Indonesian Journal of Electrical Engineering and Computer Science
Vol. 3, No. 2, August 2016, pp. 343 ~ 349
DOI: 10.11591/ijeecs.v3.i2.pp343-349

Tuning Methods of PID Controller for DC Motor Speed Control

Ashwaq Abdulameer, Marizan Sulaiman, MSM Aras, Dawood Saleem
Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka (UTeM),
Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
Corresponding author, e-mail: shahrieel@utem.edu.my

Abstract

The traditional PID controllers are used for a long time to control the DC motor for many industrial processes, that because of the simplicity, flexibility, and satisfactory performance of this type of controller. This paper discusses the basic PID tuning method (Ziegler-Nichols) and its modification (Chien-Hrones-Reswick). Also, analysis the speed control DC motor response using the PID controller parameters that result from the tuning methods mentioned earlier. Moreover, explain the advantage and disadvantage of each formula of these methods. GUL/MATLAB windows used to implementing both methods to create more comfortable and friendly environment for better understanding of the PID controller tuning methods formula for engineering students and practicing engineers.

Keywords: *DC Motor, PID Controller, GUI/MATLAB, Ziegler-Nichols Method, Chien-Hrones-Reswick Method*

Copyright © 2016 Institute of Advanced Engineering and Science. All rights reserved.

1. Introduction

The direct current machine becomes more popular and more useful in the industry control area for a long time because of its features such as high start torque, high-speed response, portability, and conform with many types of control tuning methods, Nowadays DC motors are used widely in many control applications, including robots, electrics vehicle application, disk drivers, machine tools, and servo-valve actuators. The speed of the DC motor can be adjusted by varying its terminal voltage [1]. This paper produces two common tuning methods for the PID controller parameters to control the velocity of the DC motor these methods are Ziegler-Nichols method and Chien-Hrones-Reswick method [2].

2. Modeling of the DC Motor

This paper discusses the speed control for the separately excited direct current motor system (DC motor), which is usually used for speed setting and the angular position adjustment. The electrical diagram circuit of the direct current (DC) motor using the armature current control method is shown in Figure 1 [3].

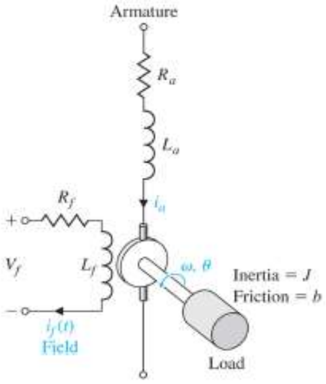

Figure 1. electrical diagram for DC motor

Received March 2, 2016; Revised June 25, 2016; Accepted July 10, 2016

DC motor is used to converts the electrical energy (direct current) into mechanical energy (rotational motion). The motor torque given in Equation (1) [4] is results to a constant field current established in a field coil. While the relation between the input voltage to the armature and the armature current is shown in Equation (2) [4] , also the relation between back electromotive voltage and motor speed explained in Equation (3) [5]. Equation (5) show the relation between motor torque and both load torque and disturbance torque [3].

$$T_m(s) = K_T I_a(s) \tag{1}$$

$$V_a(s) = (R_a + L_a s) I_a(s) + V_b(s) \tag{2}$$

$$V_b(s) = K_b \omega(s) \tag{3}$$

$$I_a(s) = \frac{V_a(s) - K_b \omega(s)}{R_a + L_a s} \tag{4}$$

$$T_L(s) = Js\omega(s) + b\omega(s)$$
$$= T_m(s) - T_d(s) \tag{5}$$

$$(Js + b)\omega(s) = K_T \frac{V_a(s) - K_b \omega(s)}{(R_a + L_a s)} \tag{6}$$

Equation (6) can be implemented using block diagram as shown in Figure 2, which describes the model of DC motor speed control system [4].

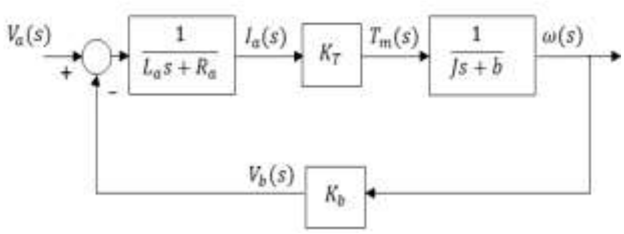

Figure 2. DC motor block diagram (speed control)

Equation (7) [4] represents the closed-loop transfer function of the DC motor speed control with respect to the input voltage [1].

$$\frac{\omega(s)}{V_a(s)} = \frac{K_T}{(R_a + L_a s)(Js + b) + K_b K_T} \tag{7}$$

$$= \frac{K_T}{L_a J s^2 + (R_a J + L_a b)s + (R_a b + K_b K_T)}$$

Where:
T_m: Motor torque.
K_T: Torque constant.
I_a: Armature current.
V_a: Input voltage.
R_a: Armature resistance.
L_a: Armature inductance.
V_b: Back electromotive force (EMF).
K_b: EMF constant.
ω: Angular velocity of rotor.
T_L: Load torque.
J: Rotating inertial measurement of motor bearing.
b: Fraction constant.

