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Modelling and Analysis of Ziegler-Nichols and Chien-Hrones-Reswick Tuning PID on DC Motor Speed Control

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***Abstract*—There have been many studies on the methods used to control DC motors, one of which is the proportional-integral-derivative (PID) control method. The tuning procedure is carried out by trial and error whose results are not necessarily correct, to overcome this problem an alternative is needed that can achieve a better and faster value for the tuning process. Our contribution is explained the conventional PID (Ziegler-Nichols) and modificated PID (Chien-Hrones-Reswick). We also analyze the response of the speed-controlled DC motor using the Proportional, Integral, and Derivative parameters obtained from the tuning method described above. We also discuss the advantages and disadvantages of each formula of these methods. Implementing both methods using a Matlab, creating a more convenient and user-friendly environment for engineering students and practicing engineers to better understand the formulas of his PID controller tuning method.**

***Keywords*— DC Motor, Tuning PID, Optimal Control.**

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I. INTRODUCTION

Apart from the development of power electronics resources, DC machines are becoming more and more convenient. Its current use is not limited to automotive applications (electric vehicles), low-power applications using battery systems, or electric and multi-motor traction systems. The DC motor speed is highly adjustable for easy control and high performance [1]-[3]. Each of these control measures has its own advantages. The proportional - integral - derivative (PID) controller is composed of three types of design controllers. The results are not good if the three types of controllers are independent [4], because each has advantages and disadvantages. Many control methods are used to control speed than DC motors. Proportional - Integral - Derivative (PID) controllers are often used in several types of DC motors in various industrial applications. The control system method can operate by processing several important parameters based on the values of Kp, Ki, and Kd to get conditions according to a good setpoint. This control can make an excellent response from DC motor speed [5].

In 1942, Ziegler-Nichols introduced tuning formulas [6] based on timing and experience. Even if the parameters are poorly chosen and excessive timing his overshoot is seen, the parameters pave the way for his tuning. His modified Ziegler-Nichols tuning based on the Chien-Hrones-Reswick (CHR) PID tuning formula [7] for setpoint control takes into account speed of response and overshoot. In this paper, modeling and analysis of PID controller for DC motor speed control regulation, is improved using Ziegler-Nichols and Chien-Hrones-Reswick.

The measure of the success of the method used is to reduce several important parameters on the type of controller with PID which will be studied separately: (a) reduce the rise time, (b) reduce the maximum overshoot point, (c) reduce the settling time.

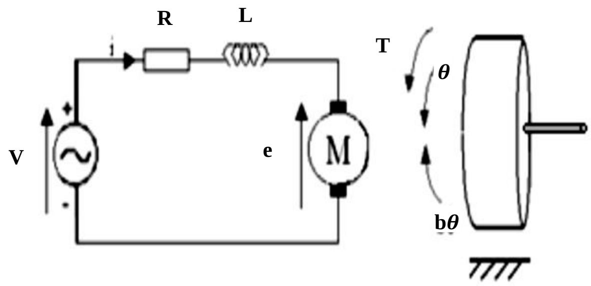

Figure 1. DC Motor Armature Equivalent Circuit

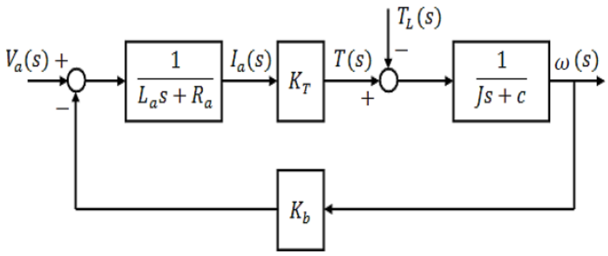

Figure 2. DC Motor Control Block Diagram

II. Related research

Several studies regarding the tuning method with PID for controlling DC motor speed have been carried out. Researcher [7] conducted a simulation with practical responses. The researcher found that the modified Ziegler-Nichols tuning method is the most suitable tuning method for DC motor types, because the This tuning provides a more dynamic response to load disturbances with acceptable overshoot.

Then, researcher [8] conducted a study on PID controller in which researcher proposed good stability in the system. From the simulation results presented, the two best tuning methods are ZN and CHR. As a result, both methods have the characteristics of the Ziegler-Nichols (Z-N) method which is an aggressive tuning method but with adjustments, better system control, and a small completion time value. Meanwhile, the Chien-Hrones-Reswick (C-H-R) method with a faster system response and higher completion time value requirements.

A. DC Motor

This article describes the speed control regulation of a separately excited DC motor. Usually used for angle position and speed adjustment. Design of a DC motor with armature current control can be seen in Figure 1 [9].

