Modelling and Controller of Liquid Level system using PID controller

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Abstract— *The control of liquid level in tanks is one of the basic problem in the process industries. The thesis work deals with design of PID controller for the Liquid Level System. System identification of LLS is done and modeled through Empirical Zeigler-Nichols Tuning method. A transfer function is obtained with first order system plus delay. The system is controlled by PID controller and tuned by using Zeigler-Nichols tuning method. The PID controller is implemented in MATLAB and then simulated in Simulink to test the output of the system with respect to input. The output is obtained with less steady state error.*

Key Words- **PID controller: Zeigler-Nichols tuning: modeling of liquid level system.**

1. INTRODUCTION

Development of Liquid Level System has become an unavoidable part in many industries due to the wide use of boilers in nuclear power plants and other liquid based production techniques. . In process control, level control is a common method. Hence the level control system must be properly controlled by the suitable controller.

Table 1 liquid level system specifications

Pump		Process tank		Reservoir tank	
Model	Tullu 80	Material	Acrylic	Material	Mild Steel
Speed	6500RPM	Capacity	2 liters	Capacity	7 liters

PID controller is one of the most easiest and simplest controller that always been used in industrial. There are several methods to obtain the parameters for PID controllers such as trial and error method, Cohen-Coon (C-C) method and Ziegler-Nichols (Z-N). The values of the parameters in the controller determine the performance of system. In this paper Ziegler-Nichols (Z-N) tuning method is used.

2. MODELLING OF LIQUID LEVEL SYSTEM

The diagram of plant (the Liquid Level system) under consideration is shown in the fig 1. The plant level process controller VLPA-101-CE is truly versatile and highly reliable standard computer based level process Controller. It is a self contained process and control equipment. The VLPA- 101-CE has miniature pump, level sensor for sensing and personal computer for controlling.

Fig 1: The Liquid Level System VLPA-101-CE

To analyze the systems involving fluid flow, it essential to divide flow regimes into turbulent flow and laminar flow, according to the value of magnitude of Reynolds number. If the Reynolds number is greater than or about 3000 to 4000, then it is turbulent flow. And if the flow is laminar then the Reynolds number is less than or about 2000. And when Reynolds number is between 2000 and 3000 is called as transitional flow. In laminar flow, fluid flow mainly occurs in streamlines with no turbulence. Systems involving turbulent flow are represented by nonlinear differential equations, while systems involving laminar flow are represented in linear differential equations. (The flow of liquids in Industrial processes is often through pipes and tanks. Such flow is often turbulent and not laminar.)

In order to identify the behavior of a process, a mathematical description of the process has to be developed. But usually, the mathematical model of most of the physical processes is nonlinear in nature. On the other hand, most of the analysis like in simulation and design of the controllers, assumes that the process is linear in nature. In order to build this gap, the linearization of the nonlinear model is needed. This linearization is always done with respect to a particular operating point of the system. This section illustrates the nonlinear mathematical behavior of a process and the linearization of the model. Consider a specific example of a simple process described in Fig.2.

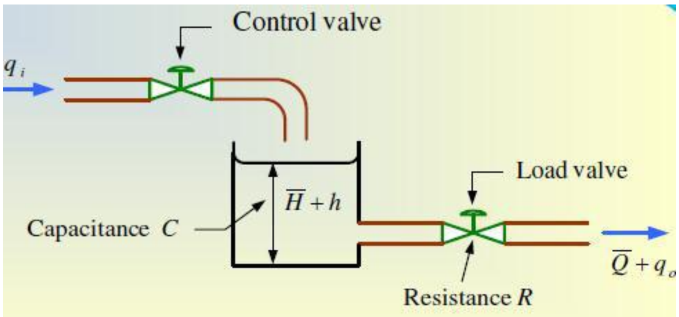

Fig 2: Example of a physical process

From the above figure it is understood that qi is the inflow rate and qo is the outflow rate (in m3/sec) of the tank, and h is the height of the liquid level of the tank at any time instant. And also assume that the cross sectional area of the tank be A. In steady state condition, both qi and qo are same, and the height h of the liquid level of the tank will be constant.

2.1 RESISTANCE OF LIQUID LEVEL SYSTEM

The resistance for liquid flow in such a pipe or restriction is defined as the change in the level difference to a unit change in flow rate; that is,

$$Resistance = \frac{change\ in\ level\ difference(m)}{change\ in\ flow\ rate(m^3/s)} \quad (1)$$

$$R = \frac{dH}{dQ} \quad (2)$$

2.2 CAPACITANCE OF LIQUID-LEVEL SYSTEMS

The capacitance of a tank is defined to be the change in quantity of stored liquid necessary to cause a unity change in the potential (head). The potential (head) is the quantity that includes the energy level of the system.

$$\frac{change\ in\ liquid\ stored, m^3}{change\ in\ head, m} \quad (3)$$

Capacitance (C) is nothing but is cross sectional area (A) of the tank.