3. PID Controller

The PID controller is a three-term controller and one of the earlier control strategies, starting from the beginning of the last century [6]. The PID controller simplicity and excellent, if not optimal, and also the ability to deal with a wide range of processes, make it performance in many application and been the standard controller in industrial settings. The time constant formula of the PID controller is given as in Equation (8) [7].

$$G_c = K_p\left(1 + \frac{1}{T_i s} + T_d s\right) \quad (8)$$

Where K_p proportional gain which used to increase the system response speed and reduce steady-state error [8], and K_i integral gain which used to eliminate the steady-stat error at all [$K_i = K_p/(T_i$ integral time constant)] but it produce unwanted increase on the response overshoot [9], while K_d derivative gain used to reduce the system response overshoot [$K_d = K_p * (T_d$ derivative time constant)] [4]. Figure 3 show the control system block diagram for the DC motor.

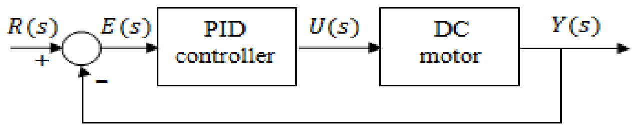

Figure 3. The block diagram of DC motor control system

4. PID Tuning Methods

The velocity of DC motor can be controlled using different tuning methods. This paper produces Ziegler-Nichols methods as the mother of all tuning methods and the Chien-Hrones-Reswick tuning method which is a modification of the Ziegler-Nichols step response method. These control tuning methods were used to get the PID controller parameters which ensure that the obtained control system would be meet given objectives.

In general, both of tuning methods produced in this paper requires a stable system with *S*-ship curve for a step input. These methods are based on a registration of the open-loop step response of the system, which is characterized by many parameters (*L,T,K*, and *a*). These parameters are determined from a unit step response of the process, as shown in Figure 4. The point where the slope of the step response has its maximum is first determined, and the tangent and coordinate axes give the parameters *a* and *L* [6]. While the intersections of the tangent line with the time axis and line y(t)=k give the time constant *T* [10].

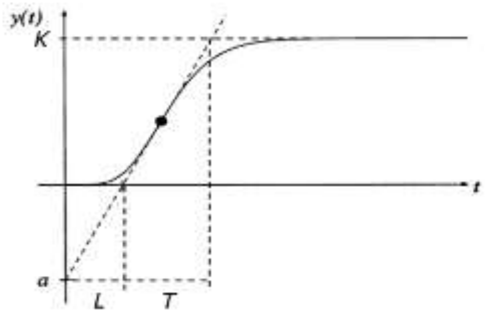

Figure 4. Open loop system step response

4.1. Ziegler-Nichols Step Response Method

This method was produced by Ziegler and Nichols in 1942. It was the first method used to represent the PID controller parameters using two sets of rules as explain in both Table 1 [10] and Table 2 where *a=KL/T* [6].

Table 1. Ziegler-Nichols tuning formula1 for step response method

Controller	Kp	Ti	Td
P	T/L	-	-
PI	0.9T/L	L/0.3	-
PID	1.T/L	2L	L/2

Table 2. Ziegler-Nichols tuning formula2 for step response method

Controller	Kp	Ti	Td
P	1/a	-	-
PI	0.9/a	3L	-
PID	1.2/a	2L	L/2

4.2. Chien-Hrones-Reswick Method

This method is a modified of the original Ziegler-Nichols method. it was produced by Chien-Hrones-Reswick in 1952 with a better control to the response overshoot. Compared with the traditional Ziegler-Nichols tuning formula, Chien-Hrones-Reswick method also uses the time constant *T* and the *a* parameters found from the step response of the open-loop system [6].

Table 3 [11, 12] and Table 4 [11, 12] summarized the Chien-Hrones-Reswick formula for set-point regulation. Where, for the ideal plant model, the system response without overshoot is labeled with (0% overshoot) as in Table 3[11], and the system response with 20% overshoot is labeled with(20% overshoot) as in Table 4 [11].

