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

Susmita Das[1], Ayan Chakraborty[2], Jayanta Kumar Ray[3], Soumyendu Bhattacharjee[4], Dr. Biswarup Neogi[5]

[1]Asst. Prof., EIE Dept., JIS College of Engineering, Kalyani, W.B
[2]Asst. Systems Engineer, Tata Consultancy Services, Karnataka, India
[3]Asst. Prof., ECE Dept., KIEM, Mankar, W.B, India
[4]Asst. Prof. & HOD, ECE Dept., KIEM, Mankar, W.B, India
[5]Asst. Prof., ECE Dept., JIS College of Engineering, Kalyani, W.B, India

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 Forging 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 can be 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

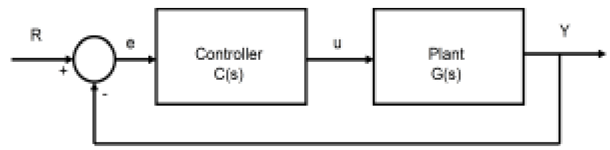

Fig1: PID Controller structure [2]

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]

Para-meter	Rise Time	Over-shoot	Settling Time	Steady-State Error
P	Decrease	Increase	Small Change	Decrease
I	Decrease	Increase	Increase	Eliminate
D	Small Change	Decrease	Decrease	Small Change

Table-2: Z-N TUNING FORMULAE [1]

Controller Type	**From step response**		
	K_p	T_I	T_D
P	1/a		
PI	0.9/a	3L	
PID	1.2/a	2L	L/2

[**a =** amplitude of decayed signal]

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, τ, and K_c are founded. K is the output steady state divided by the input step change, τ is the effective time constant of the first order response, and K_c is the dead time [9]. C-C method used the approximated mode and estimated the value of the parameters K, τ, and as indicated above. Then the derivated expressions for the best controller settings using one-quarter decay ratio. From K, τ, and the PID parameters are calculated from the following formulas [2].

$Kc = (1/K)\ (\tau/)\ (4/3 + / (4\tau))$ ------------------------ (eqn 1)

$\tau_I = (32 + 6/\tau) / (13 + 8/\tau)$ ------------------------ (eqn 2)
$\tau_D = 4 / (11 + 2 /\tau)$ ------------------------ (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

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

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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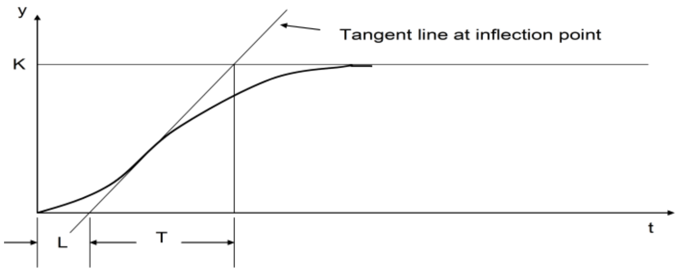


Fig-2: Step response of the plant [2]
[L = Time Delay**, K** = Process Gain**, T** = Ultimate Time Period**]**

IV. ALGORITHM & FLOWCHART REPRESENTATION OF THE SYSTEM

STEP 1:- Input open loop transfer function Gc(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 Gc(s).
STEP 8:-Determines the Open Loop gain of Gc(s).
STEP 9:-Defines variable 'vars' of Ziegler function i.e. Ziegler (keys, vars).
STEP 10:- Ziegler function is called for tuning Gc(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, G1=feedback(Gc*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.