This DC motor system is a separate excitation DC motor [10] and is widely used for speed and position regulation. Because this article focuses on the study of linear speed control of DC motors, using a separate type of excitation DC motor. DC motor speed control uses an armature voltage control scheme. The armature voltage controls the process derivative as a constant field current as well as a constant flux. Figure 2 shows an armature control block diagram for a DC motor. Based on the block diagram in Figure 2, the transfer function of the relationship between the armature voltage Va(t) and the angular velocity (t) with L(t) = 0 is obtained as equation [11]:

$$G(s) = \frac{\omega(s)}{E_a(S)} = \frac{K_T}{(L_a(s)+Ra)(Js+C)+K_b K_T} \quad (1)$$

Tm : Motor Torque
ω : An Angular Velocity of Rotor
J : Rotating Inertial Measurement of Motor Bearing
Kb : EMF Constant
KT : Torque constant
B : Friction constant

B. PID Controller

The PID is a controller with one of the earliest control design, which started at the beginning of the last century [12]. Although not optimal, the simplicity and advantages of the PID controller as well as its ability to handle many control system problems make it highly rated and become a standard control in industrial environments. To calculate the time constant for the PID controller type, it is given in equation (2) [13].

$$G_C = K_P\left(1 + \frac{K_i}{T_i S} + K_d S\right) \quad (2)$$

Proportional parameter is used to speed up the response system and minimize steady-state errors, and integral parameter is used to completely dismiss steady-state errors (integral time constants), whereas derivative gain produces an overshoot response, causing an undesired increase [14]. Used to minimize the overshoot point with differential time constant. Figure 3 shows a block diagram of a DC motor control system.

III. Methods

A. Ziegler Nichols Tuning Methods

In a real-time process control system, various design can be described by (3). If the model of the system cannot be derived mathematically, experiments can be carried out to see the parameters of the given model approach (3) Using L and a, we can obtain the controller parameters using the Ziegler-Nichols formula in Table 1 [15].

$$G(s) = \frac{Ke^{-SL}}{TS+1} \quad (3)$$

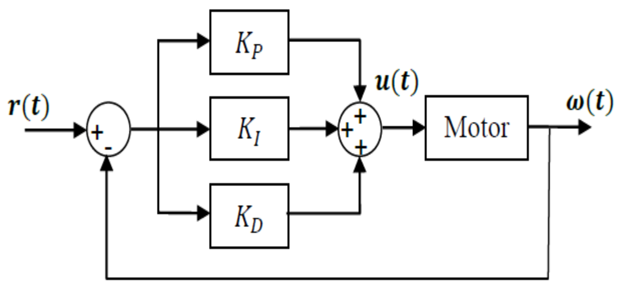

Figure 3. DC Motor with PID Controller [16]

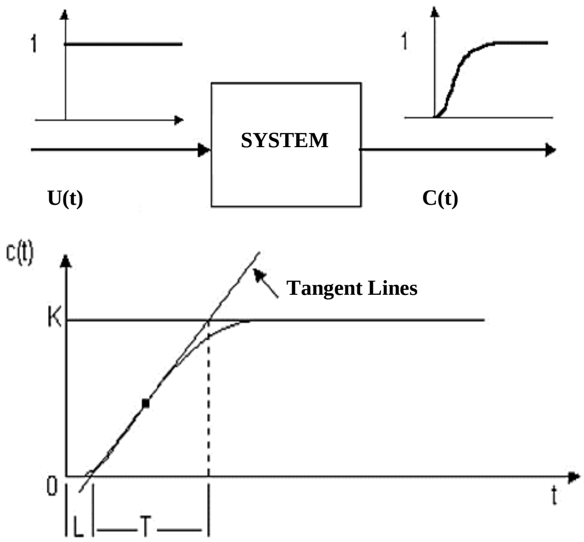

Figure 4. Response Curve for Ziegler-Nichols Method

Table 1. Ziegler-Nichols Tuning Methods

Controller	Kp	Ti	Td
P	T/L	~	0
PI	0.9 T/L	L/0.3	0
PID	1.2 T/L	2L	0.5L

For example, if the step response system of generating design can be calculated experimentally, the output signal of open-loop response system looks like Figure 4. From this, the value k, L, and T (where a = $k \cdot L/_{T}$) can be calculated by the simple approximation shown. Using L and a, we can obtain the parameters using the Ziegler-Nichols formula.

B. *Chien-Hrones-Reswick Tuning Method*

This step is a correction of the authentic Ziegler-Nichols (ZN) procedure. Manufactured by Chien-Hrones-Reswick (CHR) in 1952 with preferable overshoot response. When compared with the conventional Ziegler-Nichols equation, the Chien-Hrones-Reswick (CHR) also uses a time constant and parameters derived from the step response of an open-loop response [17].

