Research Paper

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Real Time Implementation of PI Controller for Conical Tank System

Akash A. Patel P.G. student, Applied Instrumentation, AITS, Rajkot, 8401115457, India.

Kuldip H. Tarpara Head & Professor, Department of I.C., AITS, Rajkot, 9824811042, India.

ABSTRACT

This paper deals with control of nonlinear system like conical tank system via interfacing of plant with PC using Arduino. Control of such nonlinear system is difficult task due to continuous changing of its cross sectional area with respect to height. In this paper real time conical tank system is controlled by PI controller with the help of Arduino board and Matlab/Simulink. The conical tank system is represented as a FOPDT model. For each steady state operating point, the FOPDT transfer function is identified, then controller tuning strategy has been applied using direct synthesis method and model of conical tank system is implemented in Matlab/Simulink environment. At the end of experiment comparison is done based on time domain specifications between real time result and simulation result of plant.

INTRODUCTION

In the process industries liquid level is the basic problem as it is necessary to pump the liquid, store it in tanks and then pump to the other tanks. If the fluid in the tank undergoes chemical or mixing treatment, the level control is necessary. The level and flow plays vital role in industries. Conical tanks are widely used in industries like food, hydrometallurgical, petrochemical, wastewater treatment industries, milk industries etc. conical tank gives better drainage to the solid materials, semi solid materials as well as viscous fluids. The level control in the conical tank is a challenging problem because of its constantly changing its cross sectional area. For controlling of this type of system PID controller is used. But any conventional controller can work properly with linear system. So linearity can be obtained by piecewise linearized method. Many researchers have been carried out in level control of the conical tank process. S.Anand, Aswin V. and S. Rakeshkumar [1] explained an adaptive PI controller for conical tank system. Sukanya R. Warier et al., [2] carried out experiment on level control using Model Predictive controller (MPC) based controller. H.Kala et al., [3] have been done comparative analysis of direct synthesis Pi controller and Model Predictive Controller. Tuning of Controller for nonlinear process

has been done based on intelligent controller like Genetic algorithm by D.Mercy et al., [4].

In this paper PI controller is designed and tuned by direct synthesis method. It is implemented on real time system using Arduino board. The FOPDT model has been derived by piecewise linearization. Arduino can interface the plant without any programming. It is user friendly and simple to use based on prior knowledge of Matlab/SIMULINK.

EXPERIMENTAL SETUP

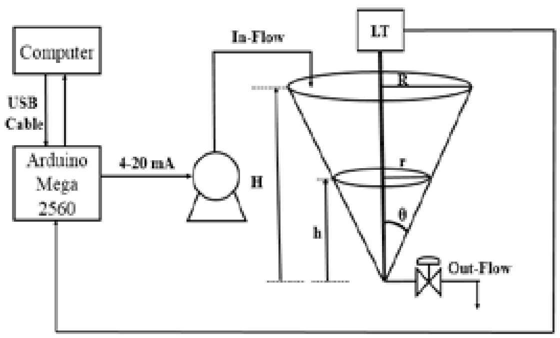

Fig.1 block diagram of conical tank system

Fig.1 shows the block diagram of Real time level control of conical Tank system. It consist of Reservoir, plunger pump, level transmitter, Arduino Mega 2560, I to V converter, V to I converter and PC. PC is connected to the Arduino board using USB cable which can give the supply as well as it can Transmit-Receive the data to and from plant.

Water is pumped with the help of plunger pump which gives flow according to input current. The inflow rate of the tank is adjusted by passing control signal from PC to plunger pump to manipulate the input current to the pump through Arduino board and V to I converter. In this system control variable is height of liquid in conical tank and manipulated variable is inlet flow of water in process.

The Arduino Mega 2560 is used for interfacing the personal computer with MATLAB and conical tank system. Level of water in conical tank is measured with the help of level transmitter (LT) which is calibrated for 0-60 cm and is converted to an output current range of 4-20 mA. This output current from LT is passed through 250 ohm resistor to convert it to 1-5 V range, which is given to the controller through Arduino board. Controller compare it with set point of height and generate control signal in form of 1-5 V, which is fed to V to I converter to convert it to 4-20 mA range and then given to the plunger pump.

