# PID Controller Tuning using Ziegler-Nichols Method for Speed Control of DC Motor



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# PID Controller Tuning using Ziegler-Nichols Method for Speed Control of DC Motor

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**Abstract:** In this paper, a weighted tuning methods of a PID speed controller for separately excited Direct current motor is presented, based on Empirical Ziegler-Nichols tuning formula and modified Ziegler-Nichol PID tuning formula. Both these methods are compared on the basis of output response, minimum settling time, and minimum overshoot for speed demand application of DC motor. Computer simulation shows that the performance of PID controller using Modified Ziegler-Nichols technique is better than that of traditional Ziegler-Nichols technique.

**Keywords:** Ziegler-Nichols Tuning, Modified Ziegler-Nichols Tuning, Optimal Control, PID Controller, DC Motor.

## I. INTRODUCTION

Inspire of the development of power electronics resources, the direct current machine became more and more useful this Nowadays their uses isn't limited in the car applications (electrics vehicle), in applications of weak power using battery system (motor of toy) or for the electric traction in the multimachine systems too. The speed of DC motor can be adjusted to a great extent as to provide controllability easy and high performance [4]-[6]. The controllers of the speed that are conceived for goal to control the speed of DC motor to execute one variety of tasks, is of several conventional and numeric controller types, the controllers can be: PID Controller, Fuzzy Logic Controller, Genetic Algorithm technique, Particle Swarm Optimization technique or the combination between them: Fuzzy-Neural Networks, Fuzzy-Genetic Algorithm, Fuzzy- Ants Colony, Fuzzy-Swarm. In 1942, Ziegler-Nichols presented a tuning formula [1, 3, 7], based on time response and experiences. Although it lacks selection of parameters and has an excessive overshoot in time response, still opens the way of tuning parameters. Modified

Ziegler-Nichols tuning based on Chien-Hrones-Reswick (CRR) PID tuning formula [3, 8] for set-point regulation accommodate the response speed an d overshoot. In this paper, an optimal PID controller for DC motor speed control is developed using Ziegler Nichols (ZN) and Modified Ziegler-Nichols .The performance measure to be minimized contains the following objectives of the PID controller, that will be studied separately, Minimize the rise time, time required for system response to rise from 10% to 90% (over damped); 5% to 95%; 0% to 100% (Under damped) of the final steady state value of the desired response, Minimize the maximum overshoot, Maximum overshoot is the maximum peak value of the response curve measured from the desired response of the system and Minimize the settling time, Time required for response to reach and stay within 2% of final value.

## II. DC MOTOR MATHEMATICAL MODEL

This DC motor system is a separately excited DC motor [7], which is often used to the velocity tuning and the position adjustment. This paper focuses on the study of DC motor linear speed control, therefore, the separately excited DC motor is adopted. Make use of the armature voltage control method to control the DC motor velocity, the armature voltage controls the distinguishing feature of method as the flux fixed, is also a field current fixedly. The control equivalent circuit of the DC motor by the armature voltage control method is shown in Fig.1.

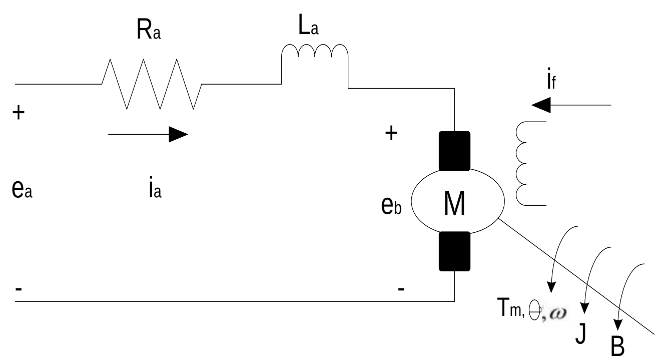



**Fig.1 The Equivalent Circuit of DC Motor using the control Armature Voltage Control.**

Where,
Ra: Armature resistance
La: Armature inductance

ia : Armature current
if : Field current
ea : Input voltage
eb : Back electromotive force (EMF)
Tm : Motor torque
w: An angular velocity of rotor
J: Rotating inertial measurement of motor bearing
Kb : EMF constant
KT : Torque constant
B : Friction constant