Rate of change of fluid volume in tank = flow in – flow out

$$\frac{dV}{dt} = q_i - q_o \quad (4)$$

Since volume is (area x height)

$$\frac{d(A \times h)}{dt} = q_i - q_o \quad (5)$$

$$A\frac{dh}{dt} = q_i - q_o \quad (6)$$

And cross sectional area can be replaced by capacitance

$$C\frac{dh}{dt} = q_i - q_o \quad (7)$$

Where the resistance R may be written as

$$R = \frac{dH}{dQ} = \frac{h}{q_0} \quad (8)$$

Then rearranging the equation (8) we get

$$q_0 = \frac{h}{R} \quad (9)$$

Substitute equation (9) in equation (7), we get

$$C\frac{dh}{dt} = q_i - \frac{h}{R} \quad (10)$$

After simplifying above equation the equation (10) becomes

$$RC\frac{dh}{dt} + h = Rq_i \quad (11)$$

Taking Laplace transform considering initial conditions to zero

$$RCsH(s) + H(s) = RQ_i(s) \quad (12)$$

The transfer function can be obtained as

$$\frac{H(s)}{Q_i(s)} = \frac{R}{(RCs+1)} \quad (13)$$

Where,

C=cross sectional area of the tank =πr^2 cm^2 =$35\pi cm^2$

Radius of the tank is 6cm.

In the middle of the process tank consists of a tube with radius 1cm.

3. SYSTEM IDENTIFICATION

The determination of the dynamic behaviour of a process by experiment is called process identification. The method used in modelling of liquid level system is the system identification is Empirical method in which the experimental input-output data is used. In this section, the transfer function model using process reaction curve method is discussed for which the input and output data are generated from the real time system response.

Open-loop identification is widely used in the industry. In open loop step testing, a step change in input is applied to the process which will produce a corresponding response. It is called process reaction curve. In the chemical industry, for many processes the process reaction curve is an S-shaped curve.

The procedure to obtain the reaction curve of a plant in an open loop experiment as follows:

1) When the plant is in open loop condition, take the plant manually to a normal operating condition.
2) Say the plant output settles at y(t) = y_0 for a constant plant input u(t) = u_0.
3) At an initial time t_0, apply a step change to the plant input from u_0 to u_∞ (this should be in the range of 10 to 20% of full scale).
4) Record the plant output until it settles to the new operating point.
5) Thus the curve obtained is called process reaction curve. Which is shown in figure 3.8, m.s.t. stands for maximum slope tangent.

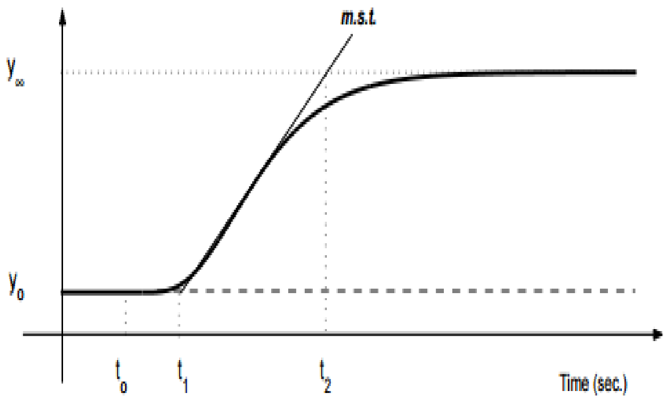

Fig 3 Plant Step Response

6) Where the process gain value K can be calculated as

$$K = \frac{y_o - y_\infty}{u_0 - u_\infty} \quad (14)$$

Where,

y_∞ and y_0 are outputs

u_∞ and u_0 are inputs

In which y_0 and u_0 are set points.

3.1 EMPIRICAL ZIEGLER AND NICHOLS METHOD

A very useful empirical tuning formula was proposed by Ziegler and Nichols in early 1942. The tuning formula is obtained when the plant model is given by a first-order transfer function model with a pure time-delay. In real-time process control systems, a large variety of plants can be modeled approximately. If the system model cannot be physically derived, experiments can be made to extract the parameters for the approximate model. Many industrial processes show step responses with pure a periodic behaviour according to Figure 3.9. This S-shape curve is characteristic of many high-order systems and such plant transfer functions may be approximated by the mathematical model can be expressed as

$$G(s) = \frac{K}{(Ts+1)} e^{-Ls} \qquad (15)$$

This contains a 1st order delay element and a dead time

Where,

K = process gain

T = process time constant ,

L = dead time of the process

3.2 TANGENT METHOD

1. Obtain the step response experimentally.

2. Draw a tangent at the inflection point.

3. Find gain value as ratio of steady - state change in output y to amplitude of input step A.

4. Dead time L= from time of step input to the intersection of the tangent line with the time axis.

5. T+L= time interval between the step input and the intersection of the tangent line with the final steady-state output level.