Table 2. Chien-Hrones-Reswick Tuning Methods

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

Table 3. DC Motor Parameter

Parameters	Values
R	5.2 Ohm
L	1.1 mH
J	0.01 kg.m
B	0.02 $N.m.sec/rad.s^{-1}$
K	0.75 $N.m.A^{-1}$

In addition, qualitative indicators of response system and value of overshoot can be recorded. The calculation for the Chien-Hrones-Reswick (CHR) tuning are explained in Table 2 for setpoint control.

IV. Result and Analysis

Research activities are more focused on designing Analog PID control on DC motor speed regulation by tuning using the Ziegler-Nichols and Chien-Hrones-Reswick methods, whose performance will be tested using a simulation that will be made.

A. *Open-Loop Characteristics*

Based on equation (1), we need parameter data from a DC motor which we will adjust the speed and then we substitute the data into the Laplace transform. These parameters are obtained from the physical system of the DC motor. Parameters of the measurement results are shown in Table 3. If the DC motor parameter values in table 2 are entered into equation (1), a mathematical model of the DC motor will be obtained as shown in equation (4). The response of the DC motor open loop system based on the mathematical model is shown in Figure 7.

$$\frac{\omega(s)}{Ea(s)} = \frac{0{,}75}{0{,}11s^2+0{,}074s+0{,}667} \quad (4)$$

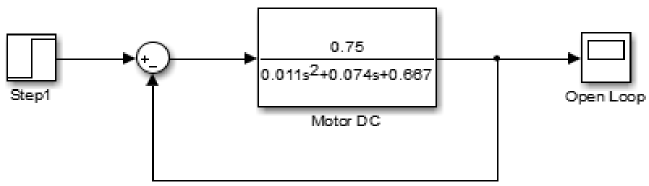

Figure 5. Open-loop Response Block Diagram

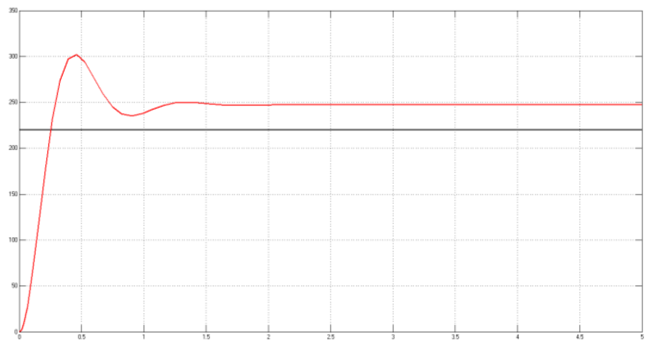

Figure 6. Open-loop Response Characteristic

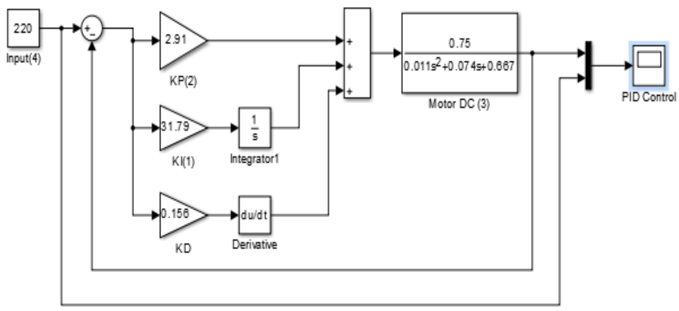

Figure 7. Ziegler-Nichols Tuning Block Diagram

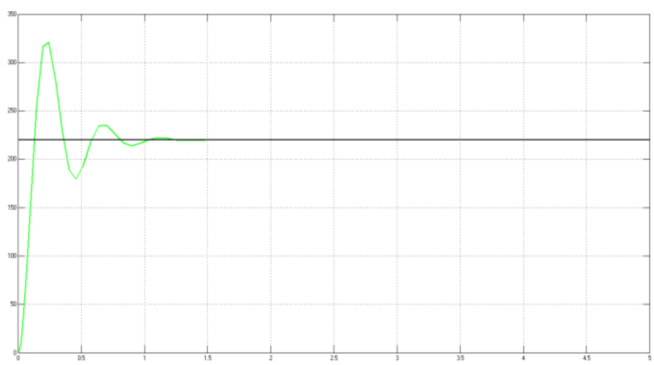

Figure 8. Ziegler-Nichols Response Characteristics

Then enter the equation into the simulink as shown in Figure 5, so that we can find out what the open loop response looks like. To see the response of the DC motor open loop system on the simullink, we can use the scope help which can be seen in Figure 6.