Because the back EMF eb is proportional to speed ω directly then,

$$e_b(t) = K_b\frac{d\theta}{dt} = K_b\omega(t) \quad (1)$$

Making use of the KCL voltage law can get

$$e_a(t) = R_a i_a(t)+L_a\frac{di_a(t)}{dt}+e_b(t) \quad (2)$$

From Newton law, the motor torque can be obtained as

$$T_m(t) = J\frac{d\theta(t)}{dt}+B\frac{d\theta}{dt} = K_T i_a(t) \quad (3)$$

Take, (1), (2), and (3) in to Laplace transform, respectively, the equation can be formulated as

$$E_a(s) = (R_a+L_a s)\ I_a(s)+E_b(s) \quad (4)$$

$$E_b(s) = K_b\omega(s) \quad (5)$$

$$T_m(s) = B\omega(S) + JS\omega(S) = K_T I_a(s) \quad (6)$$

Fig.2 describes the DC motor armature control system Function block diagram from equations (1) to (6).

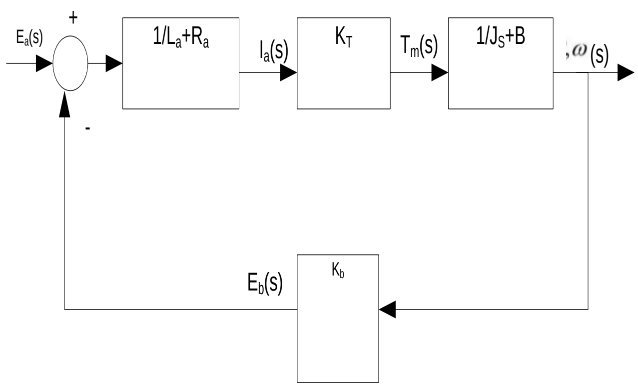



**Fig.2. DC Motor Armature Voltage Control System Function Block diagram.**

The transfer function of DC motor speed with respect to the input voltage can be written as follows,

$$G(S) = \frac{\omega(S)}{Ea(S)} = \frac{Kt}{(La(s)+Ra)(JS+B)+KbKt} \quad (7)$$

## III. PID CONTROLLER

Proportional-integral-derivative (PID) controllers [1][3] are widely used in industrial control systems because of the reduced number of parameters to be tuned. They provide control signals that are proportional to the error between the reference signal and the actual output (proportional action), to the integral of the error (integral action), and to the derivative of the error (derivative action), namely

$$U(t)=K_p[\ e(t)+\frac{1}{Ti}\int_0^t e(t)dt + Td\frac{d}{dt}e(t)] \quad (8)$$

Where u(t) and e(t) denote the control and the error signals respectively, and Kp, 'Ii and Td are the parameters to be tuned. The corresponding transfer function is given as

$$K(s)=K_p\ [1+\frac{1}{Ti(s)}+T_d(s)] \quad (9)$$

These functions have been enough to the most control processes. Because the structure of PID controller is simple, it is the most extensive control method to be used in industry so far. The PID controller is mainly to adjust an appropriate proportional gain ( K p ), integral gain (K [ ), and differential gain (KD) to achieve the optimal control performance. The PID controller system block diagram of this paper is shown in Fig.3.

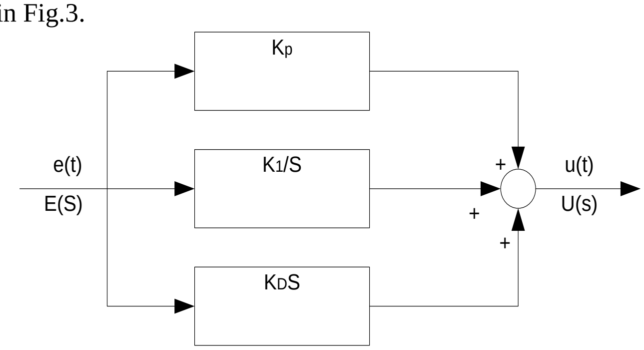



**Fig.3. PID Controller Block Diagram.**

Transfer function can also be expressed as

$$K(s)=\frac{U(s)}{E(s)}=K_p+\frac{Ki}{s}+K_d(s) \quad (10)$$

The main features of PID controllers are the capacity to eliminate steady-state error of the response to a step reference signal (because of integral action) and the ability to anticipate output changes (when derivative action is employed).

