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Design and Implementation Of IMC Based PID Controller for Conical Tank Level Control Process

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Abstract: The level control of non-linear tanks (conical, spherical, etc) is the immense challenge in process control and it cannot be effectively controlled by means of conventional linear P+I+D controller. Hence an attempt is made in this paper as Internal Model Based PID controller design for conical tank level control. For each stable operating point, a first order process model was identified using process reaction curve method. The real time implementation is done in simulink using MATLAB. The experimental results shows that proposed control scheme have good set point tracking and disturbance rejection capability**.**

Keywords: IMC;PID;CONICALTANK,LEVEL,MATLAB

I. INTRODUCTION

In most of the process industries controlling of level, flow, temperature and pressure is a challenging one. Based on the plant dynamics, they may be classified as linear and non-linear processes. In level control process, the tank systems like cylindrical, cubical are a linear one, but that type of tanks does not provides a complete drainage. For complete drainage of fluids, a conical bottomed cylindrical tank is used in some of the process industries, where its nonlinearity might be at the bottom only. The drainage efficiency can be improved further if the tank is fully conical. But continuous variation in the tank system makes it highly non-linear and hence the liquid level control in such systems is difficult. A conical shaped tank system are mainly used in Colloidal mills, Leaching extractions in pharmaceutical and chemical industries, food processing industries, Petroleum industries, Molasses, Liquid feed and Liquid fertilizer storage, Chemical holding & mix tank, Biodiesel processing and reactor tank. To avoid settlement and sludge in Storage and holding tanks, the conical tanks are used.

II. PROPOSED WORK

A. EXPERIMENTAL SETUP

The level process station was used to conduct the experiments and collect the data. The computer acts as a controller [3].It consists of the software used to control the level process station. The setup consists of a process tank, reservoir tank, control valve, I to P converter, level sensor and pneumatic signals from the compressor. When the set up is Switched on, level sensor senses the actual level values initially then signal is converted to current signal in the range 4 to 20mA.This signal is then given computer through data acquisition cord. Based on the values entered in the controller Settings and the set point the computer will take control action the signal sent by the computer is taken to the station again through the cord. This signal is then converted to pressure signal using I to P converter. Then the pressure signal acts on a control value which controls the flow of water in to the tank there by controlling the level.

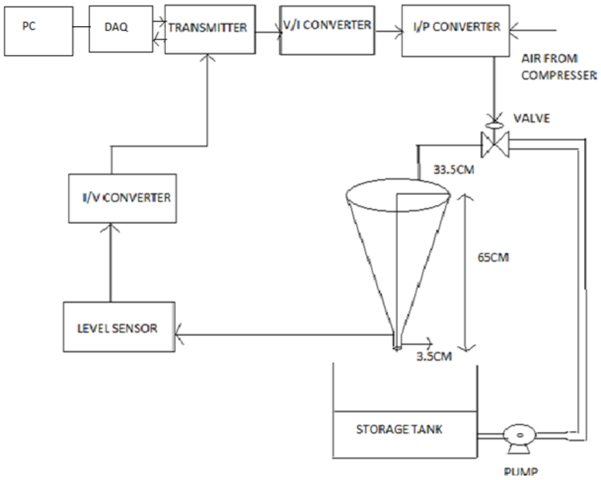

Figure 1: Level Control of Conical Tank System

B. Description of the Conical –Tank Level Process

The tank is made up of stainless steel body and is mounted over a stand vertically. Water enters the tank from the top and leaves the bottom to the storage tank. The System specifications of the tank are as follows,

TABLE I
SPECIFICATIONS OF PROPOSED SYSTEM

EQUIPMENTS	DETAILS
Conical tank	Stainless steel body, height– 65 cm, Top diameter–33.5 cm Bottom diameter – 3.5 cm
Differential Pressure Level Transmitter	Differential Pressure Level Transmitter
Pump	Centrifugal 0.5 HP
Control Valve	Size ¼ Pneumatic actuated Type: Air to open, Input 3-15PSI
Rota meter	Range 0-460 LPH

C. MATHEMATICAL MODELING OF PROCESS

A mathematical model is a description of a system using mathematical concepts and language. The process of developing a mathematical model is termed as mathematical modeling. Generally modeling of linear systems involves direct derivations whereas non- linear systems require certain approximations to arrive at the solution.

