International Journal of
Scientific Engineering and Technology Research

ISSN 2319-8885
Volume.08,
Jan-Dec-2019,
Pages:581-584

www.ijsetr.com

Design of PID Controller for DC Motor Speed Control System with Chien-Hrones-Reswich Method

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Abstract: The 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 of 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 and friendly environment for better understanding of the PID controller tuning methods formula for engineering students and practicing engineers.

Keywords: DC, Motor, PID, Controller, Chien-Hrones-Reswick Method.

I. 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]. Finding optimal parameters of PID controller can be considered as the optimization problem. Modern optimization using the selected powerful metaheuristic techniques as an optimizer (or solver) has been accepted and applied to PID design optimization, for example, of some popular metaheuristic applications, designing of the PID controller by genetic algorithm (GA) [1-3], designing of the PID controller by particle swarm optimization (PSO)[4-11] and designing of the PID controller by ant colony optimization (ACO) [3-6]. However, almost all research works considered only tracking purpose of control system design. By literatures about applications of metaheuristic techniques to optimal PID controller design as mentioned earlier, the objective functions (error between the reference input and the controlled output) were mostly set to be minimized with tracking constraint. By those approaches, the command tracking and the steady-state responses of the controlled system would be treated, but the disturbance rejection response of the controlled system would be unpredictable. The motivation of this work is to propose the general design approach for optimal PID controller in which the command tracking and disturbance rejection responses of the controlled system will be simultaneously considered. Results obtained by one of the conventional design methods named Chien-Hrones-Reswick tuning rules [12].

II. DC MOTOR'S WORKING PRINCIPLE

A simple DC motor works on the principle that when a current carrying conductor is placed in a magnetic field, it experiences a mechanical force. In a practical DC motor, the armature is the current carrying the conductor, and the field provides magnetic field.

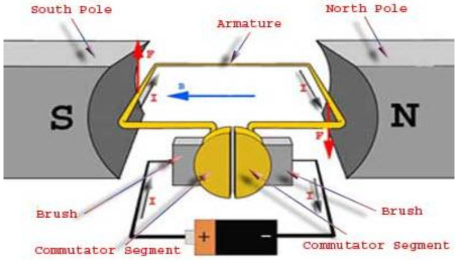

Fig.1. DC Motor working principle

When the conductor (armature) is supplied with a current, it produces its own magnetic flux. The magnetic flux either adds up to the magnetic flux due to the field windings at one direction, or cancels the magnetic flux due to field windings. The accumulation of magnetic flux at one direction compared to the other exerts a force on the conductor, and therefore, it starts rotating. According to Faraday's law of electromagnetic induction, the rotating action of the conductor produces an EMF. This EMF, according to Lenz' law, tends to oppose the cause, i.e., the supplied voltage. Thus, a DC motor has a very special characteristic of adjusting its torque in case of varying load due to the back EMF. From the above Fig1 the voltage equation of a simple DC motor is

$$V = E_b + I_aR_a \qquad (1)$$

Where, V is the supplied voltage, E_b is the back EMF, I_a is the armature current, and R_a is the armature resistance.

We already know that

$$E_b = (P\text{ø}NZ)/60A. \qquad (2)$$

Where,
P – number of poles,
A – constant
Z – number of conductors
N- speed of the motor

Substituting the value of E_b in the voltage equation as follow,

$$V = ((P\text{ø}NZ)/60A) + I_aR_a \qquad (3)$$

Or, $V – I_aR_a = (P\text{ø}NZ)/60A$

i.e., $N = (PZ/60A)\,(V – I_aR_a)/\, \text{ø}$ 4

The above equation can also be written as:

$$N = K\,(V – I_aR_a)/\, \text{ø}, \text{ K is a constant}$$

There are 3 Ways of DC Motor Speed Control

A. Flux Control Method

In this method, the magnetic flux due to the field windings is varied in order to vary the speed of the motor.

B. Armature Control Method

With this method, the speed of the DC motor can be controlled by controlling the armature resistance to control the voltage drop across the armature. This method also uses a variable resistor in series with the armature. When the variable resistor reaches its minimum value, the armature resistance is at normal one, and therefore, the armature voltage drops. When the resistance value is gradually increased, the voltage across the armature decreases. This in turn leads to decrease in the speed of the motor. This method achieves the speed of the motor below its normal range.

