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Control of Non Linear Spherical Tank Level Process

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Abstract-Control of process parameters is one of the important problems in process industry. The process considered for modeling is spherical tank liquid level system. Control of liquid level in a spherical tank is nonlinear due to the variation in the area of cross section of the level system with change in shape. The aim of this project is to implement an optimum controller for a spherical tank. The objective of the controller is to maintain the level inside the process tank in a desired value. System identification of this nonlinear process is done using piece-wise models.

I. INTRODUCTION

The industrial application of liquid level control is tremendous especially in refineries petroleum and chemical process industries. Usually, level control exists in some of the control loops of a process control system. An evaporator system is one example in which a liquid level control system is a part of control loop. Evaporators are used in many chemical process industries for the purpose of separation of chemical products. Level control is also very important for mixing reactant process. The quality of the product of the mixture depends on the level of the reactants in the mixing tank. Mixing reactant process is a very common process in chemical process industries and food processing industries. Many other industrial applications are concerned with level control, may it be a single loop level control or sometimes multi-loop level control. In some cases, level controls that are available in the industries are for interacting tanks. Hence, level control is one of the control system variables which are very important in process industries. Nowadays, chemical engineering systems are also at the heart of our economics. The process industries such as refineries petrol, petro-chemical industries, paper making and water treatment industries require liquids to be pumped, stored in tanks, and then pumped to another tank. In the design of control system, one often has a complicated mathematical model of a system that has been obtained from fundamental physics and chemistry. The above mentioned industries are the vital industries where liquid level and flow control is essential. Many times the liquids will be processed by chemical or mixing treatment in the tanks, but always the level fluid in the tanks must be controlled, and the flow between tanks must be regulated. Level and flow control in tanks are the heart of all chemical engineering systems.

Chemical process present many challenging control problems due to nonlinear dynamic behavior, uncertain and time varying parameters, constraints on manipulated variable, interaction between manipulated and controlled variables, unmeasured and frequent disturbances, dead time on input and measurements. Because of the inherent nonlinearity, most of the chemical process industries are in need of conventional control techniques. Spherical tanks find wide spread usage in gas plants. They are non-linear system because their area of cross-section keeps varying with the height of the tank. A sphere is a very strong structure. The even distribution of stresses on the sphere's surfaces means that there are no weak points. Moreover, they have a smaller surface area per unit volume than any other shape of vessel. This means, that the quantity of heat transferred from warmer surroundings to the liquid in the sphere, will be less than that for cylindrical or rectangular storage vessels. Thus causing less pressurization due to external heat. Control of a spherical tank is important, because the change in shape gives rise to the nonlinearity.

Conventional controllers are widely used in industries since they are simple robust and familiar to the field of operator. The most basic and pervasive controller algorithm used in the feedback control is proportional integral derivative controller algorithm. PID controller is widely used to control strategy to control most of industrial automation process because of its remarkable efficiency and simplicity. Hence a mathematical model is derived and a simulation is carried out for the given mathematical equation.

II. WORKING METHODOLOGY

The control parameter which we have chosen is the level. Capacity sensors and level transmitter arrangement senses the level from the process and converters into electrical signal. Then the electrical signal is fed to the I-V converter which in turn provides

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corresponding voltage to the controller.

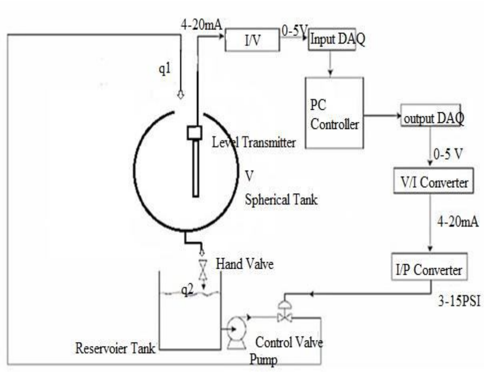

Fig 1. Block diagram for the system

The closed loop control system is one in which control action is dependent on the output. This maintain water level in storage tank. The system performs this task by continuously sensing the level in the tank and adjusting a supply valve to add more or less water to the tank. The actual storage tank level sensed by the level transmitter is fed back to the level controller. This feedback is compared with the desired level. Now the controller describes the control action and it is given to the I-V and then to I-P converter. The final control element is now controlled by the resulting air pressure. This in turn controls the inflow to the spherical tank and level is maintained.

