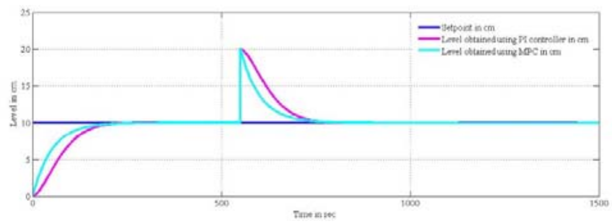


**Fig 6: Closed loop response for setpoint 10 cm using PI controller and MPC**

The closed loop response obtained for the setpoint = 30cm using PI controller and MPC is shown in the figure 7.

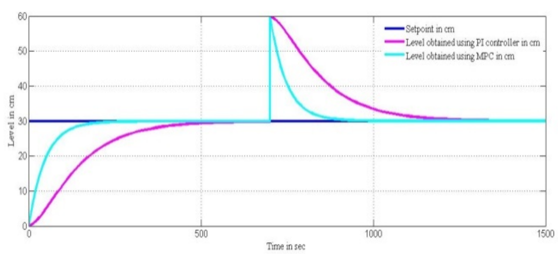


**Fig 7: Closed loop response for setpoint 30 cm using PI controller and MPC**

To compare the controller action various parameters such as rise time, peak time, peak overshoot and settling time are taken.The regulatory operation is obtained by keeping set point as constant and varying load. The disturbances occur in the system due to sudden change in the inflow rate or change in the outflow rate. This change should be tracked automatically and the desired level should be maintained.

TABLE 1: COMPARISON OF RESULTS FOR SET POINT=10CM

| S.No | Parameters | PI(IMC tuning) | MPC |
|---|---|---|---|
| 1 | Rise time(sec) | 398 | 199.8 |
| 2 | Settling time(sec) | 650 | 300 |
| 3 | Peak time(sec) | 415 | 213 |
| 4 | Integral Absolute Error(IAE) | 2448 | 1220 |

As shown in Table 1 and Table 2 the peak overshoot is reduced in MPC when compared to the PI controller. The settling time is also reduced in MPC which means it gives the faster response.

**Table 2: Comparison of results for set point=30cm**

| S.No | Parameters | PI(IMC tuning) | MPC |
|---|---|---|---|
| 1 | Rise time(sec) | 298 | 92 |
| 2 | Settling time(sec) | 600 | 289 |
| 3 | Peak time(sec) | 312 | 190 |
| 4 | Integral Absolute Error(IAE) | 1890 | 1009 |

## VII. ONCLUSION

Conical tank system is a highly nonlinear process because of its variable cross section. The PI controller parameters are obtained using IMC based tuning. The MPC is designed using the MATLAB. Both the results are compared and from the results it has been found that the MPC produces better performance than its counterpart. The PI and MPC are designed in such a way that the system is physically realizable. But due to the presence of dead time, the performance of the system is affected. Using advanced control scheme such as Model Reference Adaptive Controller better performance and robustness can be obtained.

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## REFERENCES

[1] D. Angeline Vijula, K. Vivetha,K. Gandhimathi, and T. Praveena(2014) ‘Model basedcontroller design for conical tank system’, International Journal of Computer Applications,Vol.85, No.12, pp.8-11.

[2] Anna Joseph and J. Samson Isaac, (2013) ‘Real time implementation of Model reference adaptive controller for a conical tank’, proceedings of International Journal on Theoretical and Applied Research in Mechanical Engineering, Vol.2, No.1, pp. 57-62.

[3] Abhishek Sharma and Nithya Venkatesan (2013) ‘Comparing PI controller performance for nonlinear process model’, proceedings of International Journal of Engineering Trends and Technology, Vol.4, No.3, pp. 242-245.

[4] P. Sowmyal, N. Srivignesh, N. Sivakumaran, and G. Balasubramanian, (2012) ‘A Fuzzy Control Scheme for Nonlinear Process’, IEEE transactions on International Conference On Advanced Engineering Science and Management , pp. 683-687.

[5] D. Marshiana, and P. Thirusakthimurugan, (2012) ‘Design of zieglernichols tuningcontroller for a nonlinear system’, proceedings of International Conferenceon Computing and Control Engineering, Vol.3, No.9, pp.121-124.

[6] S.R.Warier,.S. Venkatesan (2012) ‘Design of controllers based on MPC for a conical tank system’, International Conference on Advances in Engineering, Science and Management (ICAESM),pp. 309-313.

[7] N.Venkatesan, and N. Anantharaman, (2012) ‘Controller design based on Model Predictive Control for a nonlinear process’, http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=6215173&queryText%3Dconical+tankproceedings of Mechatronics and its Applications , pp. 1-6.

[8] Process Dynamics and Control by Dale E. Seborg, Thomas F. Edgar, Duncan A. Mellichamp

[9] S. Nithya, S. Sivakumaran, T. Balasubramanian, and N. Anantharaman, (2008) ‘Model based controller design for a spherical tank process in real time’, proceedings of International Journal of Simulation, Systems, Science and Technology, Vol. 9, No. 4, pp. 247-252.

[10] Anandarajan, R., Chidambaram, M. and Jayasingh, T. (2006) ‘Limitations of a PI controller for a first order nonlinear process with dead time’, ISA trancastions, Vol.45, No.2, pp.185-199.

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