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LABVIEW BASED TUNING OF PI CONTROLLERS FOR A REAL TIME NON LINEAR PROCESS

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ABSTRACT

The phenomenal growth that has been evidently seen in the last two decades has brought a multifold development in the process industry. The experts have always focused upon the control of the level and other process parameters. In this paper we have chosen a real time Single Spherical Tank Liquid Level System (SSTLLS) for our investigation. The aim of this paper is to compare the design and implementation of Ziegler-Nichols (ZN) and Skogestad's tuning based PI controllers for the SSTLLS using LabVIEW and NI-DAQmx 6211 data acquisition card. The real time model identification and Graphical User Interface (GUI) are discussed and their PI Controller implementation using LabVIEW are outlined.

Keywords: *Single Spherical Tank Liquid Level System (SSTLLS), Graphical User Interface (GUI), PI Controller, Z-N Method, Skogestad's Method, LabVIEW.*

1. INTRODUCTION

In common terms, most of the industries have typical problems raised because of the dynamic non linear behavior. Its only because of the inherent non linearity, most of the chemical process industries are in need of classical control techniques. Hydrometallurgical industries, food process industries, concrete mixing industries and waste water treatment industries have been actively using the spherical tanks as an integral process element. Due to its constantly changing cross section and non linearity of the tank a spherical tank provides a challenging problem for the level control.

Liquid level control systems have always pulled the attention of industry for its very important manipulated parameter of level, which finds many applications in various fields. An accurate knowledge of an adequate model is often not easily available. An insufficiency in this aspect of model design can always lead to a failure in some non linear region with higher non linearity. The evidence of mushrooming interest in the nonlinear models and their controlling strategies [1, 2], which in turn described about the process dynamics around a larger operating region than the corresponding linear models have been gaining great popularity [3].The non linear models are obtained from first principles and further from the parameters which appear within such models that are procured from the data of the process. However the conventional methods for developing such models are still in search. Once the model has been developed, then the need for the controller design comes in to picture to maintain the process under steady state. Proportional Integral Derivative (PID) controller is the name that is widely heard as a part of process control industry. Despite much advancement in control theory which has been recently seen, PID controllers are still extensively used in the process industry. Conventional PID controllers are simple, inexpensive in cost [4], easy to design and robust provided the system is linear. The PID controller operates with three parameters, which can be easily tuned by trial and error ,or by using different tuning strategies and rules available in literature such as ZN [5], Zhuang and Atherton [6],Sung et al. [7].These rules have their bases laid on open-loop stable first or second –order plus dead time process models. There are many other methods and approaches which have periodically evolved to improvise the performance of PID tuning, For instance the Aström–Hägglund phase margin method [8], the refined ZN method by Cohen and Coon [9] as well as Hang et al. [10], the internal model control (IMC) design method [11,12],gain and phase margin design methods [13,14], and so on. The software and technology have been assisting the mankind by offering a potential to design and implement more sophisticated control algorithms. Despite all the effort, industries emphasize more on robust and transparent process control structure that uses simple controllers which makes PID controller the most widely implemented controller.

SSTLLS has been a model for quite a many experiments performed in the near past. S.Nithya et al [18] have designed a model based controller for a spherical tank, which gave a comparison between IMC and PI controller using MATLAB. Naresh N.Nandola et al[19] have studied and mathematically designed a predictive controller for non linear hybrid system. A model reference adaptive controller has been designed and simulated by K.Hari Krishna et al [20] for a spherical tank. A gain scheduled PI controller was designed using a simulation on MATLAB for a second order non linear system by D.Dinesh Kumar et al[21] which gave information about servo tracking for different set points. A fractional order PID controller was designed for liquid level in spherical tank using MATLAB, which compared the performance of fractional order PID with classical PI controller by K.Sundaravadivu et al [22].

This paper endeavors to design a system using the process reaction curve method which is also known as first method. We obtain experimentally the response of the plant to a unit-step input. If the plant involves neither integrator(s) nor dominant complex-conjugate poles, then such a unit step response curve may look S-shaped curve. Such step response curve may be generated experimentally or from a dynamic simulation of the plant. The S-shaped curve may be characterized by two constants, delay time L and time constant T. There on we implement the Skogestad's and ZN tuning techniques to design the PI controller so as to control the level parameter of the SSTLLS.