Fig.1. shows the block diagram of the system. The flow rate to the spherical tank is regulated by changing the stem position of the pneumatic valve by passing control signal from computer to the I/P converter through DAQ CARD and V/I converter. The operation current for regulating the valve position is 4-20mA, which is converted to 3-15psi of compressed air pressure. The water level inside the tank is measured with the differential pressure transmitter which is calibrated and is converted to an output current of 4-20mA.This output current is converted into 0-5V using I/V converter ,which is given to the controller through DAQ CARD. The USB based DAQ CARD is used for interfacing the personal computer with the spherical tank.

The principle of capacitive level measurement is based on change of capacitance. An insulated electrode acts as one plate of capacitor and the tank wall (or reference electrode in a non-metallic vessel) acts as the other plate. The capacitance depends on the fluid level. An empty tank has a lower capacitance while a filled tank has a higher capacitance. A simple capacitor consists of two electrode plate separated by a small thickness of an insulator such as solid, liquid, gas, or vacuum. This insulator is also called as dielectric. Value of C depends on dielectric used, area of the plate and also distance between the plates.

The sensor and the wall of the container form the two electrodes of a capacitor. When the level changes, the electrical capacitance between the electrodes also changes. This change is evaluated by the electronics and converted into an output signal. Robust cable and rod versions cover a variety of applications. Level **s**ensors detect the level of liquids and other fluids and fluidized solids, including slurries, granular materials, and powders that exhibit an upper free surface.

III. SYSTEM MODELING

It is quite often the case that we have to design the control system for a process before the process has been constructed. In such a case we need a representation of the process in order to study its dynamic behavior. This representation is usually given in terms of a set of mathematical equations whose solution gives the dynamic or static behavior of the process. The process considered is the spherical tank in which the level of the liquid is desired to be maintained at a constant value. This can be achieved by controlling the input flow into the tank.

Transfer function of the system,

$$\frac{H(s)}{Q_1(s)} = \frac{R_t}{(R_t S \frac{1}{2} \pi h_s{}^2 + 1} \qquad (1)$$

take

$$\tau = R_t \frac{1}{2} \pi h_s^2$$

Equation (1) becomes,

$$\frac{H(s)}{Q_1(s)} = \frac{R_t}{\tau s + 1}$$

Where τ - time constant

$$\tau = R_t \frac{1}{2} \pi h_s^2$$

$$R_t = \frac{2\sqrt{h_s}}{c}$$

A. System Identification

The system identification problem deals with the determination of a mathematical model for a system or a process by observing the input-output data. 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 four different linear regions. Here system identification is done with piece-wise models around four operating points as shown in the level ranges. The transfer function model parameters are found for all the regions and the controller parameters are tuned further. The transfer function models are required only for the simulation studies of the controller design.

Transfer function,

$$\frac{H(s)}{Q_1(s)} = \frac{R_t}{\tau s + 1}$$

Here we have to find values for *R* & τ .

Transfer function parameters

The valve constant c = 6.3836

We know that

$$\tau = R_t \frac{1}{2} \pi h_s^2 \qquad R_t = \frac{2\sqrt{h_s}}{c}$$

With all the above information the following calculation is obtained

Table 3.1.1: Transfer Function model parameters

LevelRange (cm)	R_t (Gain)	τ (Time Constant in sec)
7	.8289	63.77
10	.9907	155.54
20	1.401	879.83

Region: 1

Level Range: 7cm

$$G(s) = \frac{H(s)}{Q_1(s)} = \frac{.8289}{(63.77s + 1)}$$

Region: 2

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Level Range: 10cm

$$G(s) = \frac{H(s)}{Q_1(s)} = \frac{.9907}{(155.54s + 1)}$$

Region: 3
Level Range: 20cm

$$G(s) = \frac{H(s)}{Q_1(s)} = \frac{1.401}{(979.93s + 1)}$$

IV. CONTROLLER DESIGN

A. PID Controller

In the control of dynamic systems, no controller has enjoyed both the success and the failure of the PID control. Of all control design techniques, the PID controller is the most widely used. Over 85% of all dynamic controllers are of the PID variety. There is actually a great variety of types and design Methods for the PID controller. What is a PID controller? The acronym PID stands for Proportional-Integral-Differential control. Each of these P, I and the D are terms in a control algorithm, and each has a special purpose. Sometimes certain of the terms are left out because they are not needed in the control design. This is possible to have a PI, PD or just a P control. It is very rare to have a ID control. Here we use Ziegler Nichols (ZN) tuning method for tuning the PID controller. There are mainly two types of Z-N tuning method.
Zeigler Nichols open loop tuning method
Zeigler Nichols closed loop tuning method

Here I choose ZN open loop tuning method. These rules were first proposed by Ziegler and Nichols also referred as process reaction method. This method can be used for only systems with self regulation. In a typical open loop controller response, the disturbances applied at two times. We expressed the deviation as the percentage range. Using these time constant and lag time is measured.

