Study on Different Tuning Approach with Incorporation of Simulation Aspect for Z-N (Ziegler-Nichols) Rules

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Abstract- This paper is based on PID tuning approach using traditional Ziegler-Nichols tuning method with the help of simulation aspects. The most important reason behind this PID tuning approach is due to its simple control structure and satisfactory results. Nowadays there are various optimization techniques like Particle Swarm Optimization(PSO), Bacterial Foraging Optimization(BFO), Genetic Algorithm(GA) etc used for distributed optimization and tuning of various systems. For PID tuning software tools are also used somewhere in which programming has been done previously. But here Z-N tuning rule is chosen as it is the mother of all the globally accepted modern Optimization Algorithms and easy to implement during MATLAB simulation. In this tuning approach Z-N’s First Method is used which is efficient in tuning stable systems. The Algorithm and Flowchart study of the Z-N tuning rule is also incorporated. The flowchart defines the sequential statements and functions executed during simulation and also show the transfer of function calls. The algorithm makes the coding efficient and prevents runtime error. The coding is completely done using MATLAB and for its execution minimum requirement version is’ MATLAB R2010a’. The MATLAB coding consists of two parts i.e. Routh-Hurwitz coding to determine whether the system is stable or unstable and the code of Z-N tuning rule that performs the tuning of the systems provided by the user. The tuning code runs with the help of two functions, Ziegler( ) and WRITEPID( ). This tuning approach would be advantageous for the future industries as PID is used for industry related work and projects.

Index Terms- Introduction, PID tuning, Algorithm & Flowchart, Applications, Conclusion, References.

I. INTRODUCTION

The PID controllers in the initial days were all pneumatic which were experimented by Ziegler and Nichols. As the microprocessors and microcontrollers are coming on the focus of development towards the implementation with digital PID controllers the program of controllers’ parameter can be easily changed without changing any hardware. It has a wide range of applications in industrial control [1]. A PID controller is a simple three-term controller. The letters P, I and D stand for [2]:

- P – Proportional
- I – Integral
- D – Derivative

Fig1: PID Controller structure [2]

In the above figure, the controller is used in a closed-loop unity feedback system. The variables R, e, u & Y respectively denote the Input signal, Error signal, Controller signal and Output the error plus the integral gain (K_i) times Derivative of the error i.e. u = K_P e(t) + K_I \int e(t)dt + K_D de(t)/dt [2]

II. APPROACH TO PID TUNING

Tuning a control loop is the adjustment of its control parameters (gain/proportional band, integral gain/reset, derivative gain/rate) to the optimum values for the desired control response. Generally stability of response is required and the process must not oscillate for any combination of process conditions and set points.

2.1 Manual Tuning:

If the system is online first all values are set to zero. Values are increased until the output of the loop oscillates and any offset is corrected too and if required, until the loop is acceptably quick to reach its reference after a load disturbance. However, too much will cause excessive response and overshoot. A fast PID loop tuning usually overshoots slightly to reach the setpoint more quickly.

2.2 Z-N (Ziegler-Nichols) Method:

The Z-N tuning rule was discovered by Ziegler and Nichols in the year 1942[6].

In this method, the dynamic characteristic of the process are represented by the ultimate gain of a proportional controller and the ultimate period of oscillation of the loop. It usually determine the ultimate gain and period from the actual process by the following procedure:
The integral and derivative modes of the feedback controllers are switched off so as to have a proportional controller.

In the automatic controller the proportional gain (or reduce the proportional band) is increased until the loop oscillates with constant amplitude.

With the help of a time recording of the controlled variable the period of oscillation is measured and recorded as $T$ the ultimate period.

### Table-1: Tuning effect [1]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rise Time</th>
<th>Over-shoot</th>
<th>Settling Time</th>
<th>Steady-State Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>Decrease</td>
<td>Increase</td>
<td>Small Change</td>
<td>Decrease</td>
</tr>
<tr>
<td>I</td>
<td>Decrease</td>
<td>Increase</td>
<td>Increase</td>
<td>Eliminate</td>
</tr>
<tr>
<td>D</td>
<td>Small Change</td>
<td>Decrease</td>
<td>Decrease</td>
<td>Small Change</td>
</tr>
</tbody>
</table>

For the desired response of the close loop, Z-N method specified a decay ratio of one-fourth. The decay ratio is the ratio of the amplitudes of two successive oscillations. It should be independent of the input to the system and should depend only on the roots of the characteristic equation for the loop [4].