## IV. ZIEGLER-NICHOLS TUNING

### A. Traditional Method

This method is applied to plants with step responses of the form displayed in Fig.4. This type of response is typical of a first order system with transportation delay. 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 intersections with the time axis and the steady state value. The plant model is therefore

$$G(S) = \frac{Ke^{-SL}}{TS+1} \quad (11)$$

Ziegler and Nichols derived the following control parameters based on this model.

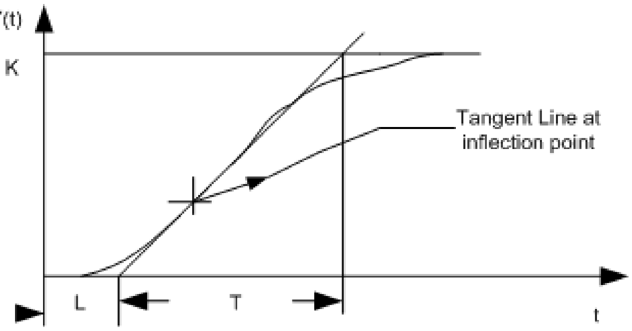



**Fig.4. Response Curve for Ziegler-Nichols Method.**

In real-time process control systems, a large variety of plants can be approximately modeled by (11). If the system model cannot be physically derived, experiments can be performed to extract the parameters for the approximate model (11). For instance, if the step response of the plant model can be measured through an experiment, the output signal can be recorded as sketched in Fig. 4, from which the parameters of k, L, and T can be extracted by the simple approach shown. More sophisticated curve fitting approaches can also be used. With L and a, the Ziegler-Nichols formula in Table 1 can be used to get the controller parameters.

**TABLE I: Ziegler-Nichols Tuning First Method**

| Controller | Kp | Ti | Td |
|---|---|---|---|
| P | T/L | | |
| PI | 0.9T/L | L/0.3 | |
| PID | 1.2T/L | 2L | 0.5L |

### B. Modified Ziegler-Nichols Tuning Method

Modified Ziegler-Nichols tuning using Chien-HronesReswick (CHR) tuning algorithm emphasizes on set-point regulation. In addition one qualitative specification on the response speed and overshoot can be accommodated. Compared with the traditional Ziegler-Nichols tuning formula, the CRR method uses the time constant T of the plant explicitly. The CRR PID controller tuning formulas are summarized in Table 2 for set-point regulation.

**TABLE II: Modified Ziegler-Nichols Tuning Second Method**

| Controller | Kp | Ti | Td |
|---|---|---|---|
| P | 0.7/a | | |
| PI | 0.6/a | T | |
| PID | 0.95/a | 1.4T | 0.47T |

Here the parameters k, L, and T are obtained from the response curve of figure 4. With KI=Kp/Ti and KD=Kp*Td. Thus the values of Kp, Ki and Kd are obtain from tables 1 and 2 to form the transfer function for PID controller as given by (9).

## V. SIMULATION AND ANALYSIS

A standard test model as considered is taken for study of DC motor with Z-N tuning controller. The test model below shown is completely designed in SISO tool. Fig.5 shows the block diagram of DC motor driving an inertial load.

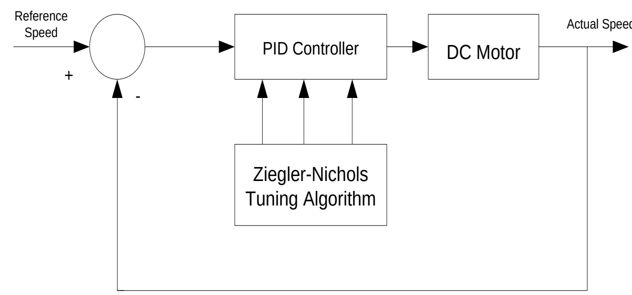



**Fig.5. Block Diagram of DC Motor Control System.**

From the state equation (refer (1), (2), (3)) previously, we can construct the model with the environment MA TLAB (R201Oa) Simulink. The model of the DC motor in Simulink is shown in Fig.2. The various parameters of the DC motor are shown in Table 3.