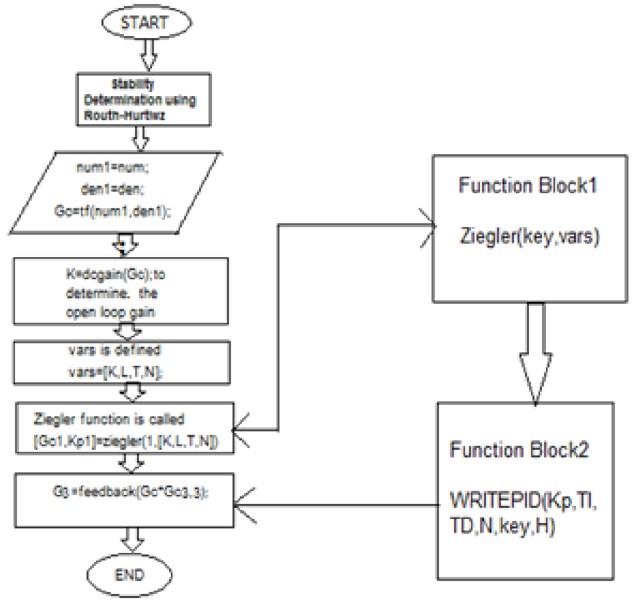
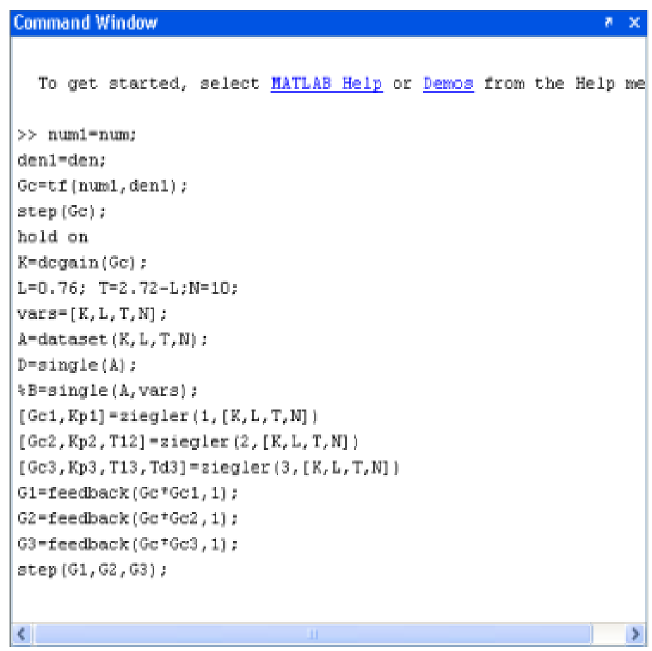


Fig-3: Flowchart of MATLAB tuning code



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Command Window

  To get started, select MATLAB Help or Demos from the Help me

>> num1=num;
den1=den;
Gc=tf(num1,den1);
step(Gc);
hold on
K=dcgain(Gc);
L=0.76; T=2.72-L;N=10;
vars=[K,L,T,N];
A=dataset(K,L,T,N);
D=single(A);
%B=single(A,vars);
[Gc1,Kp1]=ziegler(1,[K,L,T,N])
[Gc2,Kp2,T12]=ziegler(2,[K,L,T,N])
[Gc3,Kp3,T13,Td3]=ziegler(3,[K,L,T,N])
G1=feedback(Gc*Gc1,1);
G2=feedback(Gc*Gc2,1);
G3=feedback(Gc*Gc3,1);
step(G1,G2,G3);
```

Fig-5: MATLAB code for tuning

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Command Window

  To get started, select MATLAB Help or Demos from the Help

>> function [Gc,H]=writepid(Kp,T1,Td,N,key,H)
%UNTITLED Summary of this function goes here
%   Detailed explanaTion goes here
switch key
 case 1, Gc=Kp;
 case 2, Gc=tf(Kp*[T1,1],[T1,0]); H=1;
 case 3, nn=[Kp*T1*Td*(N+1)/N,Kp*(T1+Td/N),Kp];
 dd=T1*[Td/N,1,0]; Gc=tf(nn,dd); H=1;
 case 4, d0=sqrt(T1*(T1-4*Td)); T10=T1; Kp=0.5*(T1+d0)*Kp/T1
 T1=0.5*(T1+d0); Td=T10-T1; Gc=tf(Kp*[T1,1],[T1,0]);
 nH=[(1+Kp/N)*T1*Td, Kp*(T1+Td/N), Kp];
 H=tf(nH,Kp*conv([T1,1],[Td/N,1]));
 case 5, Gc=tf(Kp*[Td*(N+1)/N,1],[Td/N,1]);
     H=1;
end
```

Fig-4: MATLAB code for PID tuning

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Command Window

>> function [Gc,Kp,T1,Td,H]=ziegler(key,vars)
 T1=[]; Td=[]; H=1;
if length(vars)==4
 K=vars(1); L=vars(2); T=vars(3); N=vars(4); a=K*L/T;
 if key==1, Kp=1/a;
 elseif key==2, Kp=0.9/a; T1=3.33*L;
 elseif key==3 || key==4, Kp=1.2/a; T1=2*L; Td=L/2;
 end
 elseif length(vars)==3,
 K=vars(1); Tc=vars(2); N=vars(3);
 if key==1, Kp=0.5*K;
 elseif key==2, Kp=0.4*K; T1=0.8*Tc;
 elseif key==3 || key==4, Kp=0.6*K; T1=0.5*Tc; Td=0.12*Tc;
 end
 elseif length(vars)==5,
 K=vars(1); Tc=vars(2); rb=vars(3); N=vars(5);
 pb=pi*vars(4)/180; Kp=K*rb*cos(pb);
 if key==2, T1=-Tc/(2*pi*tan(pb));
 elseif key==3||key==4, T1=Tc*(1+sin(pb))/(pi*cos(pb)); Td=T
 end
 end
[Gc,H]=writepid(Kp,T1,Td,N,key,H);
```

Fig-6: MATLAB code for Z-N tuning

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clc;
num=input('enter the value of num=');
den=input('enter the value of den=');
sys=tf(num,den);
disp('            ')
D=den;
disp('Input coefficients of characteristic equation,i.e:[an an-1 an-2 ... a0]=den ');
l=length (D);
disp('                                        ')
disp('----------------------------------------')
disp('Roots of characteristic equation is:')
roots(D)

%%======================Program Begin========================

% -------------------Begin of Bulding array-------------------------------
if mod(l,2)==0 %l=4
    m=zeros(l,l/2);%row=4,col=2
    [cols,rows]=size(m);%row of m matrix equal to rows and cols = col of m
    for i=1:rows
        m(1,i)=D(1,(2*i)-1);
        m(2,i)=D(1,(2*i));
    end
else
    m=zeros(l,(l+1)/2);
    [cols,rows]=size(m);
```