2. EXPERIMENTAL PROCESS DESCRIPTION

The laboratory set up for this system basically comprises two spherical interacting tanks which are connected with a manually operable valve between them. Both the tanks have an inflow and outflow of water which is being pumped by the motor, which continuously sucks in the water from the water reservoir. The flow is regulated in to the tanks through the pneumatic control valves, whose position can be controlled by applying air to them. We employ a compressor so as to apply pressure to close and open the pneumatic valves. There is also provision given to manually measure the flow rate in both the tanks using rotameter. The level in the tanks are being measured by a differential pressure transmitter which has a typical output current range of 4-20mA.This differential pressure transmitter is interfaced to the computer connected through the NI-DAQmx 6211 data acquisition module card which can support 16 analog inputs and 2 analog output channels with a voltage ranging between ±10 Volts. The sampling rate of the acquisition card module is 250Ks/S with 16 bit resolution. The graphical program written in LabVIEW is then linked to the set up through the acquisition module. Figure 1 shows the real time experimental setup of the process.

Figure 1: Real Time Experimental Set Up Of The Process.

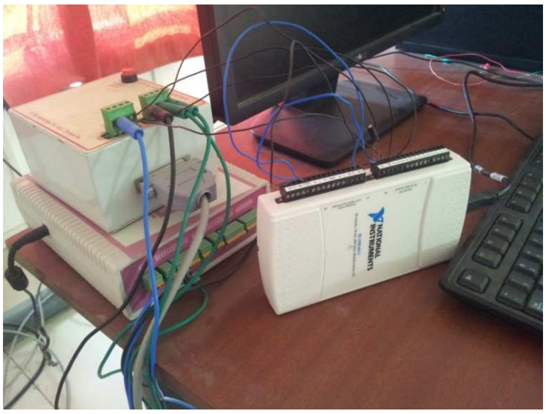

Figure 2: Interfaced NI-Daqmx 6211 Data Acquisition Module Card.

The process of operation starts when pneumatic control valve is closed by applying the air to adjust the flow of water pumped to the tank. This paper talks only about a single spherical tank liquid level system (SSTLLS), so we shall use only the spherical tank one for our usage throughout the experiment. The level of the water in tank is measured by the differential pressure transmitter and is transmitted in the form of current range of 4-20mA to the interfacing NI-DAQmx 6211 data acquisition module card to the Personal Computer (PC).After computing the control algorithm in the PC, control signal is transmitted to the I/P converter which passes the pressure to the pneumatic valve proportional to the current provided to it. The pneumatic valve is actuated by the signal provided by I/P converter which in turn regulates the flow of water in to the tank. Figure 2 shows the interfaced NI-DAQmx 6211 data acquisition module card. Table 1 shows the technical specifications of the interacting two tank spherical tank liquid level system setup. A Graphical User Interface of the SSTLLS, which is designed by using LabVIEW, can also be seen in Figure 3.

3. SYSTEM IDENTIFICATION AND CONTROLLER DESIGN

3.1. Mathematical Modeling of SSTLLS

The SSTLLS is a system with non linear nature in virtue of its varying diameter. The dynamics of non linearity for this system can be described by the first order differential equation.

$$\frac{dV}{dt} = q_1 - q_2 \qquad (1)$$

Where,

V is the volume of the tank

q_1 is the Inlet flow rate and

q_2 is the Outlet flow rate.

The volume V of the spherical tank is given by,

$$V= \frac{4}{3}\pi h^3 \qquad (2)$$

Where h is the height of the tank in cm.

On application of the steady state values, and by solving the equations 1 and 2,the non linear spherical tank can be linearized by the following model,

$$\frac{H(S)}{Q1(S)} = \frac{Rt}{\tau s+1} \qquad (3)$$

Where, $\tau = 4\pi R_t h_S$ and $Rt = \frac{2hs}{Q2s}$

Table 1: Technical Specifications of the Experimental Setup

PART NAME	DETAILS
Spherical Tank	Material: Stainless Steel Diameter:45 cm
Storage Tank	Material: Stainless Steel Volume:100 liters
Differential Pressure Transmitter	Type: Capacitance Range:(2.5 to 250)mBAR Output:(4 to 20)mA
Pump	Centrifugal 0.5 HP
Control Valve	Size:1/4”,Pnematic actuated Type: Air to close Input(3-15)PSI 0.2-1 Kg/cm2
Rotometer	Range:(0-440)LPH
Air Regulator	Size 1/4” BSP Range:(0-2.2)BAR
I/P Converter	Input:4-20 mA Output: (3-15) PSI
Pressure Gauge	Range:(0-30) PSI Range:(0-100) PSI

