Non Linear Tank Level Control using LabVIEW
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Abstract—Modeling and control of highly nonlinear system is important in industries. The work on the development of model identification and controller designing for spherical tank level control process. [1] Spherical tank is considered as nonlinear system, where the aim is to control the liquid level of tank. Control of liquid level in spherical tank system is highly challenging due to variation in the area of cross section of spherical tank with change in shape. So, tank is liberalized into different operating regions by step test method. First order plus dead time model is identified from real time process tank at different operating point and multiple PID controller were planned to implement. Different type of tuning algorithm (ZN, CC, and IMC) was to be applied in simulation environment and optimized controller setting is highlighted on the basis of time domain analysis, error criterion test, and by stability analysis.[1]

Key words: Spherical tank, PID controller, First order plus dead time model, ZN, CC, IMC

I. INTRODUCTION
Most of the chemical industries have many challenging problems during nonlinear dynamic behavior. Because of the nonlinearity, most of the chemical industries are in need of traditional control techniques control of a level in spherical tank is important because the change in shape gives rise to the nonlinearity. The chemical industries need the liquids to be pumped, stored in tank and then pumped to another tank. Most of the times the liquid will be processed by chemical and mixing treatment in the tanks, but always the level of the fluid in the tanks must be controlled. A level that is too high may upset the reaction equilibrium, cause damage to the equipment or result spillage of valuable or hazardous material.[3] If level is too low, it may have wrong consequences for the sequential operations. Hence, the controlling of liquid level is an important and common in chemical and process industries. Spherical tank is widely used in hydrometallurgical industries, food process industries, concrete mixing industries and waste water treatment. In these type process depends on two types of operational factors. They are rate of change of flow from one vessel to another and level of fluid in the tank. Level control of liquid in a spherical tank presents a challenging problem due to its constantly changing cross section and non linearity of the tank. Hence, control of liquid level is an important task in process industries. Their shape used for better drainage of solid mixtures, slurries and viscous liquids. Conventional controllers are widely used in process industries because they are simple and have good robustness. PID controller is widely used control strategy to control industrial automation process because of its good efficiency and simplicity. The mathematical model is derived and a simulation is carried out for the given mathematical equation. Then the output of the simulation is split up into four regions and then the controller is designed for the problem.[3]

A. Mathematical Modeling of Spherical Tank:

Consider a spherical tank, as shown in figure, of radius R.

The water flows in at a rate Fin and flows out at a rate Fout.

Volume of a sphere is given by, \( V = \frac{4}{3} \pi R^3 \)

The first order differential equation of the system is given by,

\[
F_i = \frac{F_i}{R} \quad \text{flow rate at inlet of the tank}
\]

\[
F_o = \frac{F_o}{R} \quad \text{flow rate at outlet of the tank}
\]

\[
h = \text{height of the liquid in the tank}
\]

\[
R = \text{resistance to flow}
\]

A = area of cross section area of tank

\[
A \frac{dh}{dt} = F_i - F_o = F_i - h/R
\]

At steady state

\[
H_s = R F_i, s
\]

In terms of deviation variables from 1 and 2

\[
A \frac{dh}{dt} + h = RF_i'
\]

Where \( h = h - h_s \) and \( F_i' = F - F_o \)

\[
T_p = \text{AR time constant the process}
\]

\[
K_p = \text{steady state gain of the process}
\]

Transfer function

\[
G(s) = \frac{h(s)}{F_i(s)} = k_p/\tau s + 1
\]

\[
G(s) = H(s)Q(s) = R/ \tau s + 1
\]

Where

\[
\text{Time Constant = Storage Capacity x Resistance to flow}
\]
II. PROCESS DESCRIPTION

![Diagram of Process Description](image)

**Table 1: Process Description**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value (Cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>D</strong></td>
<td>Diameter</td>
<td>18</td>
</tr>
<tr>
<td><strong>R</strong></td>
<td>Radius</td>
<td>9</td>
</tr>
<tr>
<td><strong>H</strong></td>
<td>Height</td>
<td>9</td>
</tr>
<tr>
<td><strong>Fin</strong></td>
<td>Maximum flow rate</td>
<td>60 lph</td>
</tr>
</tbody>
</table>

The fabrication of one spherical tank is a very challenging task, and design of controller for that process is a tedious work. The setup of single tank is shown in fig.1. The water enters the tank through the inlet pipe via valve 1 the outlet has a valve by which the water can be controlled. With the help of the rotameter water is supplied into the tank. The reading of the tank is taken for the particular flow and the reading is taken until the fluid settles at a particular level.