C. Voltage Control Method

Both the above mentioned methods cannot provide speed control in the desirable range. Moreover, the flux control method can affect commutation, whereas the armature control method involves huge power loss due to its usage of resistor in series with the armature. Therefore, a different method is often desirable – the one that controls the supply voltage to control the motor speed.

III. DC MOTOR PLANT MODEL

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].

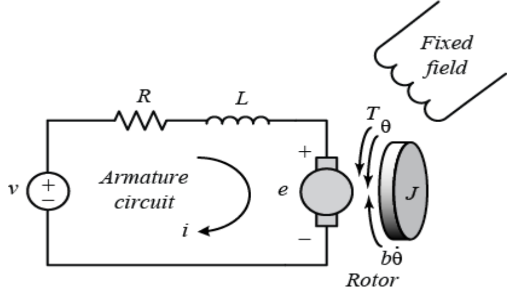

Fig.1. An armature-controlled DC motor.

DC motor is used to converts the electrical energy (direct current) into mechanical energy (rotational motion). The motor torque given in Equation (5) [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(6) [4] also the relation between back electromotive voltage and motor speed explained in Equation (7) [5]. Equation (9) show the relation between motor torque and both load torque and disturbance torque [3].

$$T_m(s) = K_r l_a(s) \qquad (5)$$

$$V_a(s) = (R_a + l_a s)\, l_a(s) + V_b(s) \qquad (6)$$

$$V_b(s) = K_b \omega(s) \qquad (7)$$

$$l_a(s) = \frac{V_a(s) - K_b\omega(s)}{R_a + l_a s} \qquad (8)$$

$$T_L(s) = Js\omega(s) + b\omega(s)$$
$$T_L(s) = T_m(s) - T_b(s) \qquad (9)$$

$$(Js + b)\omega(s) = K_T \frac{V_a(s) - K_b\omega(s)}{R_a + l_a s} \qquad (10)$$

Equation (10) can be implemented using block diagram as shown in Figure 2, which describes the model of DC motor speed control system [4].

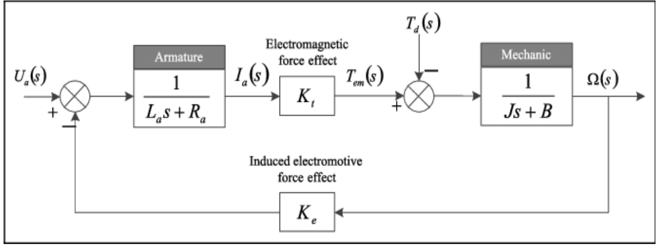

Fig3. DC motor block diagram (speed control).

Equation(11)[4] represents the closed-loop transfer function of the DC motor speed control with respect to the input voltage [1].

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

$$\frac{\omega(s)}{V_a(s)} = \frac{K_t}{JL_a s^2 + (bL_a + JR_a)s + (bR_a + K_b K_T)} \tag{11}$$

A DC motor is a useful machine transforming electrical energy to mechanical energy. It is a well-known device and widely used in industrial applications as an actuator. The schematic diagram of an armature-controlled DC motor can be represented in Fig. 1, where $e_a(t)$ is armature voltage, $e_f(t)$ is field voltage, R_a is armature resistance, L_a is armature inductance, R_f is field resistance, L_f is field inductance, $i_a(t)$ is armature current, $i_f(t)$ is field current, $e_b(t)$ is back-emf voltage, T(t) is motor torque, J is moment of inertia, b is viscous friction, w(t) is motor speed and q(t) is motor position.

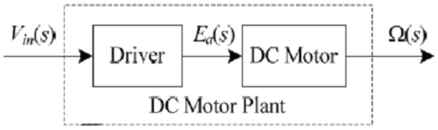

Fig.2. DC Motor Plant.

Once $i_f(t)$ is assumed to be constant, the induced torque T(t), the armature voltage $e_a(t)$ and the back-emf voltage $e_b(t)$ can be expressed in (5), (6) and (7), respectively [4, 8, 15], where K_t is torque constant and K_b is back-emf constant. By taking the Laplace transform of (5), (6) and (7), the s-domain transfer function of a DC motor can be formulated and written as stated in (8). Commonly, using a DC motor needs a power amplifier as a driver. Due to this scheme, the DC motor plant consists of a driver and a DC motor as shown in Fig. 3.