**TABLE III: Dc Motor Parameters**

| Parameters | Motor1 | Motor2 | Motor3 |
|---|---|---|---|
| Armature resistance Ra (Ω) | 2 | 2 | 1 |
| Armature inductance La (H) | 0.5 | 0.5 | 0.5 |
| Moment of inertia J ($Kgm^2$) | 0.02 | 1.2 | 0.01 |
| Friction constant B | 0.2 | 0.2 | 0.00003 |
| Torque constant Kt | 0.015 | 0.2 | 0.023 |
| EMF constant | 0.01 | 0.2 | 0.023 |

The system is simulated for the unit step response for various parameter models for different motors as shown in table 3.The Transfer function these three motors are given by following equations.

Transfer function for motor 1,

$$G_1(S)=\frac{0.015}{0.01S^2+2.5S+0.44} \quad \textbf{(12)}$$

Transfer function for motor2,

$$G_2(S)=\frac{0.2}{0.1S^2+2.5S+0.44} \quad \textbf{(13)}$$

Transfer function for motor 3,

$$G_3(S)=\frac{0.023}{0.005S^2+0.010015S+0.000559} \quad \textbf{(14)}$$

### A. Traditional Method

Flow Chart as shown in fig.6 and 7 is used for MA TLAB coding to find the PID controller parameters and to get DC motor Close loop unit step response of the overall transfer function.

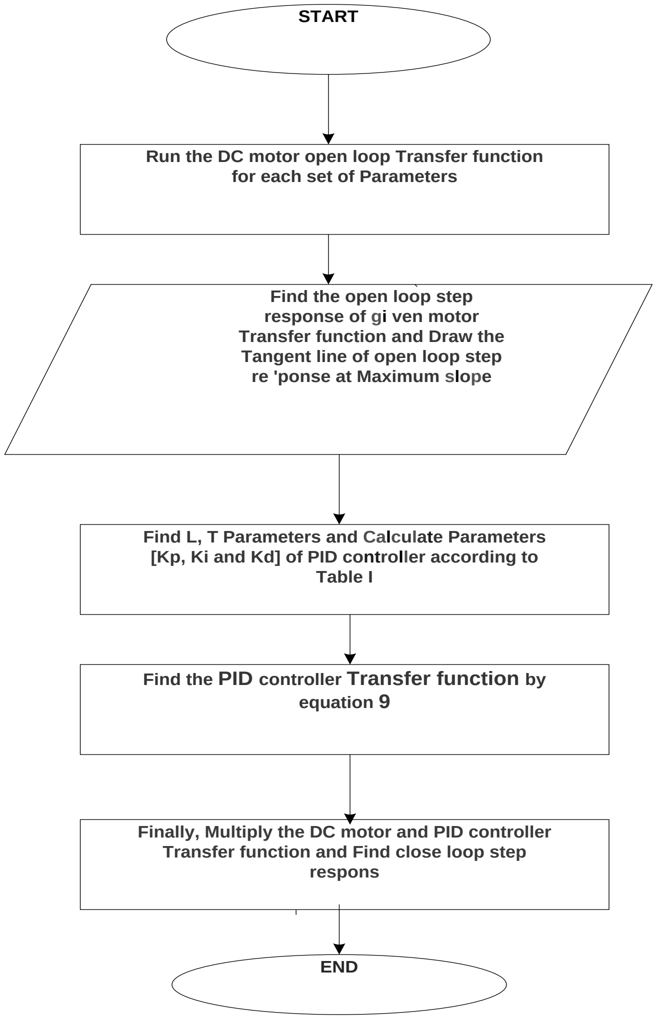



**Fig.6. the flow chart of Ziegler- Nichols Tuning method.**

The controller is connected in cascaded fashion and steresponses for different motors are shown by 8(a), 9(a).