Types of Non-linear Approximations:

- Taylor Series Approximation
- Optimal Approximation
- Global Approximation
- Jacobian Method

Of these methods, Taylor's series method is simple and accurate over certain range near the steady state point.

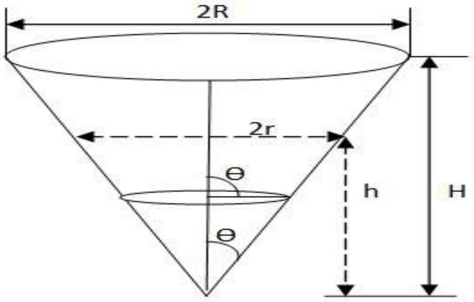

Figure 2: Mathematical Modeling

Where,

R = Top radius of the tank
H = Total height of the tank
r = Radius at the liquid level (h)
h = Level of the liquid (Variable)

tanƏ= r/h and also tanƏ=R/H

(1)

Therefore, $r/h=R/H$

(2)

$R =(R*h)/H$

(3)

Area $A=\pi r^2$

(4)

$dA/dt=d\{\pi((R*h)/H)^2\}/dt$ (5)

$=\pi(R/H)^2 *2h\ dh/dt$

(6)

Volume $V=1/3 *\pi r^2 h$

(7)

$=1/3*Ah$ (8)

$dV/dt=1/3*\{A\ dh/dt+h dA/dt\}$ (9)

$=1/3 *dh/dt\{A+2\pi(R/H)^2*h^2\}$

(10)

By Newton's law

$F_{in}-F_{out}=1/3 *dh/dt\{A+2\pi(R/H)^2*h^2\}$

(11)

Output flow rate,

$F_{out}= K\sqrt{h}$

(12)

$F_{in}-K\sqrt{h} =1/3 *dh/dt\{A+2\pi(R/H)^2*h^2\}$

(13)

$dh/dt = \{3(F_{in}-K\sqrt{h})\}/\{ A+2\pi(R/H)^2*h^2\}$

(14)

$dh/dt = \{3(F_{in}-K\sqrt{h})\}/\{ 3\pi(R/H)^2*h^2\}$

(15)

$= \{(F_{in}-K\sqrt{h})\}/\{ \pi(R/H)^2*h^2\}$

(16)

$\alpha = 1/ \pi(R/H)^2$

(17)

$\beta = K\alpha$

(18)

$dh/dt = \alpha F_{in}\, h^{-2}-\beta h^{-3/2}$

(19)

By Taylor's series:

$F(h,F_i) = f(h_s ,F_{is}) + (\partial f/\partial h)_{(hs,Fis)} (h-h_s) + (\partial f/\partial F_i)_{(hs-fis)}F(f_i-F_{is})$

(20)

$F(h,F_i) = f(h_s ,F_{is}) - 2F_{is}\, h_s^{-3}(h-h_s) + h_s^{-2}(F-F_{is})$

(21)

$h^{-3/2} = h_s^{-3/2} - (3/2)h_s^{-5/2}(h-h_s)$

(22)

$dh/dt = \alpha[\ f(h_s, F_{is}) - 2F_{is} h_s^{-3}(h-h_s) + h_s^{-2}(F-F_{is})] - \beta[h_s^{-3/2} - (3/2)h_s^{-5/2}(h-h_s)]$

(23)

At steady state,

$dh_s/dt = \alpha F_{is} h_s^{-2} - \beta h_s^{-3/2} = 0$

(24)

$d(h-h_s)/dt = -2\alpha F_{is} h_s^{-3}(h-h_s) + \alpha h_s^{-2}(F-F_{is})] + 3/2\beta h_s^{-5/2}(h-h_s)$