Similarly for various flow rate the settling level is noted and thus the tank is divided into four regions. Open loop response curve is drawn for each region. Using this open loop curve transfer function of each region is found.

III. DESIGN OF PID CONTROLLER

From the open loop response curve we have taken the transfer function.
Table 2: Transfer Function

The above table shows transfer function for each region. We have taken readings for separately for each region and from the open loop response curve we have taken the transfer function.

Different tuning methods are used for design correct controller for each region. Here we are used zeigler nichols, cohen coon and internal model controller methods.[5]

A. Zeigler Nichols method:
In 1942 Ziegler and Nichols proposed this method. ZIEGLER NICHOLS is a heuristic PID tuning rule that attempts to produce good value for PID parameters. This will work better for analog controller. The output is achieved by setting the integral gain and derivative gain to zero. The proportional gain is increased as long as it reaches the ultimate gain (Ku). In this situation the output oscillate with constant amplitude.[3]

1) Formula:

\[
K_p = \frac{1}{\tau I_1} \left(\frac{0.07e^{-t/\tau_d}}{100 + 1}\right) \\
T_i = 0.6K_u \\
T_d = 0.125P_u
\]

Table 3: Formula

<table>
<thead>
<tr>
<th>Region</th>
<th>Region1</th>
<th>Region2</th>
<th>Region3</th>
<th>Region4</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZN method</td>
<td>K_p=114.6</td>
<td>K_p=90</td>
<td>K_p=174.6</td>
<td>K_p=307.2</td>
</tr>
<tr>
<td>K_i=4.88</td>
<td>K_i=7.22</td>
<td>K_i=22.24</td>
<td>K_i=48.99</td>
<td></td>
</tr>
<tr>
<td>K_d=671.5</td>
<td>K_d=280.3</td>
<td>K_d=343.9</td>
<td>K_d=481.3</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Regions

2) Cohen Coon:
Cohen coon method is second popular after the Ziegler Nichols method. This method was published at 1953. This method is more flexible than Ziegler Nichols method.

Z-N method work well only on the processes where the dead time is less than half the length of the time response compared to the C-C method where the dead time is less than two times the length of the time constant.[6]

3) Formula:

\[
K_p = \frac{1}{\tau I_1} \left(\frac{0.07e^{-t/\tau_d}}{3 + 8(t/\tau_d)}\right) \\
T_i = \frac{t}{K_d} \left(\frac{2(1 + 6(\tau_d/\tau))/t}{3 + 8(\tau_d/\tau)}\right) \\
T_d = \frac{t}{2} \left(\frac{4(1 + 6(\tau_d/\tau))/t}{3 + 8(\tau_d/\tau)}\right)
\]

Table 5: Formula

<table>
<thead>
<tr>
<th>Region</th>
<th>Region1</th>
<th>Region2</th>
<th>Region3</th>
<th>Region4</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC method</td>
<td>K_p=122.24</td>
<td>K_p=100.4</td>
<td>K_p=195.56</td>
<td>K_p=340.39</td>
</tr>
<tr>
<td>K_i=3.31</td>
<td>K_i=5.14</td>
<td>K_i=15.97</td>
<td>K_i=34.66</td>
<td></td>
</tr>
<tr>
<td>K_d=688.21</td>
<td>K_d=290.1</td>
<td>K_d=354.31</td>
<td>K_d=493.56</td>
<td></td>
</tr>
</tbody>
</table>

Table 6: Regions

B. Internal Model Control Method:

IMC is model based controller. The above figure shows the structure of the Internal Model Controller. The process model infer the effect of immeasurable disturbance on the process output and will take corrective action to that effect. The IMC-PID tuning rules have the advantage of only using tuning parameter to achieve a clear tradeoff between closed loop performance and Robustness to model inaccuracies.

\[ G_c(s) = G_m(s)/(1 - G_m(s)G_d(s)) \]

In order to arrive at a PID equivalent form for processes with a time delay, first-order pade approximation for dead time is used. The IMC based PID tuning method can be summarized according to the following table

1) Formula:

\[
K_p = \frac{1}{\tau I_1} \left(\frac{2(1 + 6(\tau_d/\tau))/t}{3 + 8(\tau_d/\tau)}\right) \\
T_i = \frac{t}{K_d} \left(\frac{2(1 + 6(\tau_d/\tau))/t}{3 + 8(\tau_d/\tau)}\right) \\
T_d = \frac{t}{2} \left(\frac{4(1 + 6(\tau_d/\tau))/t}{3 + 8(\tau_d/\tau)}\right)
\]