Table 3. Chien-Hrones-Reswick tuning formula1 (0% overshoot)

Controller	Kp	Ti	Td
P	0.3/a	-	-
PI	0.35/a	1.2T	-
PID	0.6/a	T	L/2

Table 4. Chien-Hrones-Reswick tuning formula2 (20% overshoot)

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

5. Simulation Results

DC motor speed control described in Equation (7) with parameters [4]:

$J = 0.0113$ N-m-sec^2/rad
$b = 0.028$ N-m-sec/rad
$L_a = 0.1$ Henry
$R_a = 0.45$ ohm
$K_T = 0.067$ N-m/amp
$K_b = 0.067$ V-sec/rad

Give transfer function as shown below:

$$G_p(s) = \frac{0.067}{0.00113s^2+0.0078854s+0.0171} \quad (9)$$

The step response shown in Figure 5 give *L*=0.08125, *T*=0.6421, which can be use for all tuning methods discussed in this paper.

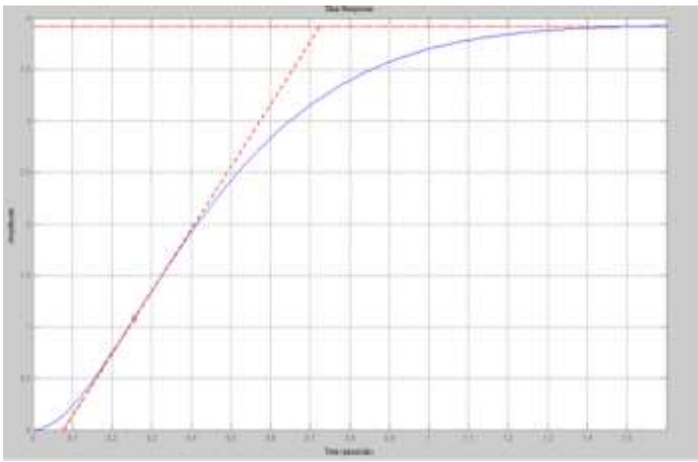

Figure 5. step response for the DC motor

5.1. Ziegler-Nichols Step Response Method

Figure 6 and Figure 7 show the GUI/MATLAB window which set to calculate P, PI, and PID controller parameters for the DC motor transfer function $G_p(s)$ with applying Ziegler-Nichols step response method formula1 shown in Table 1 and formula2 shown Table 2. The controller parameters results from this calculation window are shown in Table 5 for formula1 and Table 6 for formula2, while the response specification is given in Table 7 for formula1 and Table8 for formula2.

Table 5. Z-N method formula1 using GUI

Controller	Kp	Ti	Td
P	7.9028	-	-
PI	7.1125	0.27083	-
PID	9.4833	0.1625	0.040625

Table 6. Z-N method formula2 using GUI

Controller	Kp	Ti	Td
P	2.017	-	-
PI	1.8153	0.24375	-
PID	2.4204	0.1625	0.040625

Table 7. Response specification with Z-N method formula1

Controller	Tr	OS%	Ts	ess
P	0.0539	60.3	1.05	0.969
PI	0.0541	76.7	2.32	0
PID	0.0451	26.3	0.378	0

Table 8. Response specification with Z-N method formula2

Controller	Tr	OS%	Ts	ess
P	0.115	37.1	0.967	0.888
PI	0.113	61	2.48	0
PID	0.102	42.2	1.25	0