Time constant, $\tau = (t_2 - t_1)1.5$
Delay time, $t_{d = t2} - \tau$
t_1= 28.3% of the steady state value
t_2 = 63.2% of the steady state value

1) Proportional Controller:

$$\text{Proportional gain } Kp = \frac{\tau}{Ktd.}[1 + \frac{td}{3\tau}]$$

2) Proportional Integral Controller:

Proportional gain Kp = $(.9T)/ t_{d\ K}$
Integral time Ti = 2 t_d
Integral gain Ki = Kp/Ti

3) Proportional Integral Derivative controller:

$$\text{Proportional gain } Kp = \frac{\tau}{Ktd.}[\frac{4}{3} + \frac{td}{4\tau}]$$

$$\text{Integral time } Ti = td\,[\frac{32+\frac{6td}{\tau}}{13+\frac{8td}{\tau}}]$$

Integral gain Ki = Kp/Ti

$$\text{Derivative time } Td = t_d\,[\frac{4}{11+\frac{3td}{\tau}}]$$

Derivative gain Kd = Kp * Td

V. SIMULATION RESULTS

Simulation is done with the help of MATLAB simuLink. The name MATLAB stands for MATrix LABoratory. MATLAB was written originally to provide easy access to matrix software developed by the LINPACK (linear system package) and EISPACK

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(Eigen system package) projects. MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming environment. Furthermore, MATLAB is a modern programming language environment: it has sophisticated data structures, contains built-in editing and debugging tools, and supports object-oriented programming. These factors make MATLAB an excellent tool for teaching and research.

MATLAB has many advantages compared to conventional computer languages (e.g.,C, FORTRAN) for solving technical problems. MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. The software package has been commercially available since 1984 and is now considered as a standard tool at most universities and industries worldwide. It has powerful built-in routines that enable a very wide variety of computations. It also has easy to use graphics commands that make the visualization of results immediately available. Specific applications are collected in packages referred to as toolbox.

There are toolboxes for signal processing, symbolic computation, control theory, simulation, optimization, and several other fields of applied science and engineering. After logging into your account, you can enter MATLAB by double-clicking on the MATLAB shortcut icon on your Windows desktop. When you start MATLAB, a special window called the MATLAB desktop appears. The desktop is a window that contains other windows. The major tools within or accessible from the desktop are:

The Command Window
The Command History
The Workspace
The Current Directory
The Help Browser
The Start button

All the commands were executed in the Command Window. The problem is that the commands entered in the Command Window cannot be saved and executed again for several times. Simulink is an environment for simulation and model-based design for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that let you design, simulate, implement, and test a variety of time-varying systems, including communications, controls, signal processing, video processing, and image processing.

Simulink offers:
A quick way of develop your model in contrast to text based-programming language such as e.g., C.
Simulink has integrated solvers. In text based-programming language such as e.g., C you need to write your own solver.
The Simulink Library Browser is the library where you find all the blocks you may use in Simulink. Simulink software includes an extensive library of functions commonly used in modeling a system. These include:

Continuous and discrete dynamics blocks, such as Integration, Transfer functions, Transport Delay, etc
Math blocks, such as Sum, Product, Add, etc
Sources, such as Ramp, Random Generator, Step, etc

A. Simulink Diagram For Different Controllers

Table 5.1.1.Controller settings for ZN PID and ZN PI

Region	PID			PI	
	Kp	Ki	Kd	Kp	Ki
Region 1	105.4939	43.9046	37.5337	71.022	36.1435
Region 2	161.0498	50.664	75.7256	108.809	41.978
Region3	17.73	.2033	231.073	11.7937	.161

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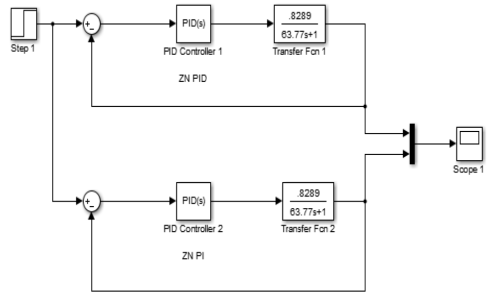