(25)

$dy/dt = -2\alpha F_{is} h_s^{-3} Y + \alpha h_s^{-2} U + (3/2)\beta h_s^{-5/2} Y$

(26)

$dy/dt = -2\beta h_s^{-3/2} h_s^{-1}\ y + \alpha h_s^{-2} U + (3/2)\beta h_s^{-5/2} Y$

$= -(1/2)\ \beta h_s^{-5/2} y + \alpha h_s^{-2} U$

(27)

$(2/\beta)\ h_s^{5/2}(dy/dt) = -y + \alpha hs^{-2} U$

$\tau(dy/dt) + y = (2\alpha/\beta)\ h_s^{1/2} U$

(28)

$\tau(dy/dt) + y = CU$

(29)

Taking Laplace Transform,

$Y(s)/U(s) = C/[\tau s+1]$

(30)

Where,

$C = (2\alpha/\beta)\ h_s^{1/2}$ → Steady State Gain.

$\tau = (2/\beta)\ h_s^{5/2}$ → Time Constant.

D. Response of Open Loop Test:

The response of the open loop test as described in chapter 6.1 is given below. It shows that the steady state gain is 12mA and time constant 7.62 sec with input step change of 100LPH.

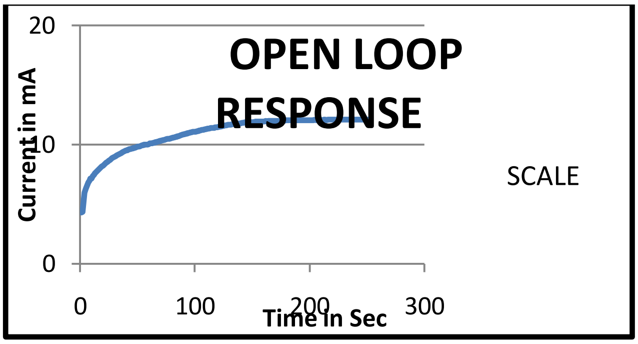

Figure 3: Openloop Response Cruve

The obtained response from open loop test which represents first order transfer function with zero dead time.

$$G(S) = \frac{Kpe^{-\tau_d (s)}}{\tau s+1} \qquad (31)$$

E. Linearization

The process steady state input output characteristics thus obtained shows the non-linear behavior as the area varies in a non-linear fashion with the process variable height (h).To obtain a linear model process steady state input – output characteristics curve is divided into five different linear regions as shown in the fig 4

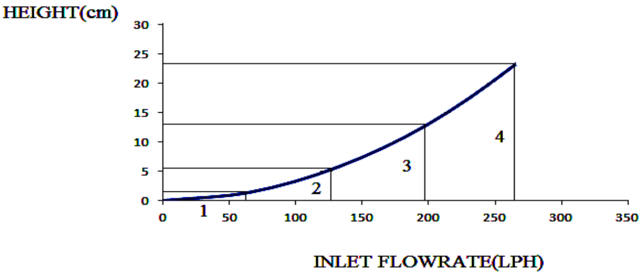

Figure 4: Piecewise Linearization Curve

TABLE II

Model Parameters

Region	Height (cm)	kp	Time Constant (secs)	Transfer Function Model
1	10	0.218	0.041	5.415/3000s+1
2	23	0.155	11.75	2.999/3500s+1

III IMC BASED PID CONTROLLER

The ability of proportional-integral (PI) and Proportional-Integral-Derivative (PID) controllers to meet most of the control objectives has led to their widespread acceptance in the control industry. It is because, for practical applications or an actual process in industries PID controller algorithm is simple and robust to handle the model inaccuracies. This error becomes severe for the process with time delay. For this we have taken some transfer functions with significant time delay.

The distinguishing characteristic of IMC structure is the incorporation of the process model which is in parallel with the actual process or the plant. Figure 5 shows the schematic diagram for IMC process.