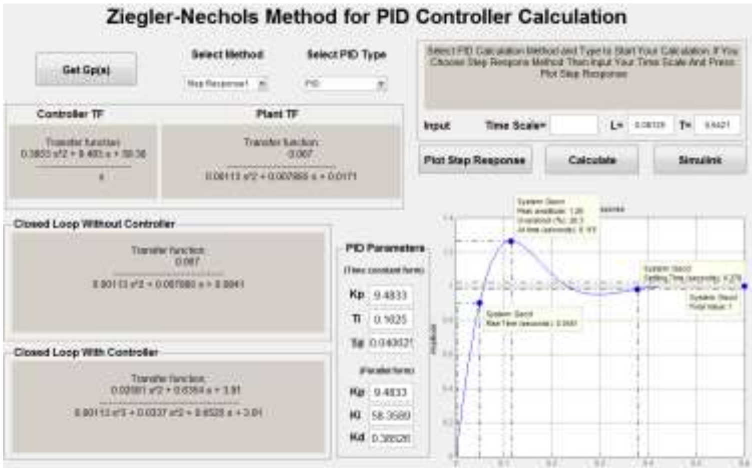

Figure 6. GUI/MATLAB for Ziegler-Nichols step response formula1

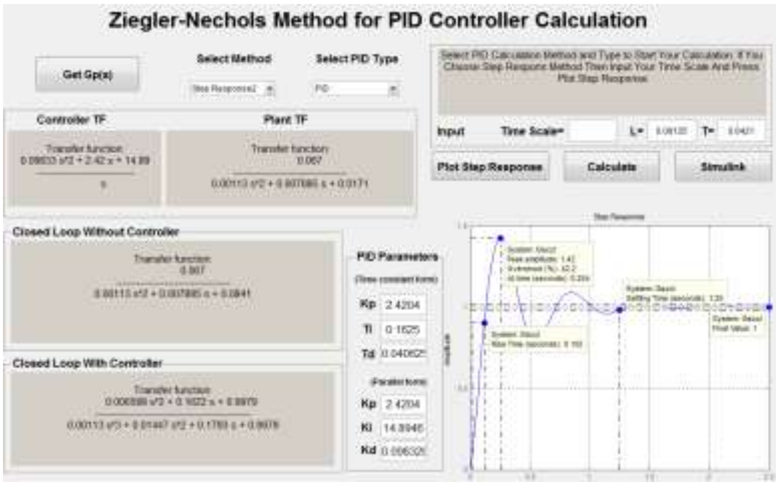

Figure 7. GUI/MATLAB for Ziegler-Nichols step response formula2

5.2. Chien-Hrones-Reswick Method Formula1

Figure 8 and Figure 9 show the GUI/MATLAB window which set to calculate P, PI, and PID controller parameters for the DC motor transfer function $G_p(s)$ with applying Chien-Hrones-Reswick method formula1 with 0% overshoot shown in Table 3 and formula2 with 20% overshoot shown in Table 4. The controller parameters results from this calculation window are shown in Table 9 for formula1 and Table 10 for formula2, while the response specification is given in Table 11 for formula1 and Table 12 for formula2.

Table 9. C-H-R method formula1 using GUI

Controller	Kp	Ti	Td
P	0.60509	-	-
PI	0.70594	0.77052	-
PID	1.2102	0.6421	0.040625

Table 10. C-H-R method formula2 using GUI

Controller	Kp	Ti	Td
P	1.4119	-	-
PI	1.2102	0.6421	-
PID	1.9161	0.89894	0.038187

Table 11. Response specification with C-H-R method formula1

Controller	Tr	OS%	Ts	ess
P	0.227	17.2	1.14	0.703
PI	0.256	7.89	2.16	0
PID	0.191	10.6	1.08	0

Table 12. Response specification with C-H-R method formula2

Controller	Tr	OS%	Ts	ess
P	0.14	30.7	1.1	0.847
PI	0.164	26.2	1.59	0
PID	0.141	13.1	1.35	0