Fig.5.1.1. Simulink diagram of ZN IN and ZN PID for region1

B. Simulation Results for Different Controllers

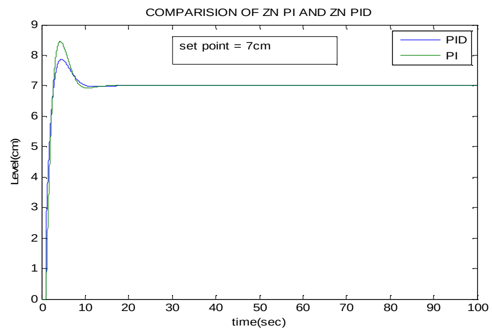

Fig.5.2.1. Comparison of ZN PID and ZN PI for region1

VI. CONCLUSION

In this, the modeling of Spherical tank is done and the transfer function parameters are obtained from the modeling. The nonlinearity of the spherical tank is analyzed and controlled with the help of conventional PI and PID controller. In future a suitable advanced controller for first order system can be implemented for the real time control of spherical tank. The performance of that controller can be compared with conventional controllers to prove its effectiveness in nonlinear system control.

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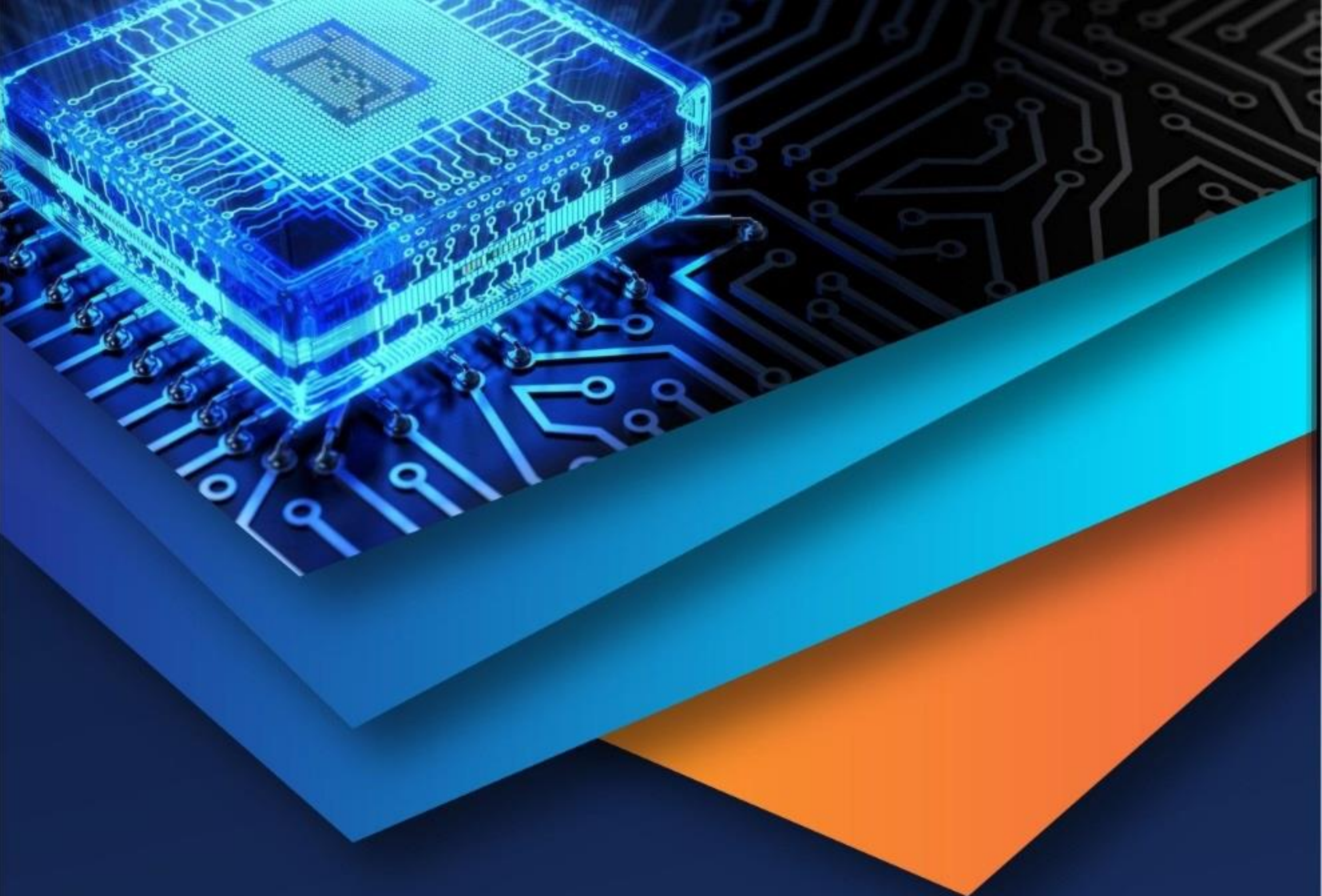

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