The system identification of SSTLLS is derived using the black box modeling. Under constant inflow and constant outflow rates of water, the tank is allowed to fill from (0-45) cm. Each sample is acquired by NI-DAQmx 6211 from the differential pressure transmitter through USB port in the range of (4-20) mA and the data is transferred to the PC. This data is further scaled in terms of level (in cm).Employing the open loop method, for a given change in the input variable; the output response of the system is recorded. Ziegler and Nichols [5] have obtained the time constant and time delay of a FOPDT model by constructing a tangent to the experimental open loop step response at its point of inflection. The intersection of the tangent with the time axis provides the estimate of time delay. The time constant is estimated by calculating the tangent intersection with the steady state output value divided by the model gain.

Cheng and Hung [15] have also proposed tangent and point of inflection methods for estimating FOPDT model parameters. The major disadvantage of all these methods is the difficulty in locating the point of inflection in practice and may not be accurate. Prabhu and Chidambaram [16] have obtained the parameters of the first order plus time delay model from the reaction curve obtained by solving the nonlinear differential equations model of a distillation column.

Sundaresan and Krishnaswamy [17] have obtained the parameters of FOPDT transfer function model by collecting the open loop input-output response of the process and that of the model to meet at two points which describe the two parameters τ_p and θ. The proposed times t_1 and t_2, are estimated from a step response curve. The proposed times t_1 and t_2, are estimated from a step response curve. This time corresponds to the 35.3% and 85.3% response times.

The time constant and time delay are calculated as follows.

$$\tau_p = 0.67(t_2 - t_1) \tag{4}$$

$$\theta = 1.3t_1 - 0.29t_2 \tag{5}$$

At a constant inlet and outlet flow rates, the system reaches the steady state. After that a step increment to the system is given by changing the flow rate and various values of the same are taken and recorded till the system becomes stable again as shown in the figure 4. The experimental data are approximated to be a FOPDT model. The model parameters are identified to be,

$$G(s) = \frac{15.e^{-82.943}}{265.15s+1} \tag{6}$$

3.2. Design of PI Controller

The derivation of transfer function model will now pave the way to the controller design which shall be used to maintain the system to the optimal set point. This can be only obtained by properly selecting the tuning parameters K_p and τ_i for a PI controller. The conventional FOPDT model is given by

$$G(s) = \frac{K.e^{-\theta s}}{\tau s+1} \tag{7}$$

By implementing the rules of PI tuning by the methods ZN method and Skogestad's Method to get the following parameters for the transfer function specified in equation 6.

Table 2: Tuned PI Controller Parameters For ZN And Skogestad's Methods

Type of Controller	K_P	τ_i(sec)
ZN Method	0.191813	248.82
Skogestad's Method	0.106563	265.15

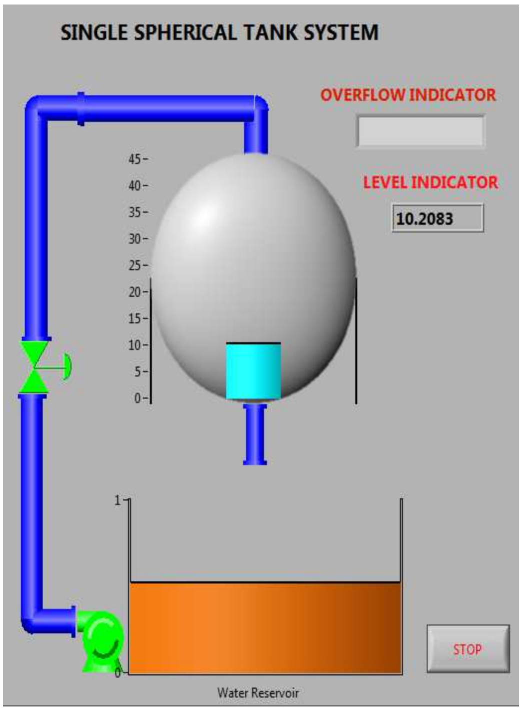

Figure 3: Graphical User Interface For The SSTLLS Designed In Labview.

