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Position Control of a DC Motor with PID, I-P and I-PD Control Methods

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Abstract

Since direct current (DC) motors have a wide usage area, they are frequently researched and studied in the literature in terms of control methods. In this study, the modeling of the Dc motor was carried out in the simulation environment by using Proportional-Integral-Derivative(PID), Integral-Proportional (I-P) and Modified I-PD control methods. In this study, the Ziegler-Nichols method was used to find the control coefficients and the closed-loop control type was used in this method. The position results of the DC motor were evaluated using the Root Mean Square Error (RMSE) and Mean Absolute Error (MSE) performance criteria. As a result, the obtained results are given in the form of graphs and tables and they are examined.

Keywords: DC motor; Modeling; Proportional- Integral-Derivative (PID); Integral- Proportional (I-P); Integral- Proportional- Derivative (I-PD)

1. INTRODUCTION

Since direct current (DC) motors have been widely used in the literature from the past, control studies have been actively researched and continue to be researched. Cost, ease of control, long life and quiet operation etc. it is used frequently because of its features. Modeling and simulation has been done for industrial DC motor using intelligent control methods [1]. The control of a DC motor was carried out using Ziegler Nichols and PID control method, whose control coefficients were obtained using genetic algorithm [2]. A comparative study has been carried out for speed control of dc motor using PID control method [3]. A review has been carried out on Shrivastava, DC motor types and the necessity of the starter motor for speed regulation [4]. Sing and Garg made a literature study on the tuning methods of PID control method for

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speed control of DC motor [5]. The control of the DC motor was carried out by using the adaptive PID control method [6]. In another study, a kalman filter was used to estimate the DC motor speed, and both PID and LQR controllers were used to control the motor [7]. A DC motor was controlled by using the PID control method, whose control coefficients were obtained by using a genetic algorithm [8]. Oladipo et al. conducted a literature study on the optimization of the PID controller with metaheuristic algorithms and for DC motors [9]. The I-PD control method is a modified version of the classical PID control method. The optimal I-PD control method, which is obtained by using the Cuckoo Search algorithm of control coefficients, has been proposed [10]. Ketthong et al. have designed and implemented I-PD controller for DC motor speed control system with adaptive tabu search [11]. Choel et al. carried out an I-PD controller design using the CDM control method[12]. For a 4-pole hybrid electromagnet, a three-axis headspace I-PD controller design based on the coefficient diagram method has been carried out [13]. An I–PD controller has been proposed for integration and time-delay systems [14]. In this study, the modeling of the dc motor was carried out in the simulation environment by using Proportional-Integral-Derivative(PID), Integral-Proportional (I-P) and Modified I-PD control methods. In this study, the Ziegler-Nichols method was used to find the control coefficients and the closed-loop control type was used in this method. The position results of the DC motor were evaluated using the Root Mean Square Error (RMSE) and Mean Absolute Error (MSE) performance criteria. As a result, the obtained results are given in the form of graphs and tables and they are examined.

2. MODELING OF DC MOTOR

Direct current (DC) motors are widely used in a variety of industrial and electronic equipment where high accuracy position control is required. The model of the dc motor is given in the equations below. Figure 1 shows the direct current (DC) motor.

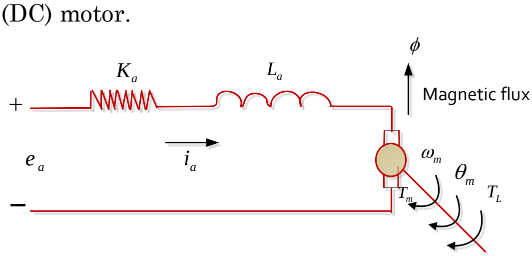

Fig.1. Direct current (DC) motor model

The moment received from the electric motor;

$$T_m(t) = K_m.\Phi.i_a(t) = K_i.i_a(t) \quad (1)$$

$$\frac{di_a}{dt} = \frac{1}{L_a}.e_a - \frac{R_a}{L_a}.i_a - \frac{1}{L_a}.e_b \quad (2)$$

$$T_m = K_i.I_a \quad (3)$$

$$e_b = K_b.\frac{d\theta_m}{dt} = K_b.\omega_m(t) \quad (4)$$

$$J_m\frac{d^2\theta_m}{dt^2} = T_m - T_L - B_m.\frac{d\theta_m}{dt} \quad (5)$$

If we take our variables as i_a, θ_m and ω_m, the equations of state from the first order can be written as follows.

$$\dot{x} = Ax + Bu \quad (6)$$

$$\begin{bmatrix} \frac{di_a}{dt} \\ \frac{d\omega_m}{dt} \\ \frac{d\theta_m}{dt} \end{bmatrix} = \begin{bmatrix} -\frac{R_a}{L_a} & -\frac{K_b}{L_a} & 0 \\ \frac{K_i}{J_m} & -\frac{B_m}{J_m} & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} i_a \\ \omega_m \\ \theta_m \end{bmatrix} + \begin{bmatrix} \frac{1}{L_a} \\ 0 \\ 0 \end{bmatrix} .e_a - \begin{bmatrix} 0 \\ \frac{1}{J_m} \\ 0 \end{bmatrix} .T_L(t) \quad (7)$$

$$\frac{\theta_m(s)}{E_a(s)} \qquad \frac{\theta_m(s)}{E_a(s)} = \frac{K_i}{L_aJ_ms^3 + (R_aJ_m + B_mL_a)s^2 + (K_bK_i + R_aB_m)s} \quad (8)$$

The parameters of the dc motor are shown in Table 1.