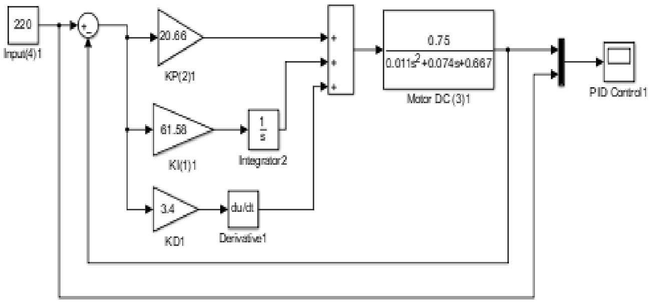

Figure 9. Chien-Hrones-Reswick Tuning Block Diagram

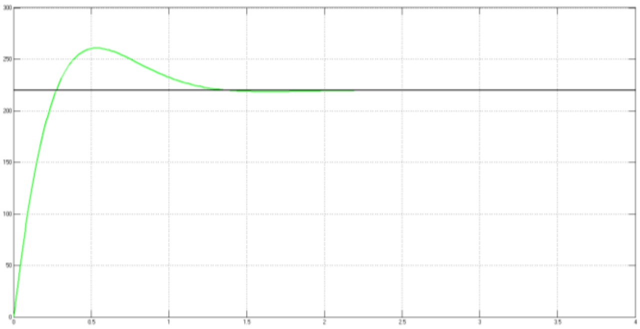

Figure 10. Chien-Hrones-Reswick Response Characteristics

From the open loop simulation that has been carried out, the values of L = 0.07 and T = 0.26 of these values are then substituted into table 1. So that we can get the values of Kp, Ki and Kd. Seen from Figure 6, it can be seen that the DC motor used is experiencing overspeed where the red line exceeds the black line, where the black line is the target of the control.

B. ZN Tuning Characteristics

The Ziegler-Nichols methods control block diagram is shown in Figure 7. The Kp and Ki values are calculated based on the rules contained in table 1 and produce a Kp value of 4.45, Ki of 31.79, and a Kd value of 0.156.

The system response shown in Figure 8 shows the system experiencing a maximum overshoot of 320.9 rpm, a steady state error of 0.002%, and a settling time value of 1.7 sec. From the simulation results, the Ziegler-Nichols tuning methods has been able to reach the target with a value of overshoot, steady state error, and long settling time.

C. CHR Tuning Characteristics

The Chien-Hrones-Reswick (CHR) tuning methods control block diagram is shown in Figure 9. The Kp and Ki values are calculated based on the rules contained in Table 2 and produce a Kp value of 20.66, Ki of 61.58, and a Kd value of 3.4. The system response shown in Figure 8. shows the maximum overshoot of 260 rpm, a settling time value of 1.5 sec and without steady state error.

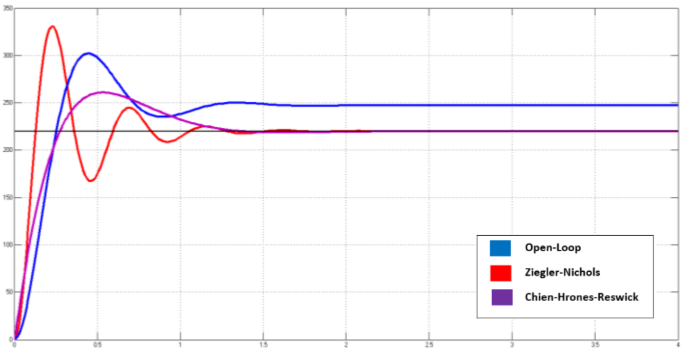

Figure 11. Z-N vs C-H-R Response Characteristics

Table 4. Tuning Point of KP, KI, and KD

Controller	Kp	Ki	Kd
ZN	4.45	31.79	0.156
CHR	20.66	61.58	3.4

Table 5. Characteristics of Response System

Controller	Error Steady State (%)	Settling Time (Sec)	Maximum Overshoot (rpm)	Rise Time (Sec)
OL	13.6	2	300	0.45
ZN	0.5	1.1	330	0.25
CHR	0.1	1.5	260	0.4

The Chien-Hrones-Reswick (CHR) tuning methods has been able to reach the target with a minimum value of overshoot, without steady state error, and better settling time. From table 5 it can be seen that the step response of the Ziegler-Nichols (ZN) method provides a faster system response for the rise time (Tr) and settling time (Ts) with overshoots that are still too large. However, if the overshoot point in the signal response is higher than the system response speed, it is recommended to use the Chien-Hrones-Reswick (CHR) method which gives a smaller overshoot point than other methods.

V. Conclusion

This articles describes the configuration of a PID control methods for a DC motor speed control system regulation. We use two favourite methods, performed and simulated using Matlab simulink, to establish a convenient environment for learning and understanding the methods and impact of each method on system response result. The simulation show that each method outperforms the other. For a chosen DC motor speed control regulation transfer function, the Ziegler-Nichols (ZN) tuning methods has been shown to give a faster system response with higher overshoot, while the Chien – Hrones – Reswick (CHR) methods has been shown to give a faster system response with acceptable system transient response and gives less overshoot.

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