The Arduino Mega 2560 is microcontroller board with ATmega 2560. It has 54 digital I/O pins of which 15 PWM outputs, 16 analog input pins, 4 UART (hardware serial ports), 16 MHz crystal oscillator. The operating voltage is 5V [12]. The Arduino board can be operated with console Arduino software and also with programming software like MATLAB.

Table 1.
Technical Specifications of Instruments

Components	Specifications	
Process Tank	Capacity Height Diameter	87.231 liter 68 cm 70 cm
Level Transmitter	Height Type Output	0-60 cm Capacitive 4-20 mA
Pump	Type Capacity Pressure	Plunger 0-240 LPH 1 Kg/ cm^2
Variable Frequency Drive	Input voltage Motor capacity Output voltage	1Φ AC 200-230 V 0.75KW 3Φ AC, 0-230V, 0.8A, 0.3kVA

MATHEMATICAL MODELING

The Mass-Balance equation is given by

Rate of accumulation of mass in tank = (rate of mass in) – (rate of mass out)

$$\frac{dV}{dt} = F_{in} - F_{out} \qquad (1)$$

Volume (V) = Area (A) * height (h)

$F_{out} = b\sqrt{h}$;

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

$A = \prod r^2$

$\tan\theta = \frac{r}{h} = \frac{R}{H}$

$r = \frac{R}{H}h$

$A = \left(\frac{\prod r^2}{H^2}\right) H^2$

LINEARIZATION OF MODEL

The nonlinear process model can be linearized around a particular steady state value and with this linearized approximation of the real model, we can obtain generalized result regarding the process behavior, but these will only approximate, never completely representing true behavior accurately.

To linearize the equation around steady state operating point $(\bar{h}, \bar{F}_{in})$ using Taylor series, suppose a nonlinear dynamic model has been derived from first principles (material, energy or momentum balance).

$$A\frac{dh'}{dt} = f_{in}' - \frac{b}{2\sqrt{h}}h'$$

Where h' and f_{in}' are deviation variables.

If we define the valve restriction K using the following relation:

$$\frac{1}{K} = \frac{b}{2\sqrt{h}}$$

Then, $$A\frac{dh'}{dt} = F_{in}' - \frac{h'}{K}$$

$$AR_v\frac{dh'}{dt} = KF_{in}' - h'$$

$$G(s) = \frac{h'(s)}{F_{in}'(s)} = \frac{K}{(\tau s + 1)} \qquad (3)$$

Where,

$$K = \frac{2\sqrt{h}}{b}$$

$$\tau = AK = \frac{2A\sqrt{h}}{b}$$

$$A = \left(\frac{\prod r^2}{H^2}\right) h^2$$

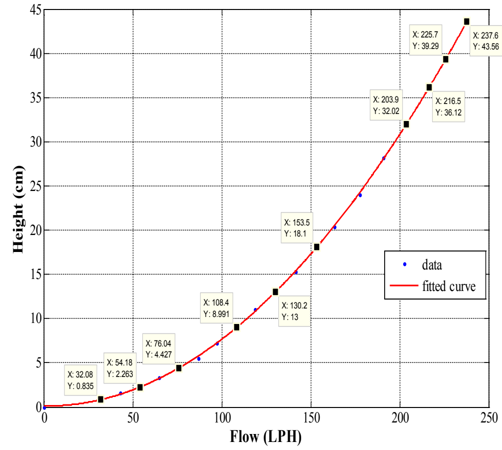

Fig. 2 Open loop response for Steady state point

TABLE 2
Model Parameter of Conical Tank

Region	Inflow (LPH)	Height (cm)	Gain	Time constant
1	0-65	3.3	0.366	3.31
2	65-119	11	0.667	67.16
3	119-178	24	0.979	469.28
4	178-238	43.5	1.319	2077.06