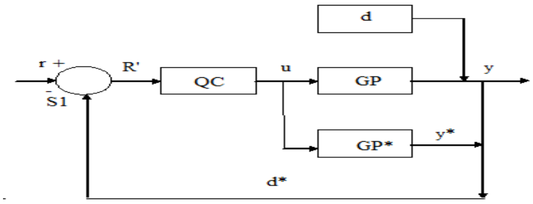

Figure 5: Structure of IMC

Hence, closed loop transfer function for IMC scheme is

$y(s) = \{Gc(s) . Gp(s). r(s) + [1 - Gc(s) . Gp^* (s)]. d(s)\} / \{1 + [Gp(s) - Gp^* (s)]\ Gc(s)\}$

(32)

IV SIMULATION AND RESULTS

The simulation result of IMC based PID with various operating points was obtained using MATLAB environment. The performance of the proposed controller is compared with existing conventional controller.

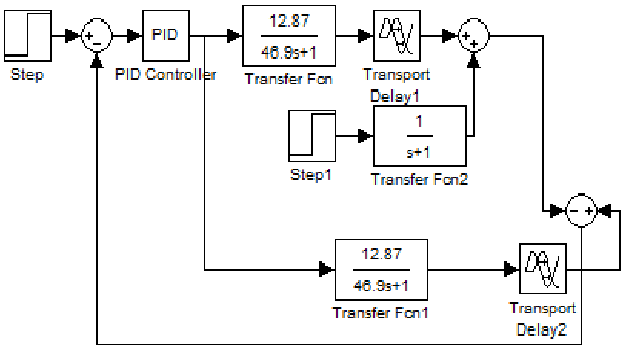

Figure 6: MATLAB Simulink Model.

It design procedure is the open loop control. Its structures for compensates for disturbance model uncertainty. The procedure is focused on set point responses. But a good set point response denotes good disturbance rejection particularly for the disturbance occurs at the process input. The modified of the design procedure is developed to improve input disturbance rejection.

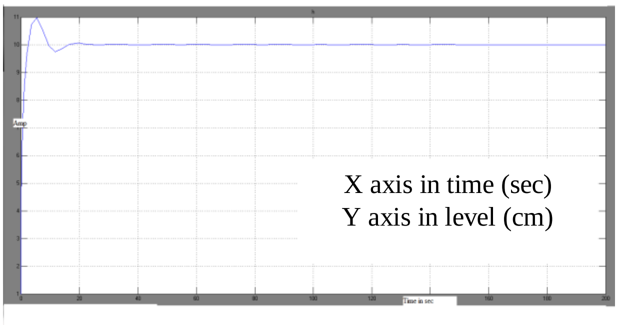

Figure 7: Simulation for IMC based PID

Figure7: Hardware implementation platform

The tank is made up of stainless steel body and is mounted over a stand vertically. Water enters the tank from the top and leaves the bottom to the storage tank.

TABLE III
COMPARISION OF PID AND IMC BASED PID

Set point (cm)	Controller	Rise time (secs)	Settling time (sec)
10	PID	11	31
	IMC based PID	6	22
23	PID	44	1195
	IMC based PID	24	523

V CONCLUSION

For practical applications or an actual process in industries IMC based PID controller algorithm is simple and robust to handle the model inaccuracies and hence using IMC-PID tuning method a clear trade-off between closed-loop performance and robustness to model inaccuracies is achieved with a single tuning parameter. It also provides a good solution to the process with significant time delays which is actually the case with working in real time environment. As far as the tuning of the controller is concerned we have and optimum filter tuning factor λ (lambda) value which compromises the effects of discrepancies entering into the system to achieve the best performance. Thus, what we mean by the best filter structure is the filter that gives the best PID performance for the optimum λ value. Also the standard IMC filter results in good set point response performances. The simulation results shows the IMC based PID controller have minimum settling time and rise time in order to reach steady state value when compare to conventional controller.

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BIOGRAPHIES

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