### B. Modified Ziegler-Nichols Tuning Method

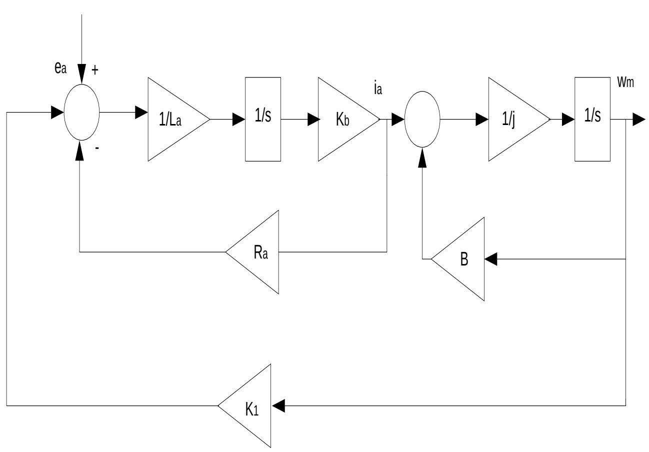
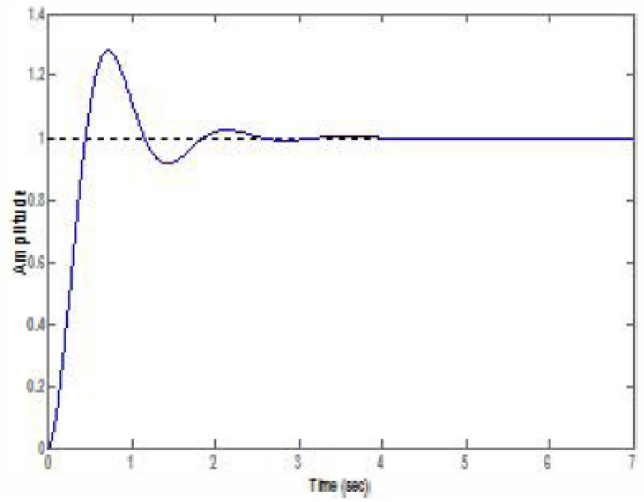
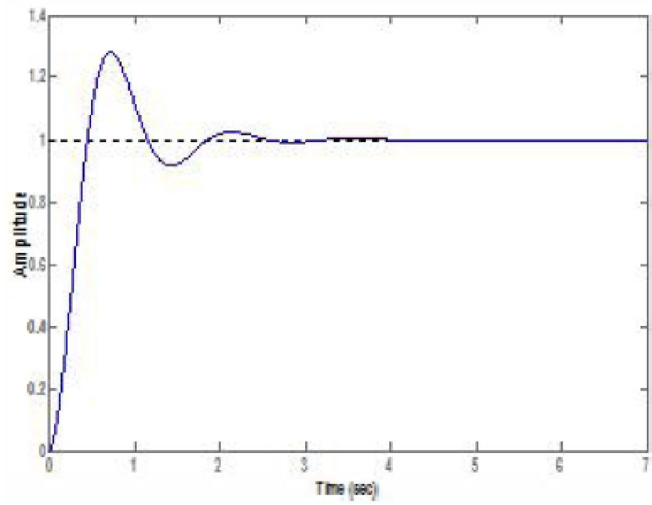