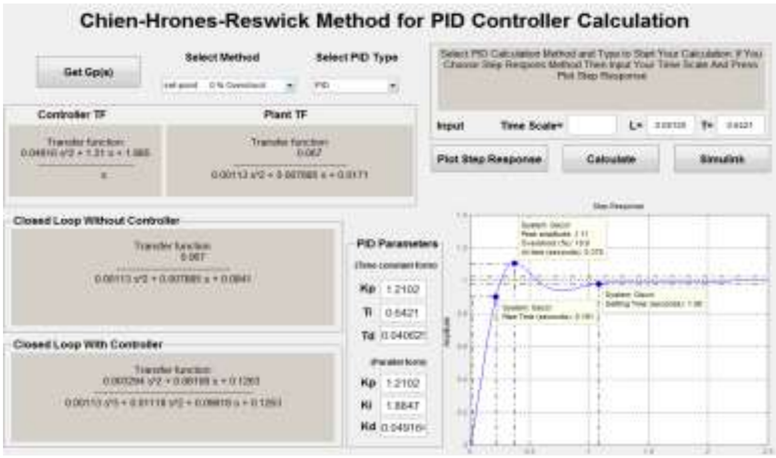

Figure 8. GUI/MATLAB for Chien-Hrones-Reswick formula1

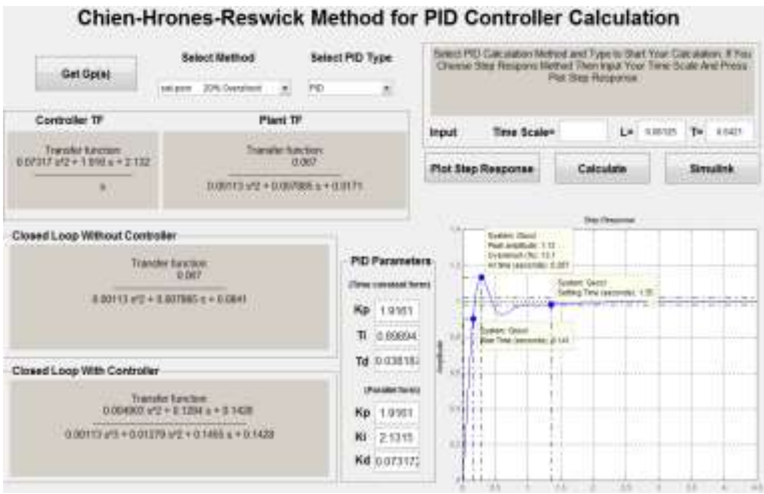

Figure 9. GUI/MATLAB for Chien-Hrones-Reswick formula2

6. Discussion of Results

Table 13 show that Ziegler-Nichols step response method formula1 give the faster response system for Time-rising *(Tr)* and Time-stalling *(Ts)* with acceptable overshoot *(OS%).* But if the overshoot on the system response is more impotent than system response speed then Chien-Hrones-Reswick method formula1 adopted which give the less overshoot value among all method mentioned in this paper.

Table 13. PID controller response specifications

Method	*Tr*	*OS%*	*Ts*
ZN formula1	0.0451	26.3	0.378
ZN formula2	0.102	42.2	1.25
CHR formula1	0.191	10.6	1.08
CHR formula2	0.141	13.1	1.35

7. Conclusion

This paper discusses the design of the PID controller for the DC motor speed control system. Two popular methods implemented and analyzed using GUI/MATLAB windows to create a friendly environment for study and teaching each method techniques and effect on the system response performance. Final results show that each method has its specific advantage over the others. For the chosen DC motor speed control transfer function, it has been shown that the Ziegler-Nichols formula1 gives faster system response with acceptable overshoot while Chien-Hrones-Reswick yields lower overshoot with acceptable system transient response.

Acknowledgements

The authors are grateful to Universiti Teknikal Malaysia Melaka (UTeM) and Ministry of Higher Education, Malaysia (MOHE) for the support under grant FRGS/2/2014/TK03/FKE/01/F00238.

References

[1] Salim, J Ohri. FUZZY Based PID Controller for Speed Control of D.C. Motor Using LabVIEW 2 DC Motor Mathematical Model. *WSEAS Trans. Syst. Control*. 2015; 10: 154-159
[2] PM Meshram, RG Kanojiya. *Tuning of PID Controller using Ziegler-Nichols Method for Speed Control of DC Motor.* 2013 IEEE Int. Conf. Control Appl. 2012: 117-122.
[3] RC Dorf, RH Bishop. Modern Control Systems. Eleventh E. Prentice-Hall, Inc. 2008.
[4] Gene F Franklin, JD Powell, A Emami-Naeini. *FEEDBACK CONTROL OF Dynamic Systems*. Fourth Edition. New Jeresy: Prentice-Hall, Inc. 2002.
[5] S Dubey, SK Srivastava. A PID Controlled Real Time Analysis of DC Motor. *Int. J. Innov. Res. Comput. Commun. Eng.* 2013; 1(8): 1965-1973.
[6] KJ Astrom, T Hagglund. PID Controllers: Theory, Design, and Tuning. USA: Instrument Society of America. 1995.
[7] A Visioli. Advances in Industrial Control-Practical PID Control. London: Springer-Verlag London Limited. 2006.
[8] F Owen. *Designing and tuning PID controllers.* In Control Systems Engineering A Practical Approach. California, Frank Owen. 2012: 1-41.
[9] CL Phillips, RD Harbor. FEEDBACK CONTROL SYSTEMS. Fourth Edition. New Jeresy: Prentice-Hall, Inc. 2000.
[10] K Ogata. Modern Control Engineering. New Jeresy: Prentice-Hall, Inc. 2010.
[11] DPA Dingyu Xue, Yang Quan Chen. *Linear Feedback Control.* In Linear Feedback Control, Philadelphia: Society for Industrial and Applied Mathematics. 2007: 183-235.
[12] KH Raunt, SR Vaishnay. A Study on Performance of Different PID Tuning Techniques. *NJIEEEICE.* 1-4.