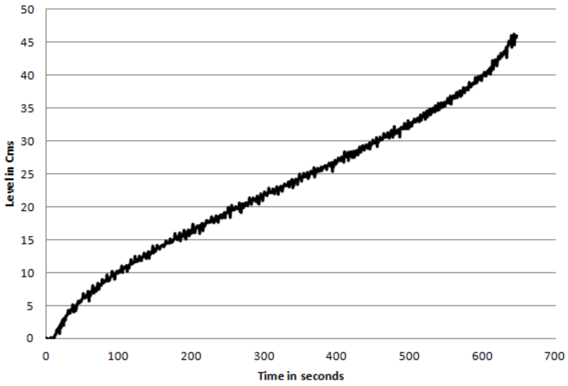

Figure 4: S-Shaped Open Loop Input-Output Response Curve

4. RESULTS AND DISCUSSIONS

The ZN and Skogestad's based PI controllers which were designed are implemented using the graphical programming code which is written on LabVIEW. Both the controllers were applied to SSTLLS and the performance of the both was compared under different conditions.

4.1. Variation of the Set Point

The Skogestad's controller is run for a sequence of set points which are 5,15,25,30 and 45 cm and is compared with the ZN Controller for the same sequence of set points. The level varies for both the controllers and their changes are seen in the figure 4.It can be observed that the level very swiftly oscillates for the ZN method and oscillation is not very much seen in the Skogestad's method. It can be also observed that the Skogestad's PI based controller tracks the set point in a very less time when compared to that of ZN method.

Table 3 gives the time domain specifications of the present system. Its evident form Table 3 that the Rise time, Peak time and Settling time for different set points for Skogestad's method are relatively low in comparison with ZN method. From Table 4 it can be seen that IAE and ISE values are also considerably very low for the Skogestad's method when looked in to ZN method.

4.2. Changes in Load

The Skogestad's and ZN tuned controllers have been used to control the level of SSTLLS while applying a load change of 7.5% for a set of set points. Initially to test the response of the tank in its non linear region, a set point of 5 cm was fed to the program and the readings were recorded. Similar method was employed for the set points of 25, 20 and 40 cm respectively. At all the levels, a disturbance is added to the system to observe its performance. After 25 cm a negative set point change of 20 cm was also given. From the figures 5 and 6, the regulatory load change and the set point tracking under the influence of external disturbance for Skogestad's method and ZN method respectively can be observed. The performance indices of the regulatory response can be seen in Table 5.The designed controllers were able to compensate the effect of the load changes. It can be noticed from Table 5, that the ISE and IAE values for Skogestad's method are relatively lesser than the ZN method.

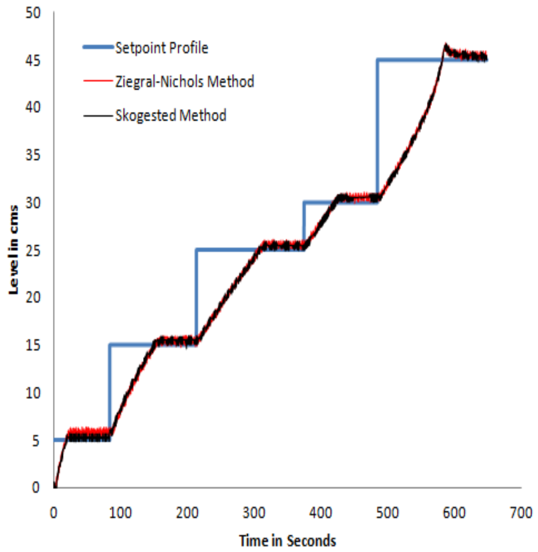

Figure 4: Comparison Of Servo Responses ZN And Skogestad's Tuned Controllers

Table 3: Comparison Of Time Domain Indices For Servo Response At Different Set Points.

Specifications	Set Point	ZN Method	Skogestad's Method
Peak Time (Sec)	5	24.93	23.734
	15	78.905625	76.355625
	25	131.85563	125.695625
	30	57.905625	51.305625
	45	103.0425	101.8525
Rise Time (Sec)	5	22.437	21.3606
	15	71.015063	68.7200625
	25	118.67006	113.1260625
	30	52.115063	46.1750625
	45	92.73825	91.66725
Settling Time (Sec)	5	60.000375	58.804375
	15	137.12875	134.57875
	25	249.03875	242.87875
	30	433.38188	426.781875
	45	546.63188	545.441875

Table 4: Comparison of performance domain indices for servo response at different set points.