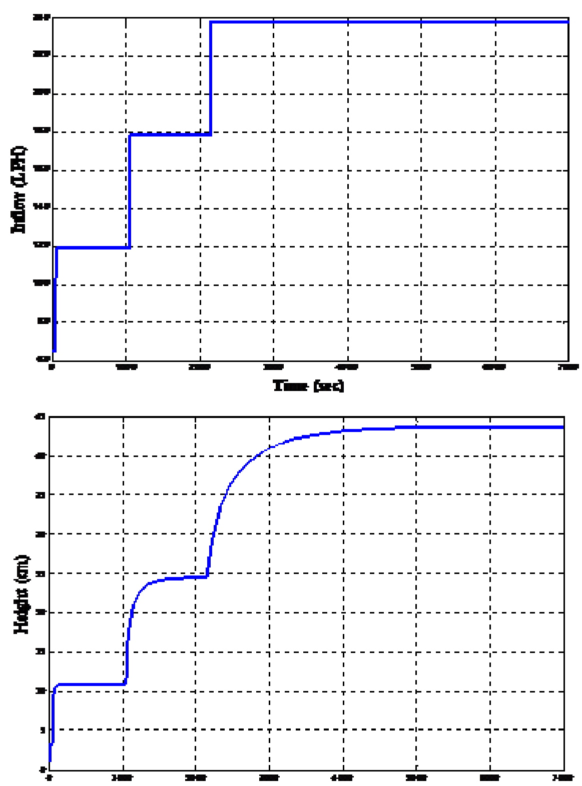

Fig. 3 Open Loop Response by step change in flow

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CONTROLLER DESIGN

After deriving the transfer function (FOPDT) model the controller must be designed for maintaining the system to the desired setpoint. Here outlet valve is set to a particular restriction.

$$G(s) = \frac{K*e^{-\theta s}}{(\tau s+1)} \qquad (4)$$

- **Direct Synthesis Method For PI Tuning**

Desired setpoint can be achieved by proper tuning of PI parameters likewise k_p and ti. For that direct synthesis method is used. In the direct synthesis method, the controller design is based on a desired closed-loop transfer function for set-point. The direct synthesis design method has a single design parameter, the desired closed-loop time constant (τ). In the direct synthesis approach, an analytical expression for the feedback controller is derived from a process model and a desired closed-loop response.

$$G_{sp}(s) = \frac{y}{r} = \frac{G_c(s)\,G_p(s)}{1+G_c(s)\,G_p(s)}$$

$$G_c(s) = \frac{\frac{y}{r}}{G_p(s)[1-\frac{y}{r}]}$$

$$G_c(s) = \frac{e^{-\theta s}}{(\tau_c+\theta)s} * \frac{(\tau s+1)}{K}$$

$$= \frac{\tau}{(\tau_c+\theta)K}\left(1+\frac{1}{(\tau s)}\right)$$

This is a PI controller with $K_p = \frac{\tau}{(\tau_c+\theta)K}$ and $\tau_I = \tau$

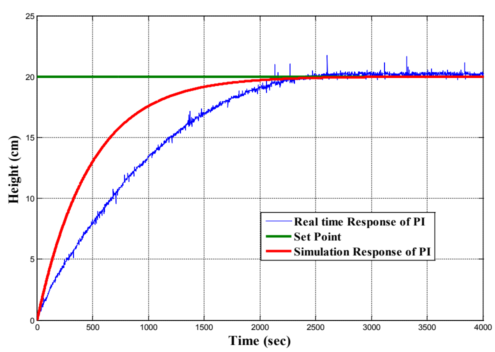

Fig. 4 Comparison of Simulation and Real Time PI Implementation

CONCLUSION

This paper proposes a traditional controller for controlling a nonlinear system by using new method of interfacing the real time process. The FOPDT model for the conical tank system is identified for different regions and tuned PI controller is applied for that in Matlab environment as well as in real time using Arduino board. Here direct synthesis method is used for tuning of PI controller which takes more time to stable. Other method of PI tuning can also be applied to obtain better response. From the comparison of simulation result and real time result of one operating point real model settle at same time but rise time will be changed.

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