6. The output signal can be recorded as sketched in Fig.3.10, from which the parameters of *K*, *L* and *T* can be extracted

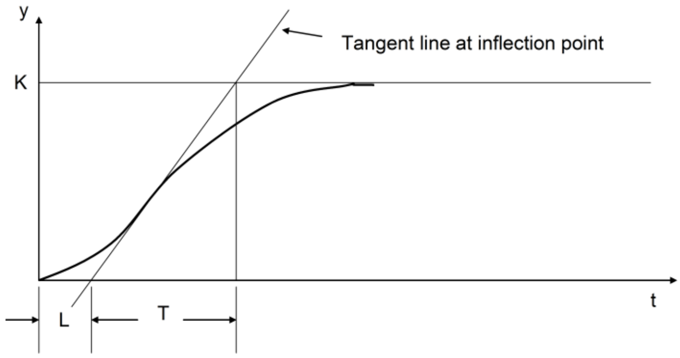

Fig: 4. Sketches of the responses of a first–order plus delay model

The transfer function model using process reaction curve method is shown here:

$$\frac{H(s)}{Q_i(s)} = \frac{1}{(5s+1)} e^{-s} \qquad (16)$$

Where,

K = 1, L = 1 and T = 5 and $a = K \times \frac{L}{T}$

4. EMPIRICAL ZIEGLER-NICHOLS TUNING FORMULA

For instance, if the step response of the plant model can be measured through an experiment, the output signal can be recorded as sketched in Fig.3, from which the parameters of *K*, *L* and *T* can be extracted.

The S-shaped reaction curve can be characterized by two constants, delay time L and time constant T, which are determined by drawing a tangent line at the inflection point of the curve and finding the intersections of the tangent line with the time axis and the steady-state level line. Using the parameters L and T, we can set the values of K_P, K_i and K_d according to the formula shown in the table below.

Table 2: Ziegler–Nichols tuning formula

controller type	From step response			From frequency		
	K_p	T_i	T_d	K_p	T_i	T_d
P	1\a			$0.5K_c$		
PI	0.9\a	3L		$0.4K_c$	$0.8T_c$	
PID	1.2\a	2L	L\2	$0.6K_c$	$0.5T_c$	$0.12T_c$

5. TUNING OF PID CONTROLLER PARAMETERS

Simulation of liquid level system using the controller PID

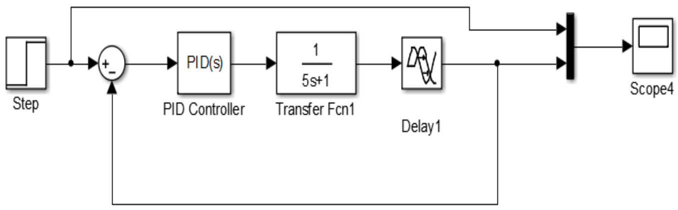

Fig 5: Simulation of single tank using pid controller

Table:3: PID Parameters from Empirical Ziegler-Nichols tuning formula

K_p	K_i	K_d
1.2	0.6	0.6

and output is obtained as

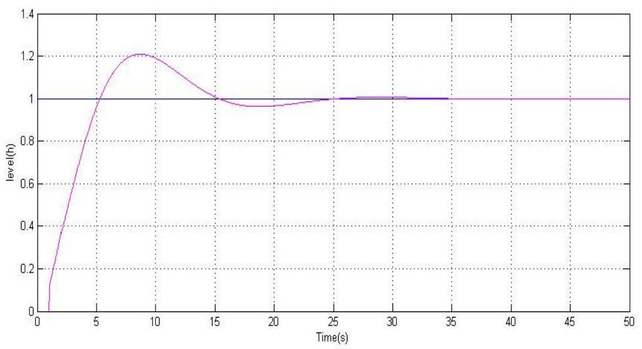

Fig 6: Simulation result of single tank using PID control

Simulation results shows that controller can maintain a level at a given value and be able to accept new set point values dynamically. And it significantly reduce the overshoot and steady state error.

6. CONCLUSION

The control of liquid level in tanks is one of the basic problem in the process industries. To achieve this, PID controller for the plant is simulated and implemented. The work mainly includes the design and modeling of liquid level system. System identification of LLS is done and modeled through Empirical Zeigler-Nichols Tuning method. A transfer function is obtained with first order system plus delay. Then the PID controller is designed by using Zeigler-Nichols tuning method.

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