### 2.3. C-C (Cohen-Coon) Method:

In this method, the system’s response is modeled to a step change as a first order response plus dead time, using the Cohen-Coon method. From this response, three parameters: $K$, $\tau$, and $L$, are found. $K$ is the output steady state divided by the input step change, $\tau$ is the effective time constant of the first order response, and $L$ is the time delay [9]. C-C method used the approximated mode and estimated the value of the parameters $K$, $\tau$, and $L$ as indicated above. Then the derivative expressions for the best controller settings using one-quarter decay ratio. From $K$, $\tau$, and the PID parameters are calculated from the following formulas [2].

$$K_c = \left(\frac{1}{K}\right) (\tau) \left(\frac{4}{3} + \frac{1}{4\tau}\right)$$  \hspace{1cm} (eqn 1)

$$\tau_1 = \left(\frac{32 + 6\tau}{13 + 8\tau}\right)$$  \hspace{1cm} (eqn 2)

$$\tau_0 = \left(\frac{4}{11 + \frac{2}{\tau}}\right)$$  \hspace{1cm} (eqn 3)

### 2.4 PID tuning software:

PID tuning and loop optimization software are used to ensure consistent results. These software packages will gather the data, develop process models, and suggest optimal tuning. Some software packages can even develop tuning by gathering data from reference changes. Advances in automated PID Loop Tuning software also deliver algorithms for tuning PID Loops in a dynamic or Non-Steady State (NSS) scenario. The software will model the dynamics of a process, through a disturbance, and calculate PID control parameters in response.

The **Internal Model Control** (IMC) method was developed with robustness in mind. The Ziegler-Nichols open loop and Cohen-Coon methods give large controller gain and short integral time, which isn’t conducive to chemical engineering applications.

The **Auto-Tune Variation** (ATV) technique is also a closed loop method and it is used to determine two important system constants without disturbing the system and tuning values for PID are obtained from these. The ATV method will only work on systems that have significant dead time or the ultimate period will be equal to the sampling period.

### Table-3: Choosing a Tuning method

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual Tuning</td>
<td>No requirement of Math, Online method</td>
<td>Requires experienced personnel</td>
</tr>
<tr>
<td>Ziegler-Nichols</td>
<td>Online &amp; Proven method</td>
<td>Process upset, some trial &amp; error, very aggressive tuning</td>
</tr>
<tr>
<td>Software Tools</td>
<td>Consistent tuning, online or offline method may include valve and sensor analysis, allow simulation before downloading, can support Non-Steady State (NSS) Tuning</td>
<td>Some cost and training involved</td>
</tr>
<tr>
<td>Cohen-Coon</td>
<td>Good process models</td>
<td>Some math required, Offline method, good for only first-order processes</td>
</tr>
</tbody>
</table>

### III. FIRST METHOD OF Z-N TUNING

The Simulation of PID tuning is achieved here using the First Method of Z-N tuning rule. It is applied to plants with step responses of the form displayed in Fig 2. The response is characterized by two parameters, $L$ the delay Time and $T$ the Time constant. These are found by drawing a tangent to the step response at its point of inflection and noting its intersection with the Time axis and the steady state value.

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IV. ALGORITHM & FLOWCHART REPRESENTATION OF THE SYSTEM

STEP 1:- Input open loop transfer function \( G_c(s) \).
STEP 2:- Determines total number of input coefficients in the characteristic equation.
STEP 3:- Determine roots of the characteristic equation.
STEP 4:- The Routh-Hurwitz array is built.
STEP 5:- Check for sign change in the first column of the Routh-Hurwitz array. [Note:-If any sign change occurs in the first column of the Routh-Hurwitz array then the system is unstable]
STEP 6:- Outputs whether the Open Loop system is stable or unstable.
STEP 7:- Displays the step response of the Open Loop system \( G_c(s) \).
STEP 8:- Determines the Open Loop gain of \( G_c(s) \).
STEP 9:- Defines variable ‘vars’ of Ziegler function i.e. Ziegler (keys, vars).
STEP 10:- Ziegler function is called for tuning \( G_c(s) \).
STEP 11:- The statement for Proportional control in the Ziegler function is executed.
STEP 12:- Call transfers from Ziegler() to WRITEPID() function to construct the P controller.
STEP 13:- Call returns to the main program and the statement, \( G_1=feedback(G_c*Gc1,1) \); Is executed i.e. closed loop system with P controller is formed.
STEP 14:- STEP 10 to STEP 13 is repeated twice again for PI and PID tuning.
STEP 15:- Step response of three systems using P, PI and PID controller respectively are displayed. P=Proportional, PI=Proportional Integral, PID= Proportional Integral Derivative.
V. APPLICATION BASED SIMULATION USING MATLAB CODE

The MATLAB coding [10] of the simulator is built using two function blocks, Ziegler(key,vars) & WRITEPID(). The coding is totally based on the concept of Z-N tuning rule. It is that much efficient to tune any system and gives the STEP response of the open-loop system using P, PI & PID controller. It also displays the value of the control parameters. It can tune properly the plant models of type [7]

\[ G(s) = \frac{Ke^{-t}}{Ts+1} \]

VI. CONCLUSION

The Z-N tuning would serve as the basis for the upcoming new generation of PID technology as it provides improved performance, low cost, and training compared to other tuning methods like Cohen coon, trial and error method etc. It can be embedded into established, convenient generalized controller products. This tuning approach works well for a wide range of practical processes than modern tuning methods like Particle Swarm Optimization (PSO). The Z-N tuning table containing the Kp, Td & Ti values makes it unique. The simulation of above application using ‘MATLAB R2010a’ enhances the significance of Ziegler-Nichols tuning approach. The MATLAB code is built considering its importance in analyzing the behaviour of any system of the model type as described above and its tuned output response based on its input. The simulation results give the value of the control parameters required for better performance of the system.

REFERENCES


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[10]

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