Table 7: Formula

<table>
<thead>
<tr>
<th>Region</th>
<th>Region1</th>
<th>Region2</th>
<th>Region3</th>
<th>Region4</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMC method</td>
<td>K_p=24.63</td>
<td>K_p=0.246</td>
<td>K_p=197.0</td>
<td>K_p=3.65</td>
</tr>
<tr>
<td>K_i=0.01</td>
<td>K_i=0.0029</td>
<td>K_i=14.6</td>
<td>K_i=0.0033</td>
<td></td>
</tr>
<tr>
<td>K_d=4</td>
<td>K_d=0</td>
<td>K_d=6.05</td>
<td>K_d=6.76</td>
<td></td>
</tr>
</tbody>
</table>

Table 8: Regions

The above table shows the different equations for different tuning method.

IV. DESIGN OF SYSTEM SOFTWARE

A. Lab VIEW:
LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) is a graphical programming language. LabVIEW uses icons instead of lines of text to create applications. LabVIEW uses dataflow programming technique. In data flow programming, the flow of data through the nodes on the block diagram determines the execution order of the Vis and functions. Vis, are LabVIEW programs that imitate physical instruments.[4]

In LabVIEW, you build a user interface by using a set of tools and objects. The user interface is known as the front panel. After you build the front panel, you add code using graphical representations of functions to control the front panel objects. You add this graphical code, also known as G code or block diagram. The block diagram somewhat
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resembles a flowchart. The block diagram, front panel, and graphical representations of code compose a VI. [5]

B. LabVIEW Front Panel Design:

Fig. 8: LabVIEW Front Panel Design

C. LabVIEW Block Diagram:

1) Region1:

Here we have shown various tuning methods for different regions in the spherical tank.

2) Region2:

Fig. 9: Region1
3) Region3:

Fig. 10: Region2

Fig. 11: Region3
We have some error criteria methods. They are IAE, ISE, ITAE and MSE. The performance indices are

1) Integral of the absolute value of the error (IAE)
   \[ IAE = \int |e(t)| \, dt \]

2) Integral of the square value of the error (ISE)
   \[ ISE = \int e^2(t) \, dt \]

3) Integral of the time weighted absolute value of the error (ITAE)
   \[ ITAE = \int t \cdot |e(t)| \, dt \]

Here \( t \) is time and \( e(t) \) is error.

Procedures to find out controller tuning parameters:
The following steps are used for design PID controller by minimum error criteria (ISE, IAE, ITAE and MSE).

The single spherical tank process model including the controller algorithms in simulink is developed. For calculating minimum error criteria mat lab m-file is used.

To minimize the minimum error criteria, a function of matlab optimization toolbox is used.

The process model is developed in simulink is executed and specified on basis of evaluation of objective function. Tuning parameter values are determined.

### A. Region 1:

<table>
<thead>
<tr>
<th>Name of the methods</th>
<th>ZN</th>
<th>CC</th>
<th>IMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAE</td>
<td>332.7799</td>
<td>239.9064</td>
<td>513.7064</td>
</tr>
<tr>
<td>ISE</td>
<td>39.55</td>
<td>37.7950</td>
<td>267.5036</td>
</tr>
<tr>
<td>ITAE</td>
<td>1.0429e+004</td>
<td>46882e+003</td>
<td>2.6487e+004</td>
</tr>
<tr>
<td>MSE</td>
<td>0.0079</td>
<td>0.0071</td>
<td>0.1486</td>
</tr>
</tbody>
</table>

Table 9: Region 1

### B. Region 2:

<table>
<thead>
<tr>
<th>Name of the methods</th>
<th>ZN</th>
<th>CC</th>
<th>IMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAE</td>
<td>205.2289</td>
<td>140.3592</td>
<td>1.6349e+003</td>
</tr>
<tr>
<td>ISE</td>
<td>22.5592</td>
<td>20.0674</td>
<td>812.1517</td>
</tr>
<tr>
<td>ITAE</td>
<td>4.1313e+003</td>
<td>1.5421e+003</td>
<td>2.4610e+004</td>
</tr>
<tr>
<td>MSE</td>
<td>0.0042</td>
<td>0.0037</td>
<td>0.1961</td>
</tr>
</tbody>
</table>