Fig-7: MATLAB code for stability checking

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]

$$G(s) = \frac{Ke^{-sL}}{Ts+1}$$

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, T_D & T_I 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**.**

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AUTHORS

First Author – Susmita Das, Asst. Prof., EIE Dept., JIS College of Engineering, Kalyani, W.B, India, susmitad2011@gmail.com

Susmita Das is awarded the degree of M.Tech in Instrumentation & Control Engg. from Calcutta University (Rajabazar Science College) in 2011. Before that she received the B.Tech degree in Electronics and Instrumentation Engineering Dept. from GNIT in 2008. Recently, she is engaged as an Assistant professor rank of EIE Dept. in JISCE, Kalyani. She has been engaged as a successful examiner of WBUT curriculum. She has initiated her PhD (engineering) under the supervision of Dr. B .Neogi. Her research interest includes Control Theory, Process control, Biomedical Engineering etc.

Second Author – Ayan Chakraborty, Asst. Systems Engineer, Tata Consultancy Services, Karnataka, India, ayanc12@gmail.com

Ayan Chakraborty is presently working as Assistant Systems Engineer for Tata Consultancy Services. He received his B.Tech degree in Electronics and Communication Engineering from WBUT in 2011. He has published several papers in national and international conferences.

Third Author – Jayanta Kumar Ray, Asst. Prof., ECE Dept., KIEM, Mankar, W.B, India, jayantakumar.ray@rediffmail.com

Jayanta Kumar Ray received degree AMIETE from IETE Calcutta Centre. After that he awarded M.Tech in Electronics and Communication Engineering Dept. from MCKV College of Engineering. Recently, he is engaged as an Assistant professor rank of ECE Dept. in KIEM, Mankar. His research interest includes Control Theory, Biomedical Engineering, Microwave Engineering etc.

Fourth Author – Soumyendu Bhattacharjee, Asst. Prof. & HOD, ECE Dept., KIEM, Mankar, W.B, India, s_vlsi@yahoo.in

Sri. Soumyendu Bhattacharjee is designated as a Head of Electronics & Communication Engineering Dept. in KIEM,

Mankar. Recently, he has initiated his PhD(engineering) under the supervision of Dr. B.Neogi. He received M.Tech degree in VLSI from B.E.S.U, Shibpur. Before that He obtained B.Tech in ECE from JIS College of Engineering, Kalyani. He is having a teaching experience of two and a half years in AIEMD Panagarh and three and a half years in KIEM, Mankar. He has been engaged as a successful examiner of WBUT curriculum. He was also awarded as for his innovative teaching idea from AIEMD Panagarh. His research interest includes Prosthetic heart Control, Biomedical Engineering, Digital Simulation, Microcontroller based Embedded System, VLSI, DSP etc.

Fifth Author – Dr. Biswarup Neogi, Asst. Prof., ECE Dept., JIS College of Engineering, Kalyani, W.B, India, biswarupneogi@gmail.com

Dr. Biswarup Neogi is awarded PhD (Engineering) from Jadavpur University, India. He received M.Tech degree in ECE from Kalyani Govt. Engg. College in 2007. Before that He obtained B.E in ECE from UIT, The University of Burdwan in 2005.He has a experience on various project of All India Radio attach with the Webel Mediatronics Ltd, Kolkata. He was a lecturer in ECE Dept, Haldia Institute of Technology. WB, India. He was working as a faculty in ECE Dept, Durgapur Institute of Advanced Technology & Management. Currently he is engaged with JIS College of Engineering, Kalyani as a Faculty member and flourished R&D related activity. Recent now he is also engaged as a consultant executive engineer of YECOES Ltd, Hooghly, and attached as an advising body of different Engineering College under WBUT. His research interest includes Prosthetic Control, Biomedical Engineering, Digital Simulation, Microcontroller based Embedded System. He is guiding five Ph.D theses in this area. He has published about fifty several papers in International and National Journal and Conference conducted both in India and abroad. Additionally, he attached as a reviewer of several journals and yearly conference.