IV. PID CONTROLLER LOOP

A feedback loop of DC motor speed control with PID controller is represented in Fig. 5, where $G_p(s)$ and $G_c(s)$ are the plant and the PID controller, respectively. The model in (7) will be used as the plant $G_p(s)$ in Fig. 4. The PID controller receives error signal E(s) and generates control signal U(s) to control output C(s) and regulate load disturbance D(s) referring to referent input R(s). The time domain and s-domain functions of the PID controller are stated in (8) and (9), where K_p, K_i and K_d are the proportional, integral and derivative gains, respectively. The closed loop transfer function with PID controller is given in (10). The main purposes of control are to make the C(s) tracking the R(s) and simultaneously regulating the C(s) whenever the D(s) is applied into the control loop at T_{dist} as virtualized in Fig. 5.

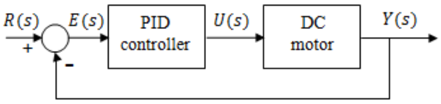

Fig.4. The block diagram of DC motor control system.

A. Chien-Hrones-Reswick Method

The velocity of DC motor can be controlled using different tuning methods. This paper produces 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. 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 1 [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) and the system response with 20% overshoot is labeled with(20% overshoot) as in Table 1 [11].

Table 1 Chien-Hrones-Reswick Tuning

Method	(K_p)	T_i	Td
Formula 1 0% overshoot	0.6/a	T	L/2
Formula 2 20% overshoot	0.95/a	1.4T	0.4/L

V. 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:

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

The step response shown in Fig5 give L=0.08125, T=0.6421, which can be use for all tuning methods discussed in this paper.

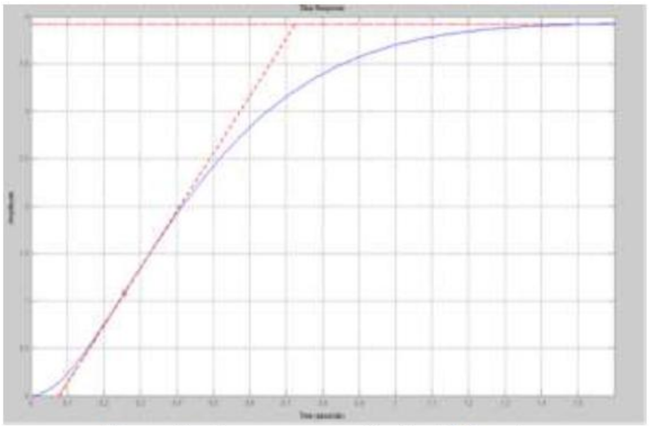

Fig.5. Step response for the DC motor.

A. Chien-Hrones-Reswick Method Formula1

PID controller parameters for the DC motor transfer function $G_p(s)$ with applying Chien-Hrones-Reswick method formula 1 with 0% overshoot shown and formula2 with 20% overshoot shown in Table 2. The controller parameters results from this calculation window are shown in Table 2 for formula1 and formula2, while the response specification is given in Table 3 for formula1 and formula 2.

Table 2 Chien-Hrones-Reswick Using GUI

Method	(K_p)	T_i	Td
Formula 1 0% overshoot	1.2102	0.6421	0.040625
Formula 2 20% overshoot	1.9161	0.89894	0.038187

Table 3. Response specification with Chien-Hrones-Reswick Method

Method	T_r	OS%	T_s	ess
Formula 1 0% overshoot	0.191	10.6	1.08	0
Formula 2 20% overshoot	0.141	13.1	1.35	0

VI. DISCUSSION OF RESULTS

Table 3 show that Chien-Hrones-Reswick method step response method formula 2 give the faster response system for Time-rising (T_r) but formula 1 give the faster response system for Time-stalling (T_s) with acceptable overshoot (OS%). 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 showed in this paper.

VII. CONCLUSION

This paper discusses the design of the PID controller for the DC motor speed control system. Modified ZN methods implemented and learning 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 Chien-Hrones-Reswick yields lower overshoot with acceptable system transient response.

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