Set Point	Controller Type	ISE	IAE
5	ZN	378.67	391.82
	Skogestad's	57.39	145.01
15	ZN	137.09	216.66
	Skogestad's	124.35	210.73
25	ZN	156.71	244.73
	Skogestad's	101.82	195.1
30	ZN	133.34	219.41
	Skogestad's	125.63	215.03
45	ZN	205.74	266.96
	Skogestad's	207.93	263.4

Table 5: Comparison of performance indices for the regulatory response at different set points

Set Point (cm)	Controller	ISE	IAE
5	ZN	14992.52	6105.478
	Skogestad's	13489.93	5901.514
25	ZN	3403.527	2625.703
	Skogestad's	2391.98	2067.556
20	ZN	4143.28	3477.369
	Skogestad's	893.2813	1003.832
40	ZN	12698.31	4532.423
	Skogestad's	11132.29	4115.277

5. CONCLUSIONS

In this study, a Skogestad's and ZN method based Controller were designed for a SSTLLS process. The model identification and controller design were done using an NI-DAQmx 6211 data acquisition card and LabVIEW. Graphical programming was used to implement the whole experiment. The experimental results evidently prove that the influence of set point and load changes are smooth for Skogestad's method of tuning. It can be also seen that minimum overshoot, faster settling time and rise time. It has a better capability of compensating all the load changes .

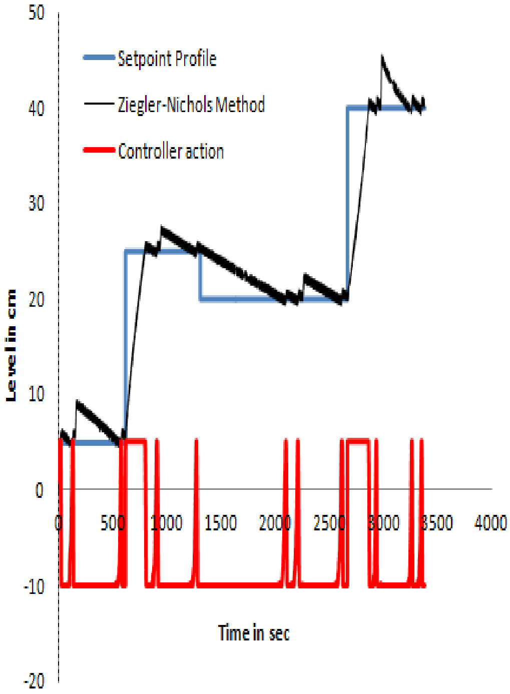

Figure 6: Regulatory Response Using ZN Tuned Controller

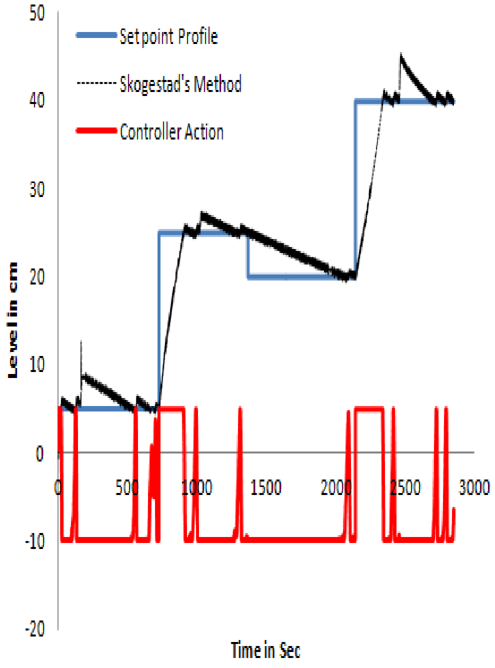

Figure 5: Regulatory Response Using Skogestad's Tuned Controller

The ISE and IAE values justify that relatively a minimum error is seen in Skogestad's way of tuning the PI controller than ZN method for both servo and regulatory responses. It can be concluded that Skogestad's method based PI controller can be implemented on real time SSTLLS using NI-DAQmx 6211 data acquisition module and LabVIEW.

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