Table 10: Region 1

### C. Region 3:

<table>
<thead>
<tr>
<th>Name of the methods</th>
<th>ZN</th>
<th>CC</th>
<th>IMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAE</td>
<td>588.0095</td>
<td>546.4265</td>
<td>2.8800e+003</td>
</tr>
<tr>
<td>ISE</td>
<td>14.4259</td>
<td>12.7933</td>
<td>1.5000e+003</td>
</tr>
<tr>
<td>ITAE</td>
<td>1.5363e+005</td>
<td>1.5256e+005</td>
<td>7.2856e+005</td>
</tr>
<tr>
<td>MSE</td>
<td>0.0712</td>
<td>0.0709</td>
<td>0.1674</td>
</tr>
</tbody>
</table>

Table 11: Region 1

### D. Region 4:

<table>
<thead>
<tr>
<th>Name of the methods</th>
<th>ZN</th>
<th>CC</th>
<th>IMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>IAE</td>
<td>2.4940e+003</td>
<td>1.4280e+003</td>
<td>2.8725e+003</td>
</tr>
<tr>
<td>ISE</td>
<td>15.7638</td>
<td>10.3015</td>
<td>1.4622e+003</td>
</tr>
<tr>
<td>ITAE</td>
<td>7.1702e+005</td>
<td>5.8745e+005</td>
<td>7.2627e+005</td>
</tr>
<tr>
<td>MSE</td>
<td>0.0013</td>
<td>0.0011</td>
<td>0.1633</td>
</tr>
</tbody>
</table>

Table 12: Region 1

VI. COMPARISON AND RESULTS

In this paper we are using ZN method, CC method and IMC method for finding best tuning method for each region of a spherical tank. From the response curve we can find best controller for each region of the spherical tank. Rise time, peak time, settling time are shown below for each region of the spherical tank.
A. Region 1:

<table>
<thead>
<tr>
<th>Method</th>
<th>Rise time (sec)</th>
<th>Peak overshoot (%)</th>
<th>Settling time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZN method</td>
<td>140</td>
<td>26</td>
<td>1000</td>
</tr>
<tr>
<td>CC method</td>
<td>18</td>
<td>30</td>
<td>90</td>
</tr>
<tr>
<td>IMC method</td>
<td>230</td>
<td>-</td>
<td>450</td>
</tr>
</tbody>
</table>

Table 13: Region 1

B. Region 2:

<table>
<thead>
<tr>
<th>Method</th>
<th>Rise time (sec)</th>
<th>Peak overshoot (%)</th>
<th>Settling time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZN method</td>
<td>10</td>
<td>60</td>
<td>100</td>
</tr>
<tr>
<td>CC method</td>
<td>9</td>
<td>40</td>
<td>45</td>
</tr>
<tr>
<td>IMC method</td>
<td>900</td>
<td>-</td>
<td>1200</td>
</tr>
</tbody>
</table>

Table 14: Region 2

C. Region 3:

<table>
<thead>
<tr>
<th>Method</th>
<th>Rise time (sec)</th>
<th>Peak overshoot (%)</th>
<th>Settling time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZN method</td>
<td>6</td>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>CC method</td>
<td>5</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>IMC method</td>
<td>1600</td>
<td>-</td>
<td>2000</td>
</tr>
</tbody>
</table>

Table 15: Region 3

D. Region 4:

<table>
<thead>
<tr>
<th>Method</th>
<th>Rise time (sec)</th>
<th>Peak overshoot (%)</th>
<th>Settling time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZN method</td>
<td>5</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td>CC method</td>
<td>9</td>
<td>40</td>
<td>25</td>
</tr>
<tr>
<td>IMC method</td>
<td>1700</td>
<td>-</td>
<td>2000</td>
</tr>
</tbody>
</table>

Table 16: Region 4

From the above tabulation INTERNAL MODEL CONTROLLER method is best method. Because it has no peak overshoot and good settling time. So IMC can track the set point better than other two methods (ZN, CC).[4]

VII. CONCLUSION

Optimum tuning parameters for controllers are estimated by three tuning methods (ZN method, CC method and IMC method) for each region of spherical tank level process in LabVIEW. From the simulation IMC controller results quick response with no peak overshoot. This method has good ability to a adapt to tuning parameters for changes in process dynamics. The summarize, the IMC controller has been proved to be an efficient method for each region of the spherical tank process. Then performance indices like ISE, IAE, ITAE and MSE values are used to validate best controller. It is results that IMC is suitable for each region to maintain the level in a spherical tank. And also this method can be used in a variety of nonlinear control systems with large transportation lag processes.

REFERENCES