**Fig.7. Matlab Simulink Model for Armature Control of DC Motor.**

## VI. RESULT AND ANALYSIS

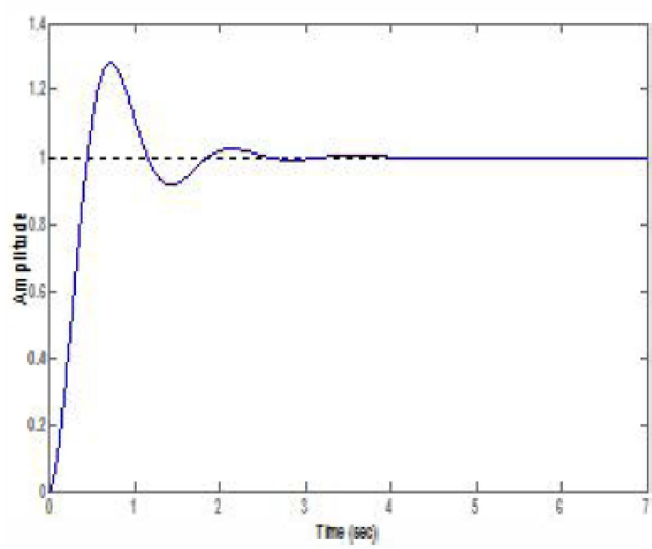



**(a)**

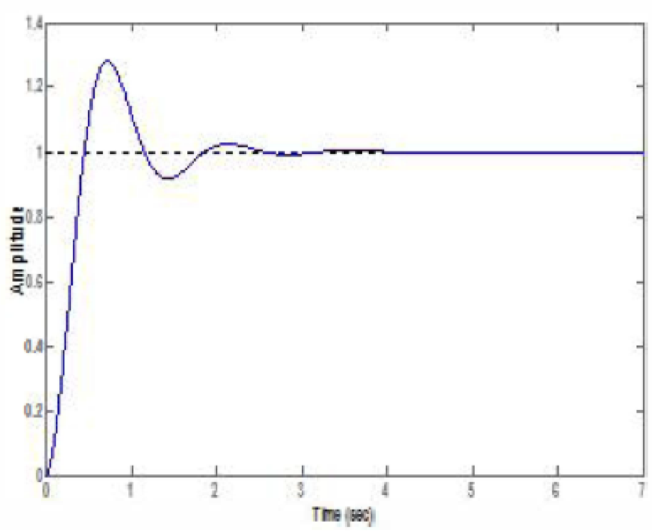



**(b)**

**Fig.8. (a) Step response with Traditional Ziegler-Nichols method. (b) Step response with Modified Ziegler-Nicolas method.**




**(a)**




(b)

**Fig.9.(a) Step response with Traditional Ziegler-Nichols method. (b) Step response with Modified Ziegler-Nichols method.**

The step response of DC motor 1 with two methods is show in fig. 8(a) and fig.8(b),the step response of DC motor 2 is shown in the fig.9(a) and fig.9(b) and the step response of DC motor 3 is shown in the fig.9(a) and fig.9(b). From both Modelling and MA TLAB coding a comparison between these two methods have been made on the basis of Objective i.e. Rise time, Overshoot and Settling time as.

**TABLE IV: Transient Response of Motor 1**

| Method | Rise time (sec) | Maximum overshoot (%) | Settling time (sec) |
|---|---|---|---|
| Traditional ZN tuning | 0.312 | 27.9 | 2.27 |
| Modified ZN tuning | 0.074 | 14.5 | 0.439 |

**TABLE V: Transient Response of Motor 1**

| Method | Rise time (sec) | Maximum overshoot (%) | Settling time (sec) |
|---|---|---|---|
| Traditional ZN tuning | 0.377 | 51.8 | 5.68 |
| Modified ZN tuning | 0.359 | 7.7 | 1.07 |

**TABLE VI: Transient Response of Motor 1**

| Method | Rise time (sec) | Maximum overshoot (%) | Settling time (sec) |
|---|---|---|---|
| Traditional ZN tuning | 0.0508 | 5.84 | 0.527 |
| Modified ZN tuning | 0.786 | 6.99 | 2.33 |

## VII. ACKNOWLEDGMENT

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## VIII. CONCLUSION

In this paper, PID controller is designed using Traditional Ziegler-Nichols and Modified Ziegler-Nichols (CHR) tuning algorithms. The results of both the methods are checked by MA TLAB coding as well as simulation. The speed of a three different DC Motor parameters is controlled by means of these two controllers. According to the results of the computer simulation, the Modified Ziegler-Nichols tuned PID controller efficiently is better than the traditional Ziegler-Nichols. The Modified Ziegler-Nichols is the best controller which presented satisfactory performances for the objectives (i.e Minimum rise time, Minimum overshoot, and Minimum settling time) But, for higher power application DC motors (Motor 1 and Motor 2) and for lower power application motor raditional method found satisfactory

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