Table 1. Parameters of Dc motor

Symbol	**Description**	**Values /Units**
m	Body Mass	10 *kg*
J	Body Inertia	0.171 kgm^2
K_m	Motor Constant	3520 *Nm/A*
R_a	Motor Resistance	55 *Ohm*
l_o	Leg Length	0.323 *m*
L_m	Motor electric inductance	0.3 *H*
B_m	Damping ratio of the system friction constant	0.097 *Nm.*

3. CONTROLLER DESIGN

The PID, I-P and I-PD control methods are used in the control of DC motor. A control method has been designed with the aim of reaching the desired position and achieving minimum error in position control.

3.1. PROPORTIONAL-INTEGRAL-DERIVATIVE (PID) CONTROL

The Proportional-Integral-Derivative(PID) control method, which is used in many applications, especially in the industry, is a control method that provides a very simple use. The basic mathematical equation of the PID control method is given below [15-16]. The most important parameters of this control method are the control coefficients. In this study, Ziegler-Nichols method was used to find control coefficients and closed-loop control type was used in this method [17-19].

θ_d Reference input angle signal, θ the output angle of the real system, $e=\theta_d-\theta$ error signal, Kp proportional gain, Ki integral gain, and Kd derivative gain.

$$u(t)=K_p e(t)+K_I\int_0^{\tau} e(t)dt+K_D\frac{d}{dt}e(t) \quad (9)$$

3.2. INTEGRAL- PROPORTIONAL-DERIVATIVE (I-PD) CONTROL

The Integral-Proportional-Derivative (I-PD) control method is a modified version of the classical PID control method. The I-PD controller has been developed to reduce the maximum overshoot. It has been used in various studies in the literature [20-22]. Unlike the PID controller, the Proportional-Derivative coefficients are multiplied by the output expression of the system, but the control expression is obtained by multiplying the integral control coefficient with the error signal. The mathematical expression of I-P and I-PD expressions are given in equations 8 and 9 below.

$$u(t)=K_p e(t)+K_I\int_0^{\tau} e(t)dt+K_D\frac{d}{dt}e(t) \quad (10)$$

$$u(t)=K_I\int_0^{\tau} e(t)dt-(K_p\theta(t)+K_D\frac{d}{dt}\theta(t)) \quad (11)$$

4. SIMULATION RESULTS

In this section, the mathematical model of the DC motor given above and the simulation studies obtained by using Proportional-Integral-Derivative (PID), Integral-Proportional (I-P) and Modified Integral-Proportional- Derivative I-PD control methods are given. The control variable is the motor angular position. A fixed input value is applied to the engine model. The proposed control methods were evaluated according to performance criteria (RMSE and MSE) and the results of the methods were examined. The simulation time was taken as 10 seconds. Angular position and error graph of the motor obtained using a fixed input value and PID control method is given in Figure 2. In Figure 3, the angular position and error graph of the motor obtained using a fixed input value and I-P control method is given. Angular position and error graph of the motor obtained by using a fixed input value and I-PD control method are given in Figure 4.

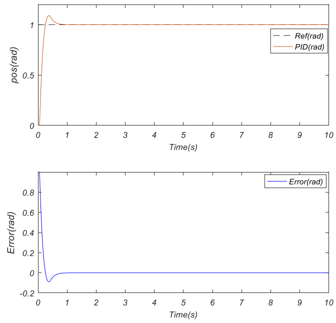

Fig.2. The angular position and error graph obtained by applying a constant input and PID control method (Kp=60 Ki=240 Kd=3.75)

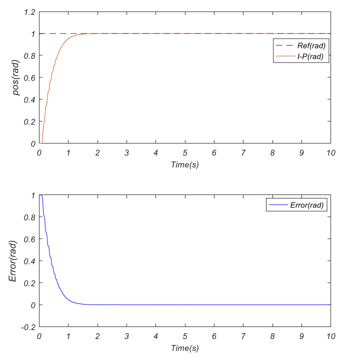

Fig. 3. The angular position and error graph obtained by applying a constant input and I-P control method (Ki=200 Kp=50)

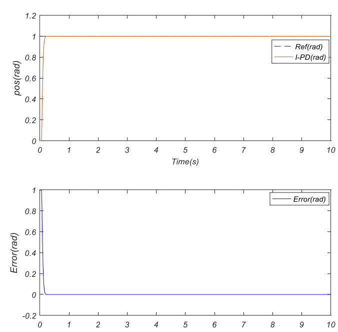

Fig. 4. The angular position and error obtained by applying a constant input and I-PD control method (Ki=200 Kp=20 Kd=0.25)

In Figure 2, it is seen that the maximum overshoot occurred in the graph obtained by using the PID control method against a fixed input value. Looking at the angular motor error graph, it was seen that the motor reached a settling time of approximately 1 second. Similarly, in Figure 3, it was seen that the maximum overshoot did not occur in the graph obtained by using the I-P control method against a constant input value. However, looking at the angular motor error graph, it was seen that the motor reached a settling time of about 2 seconds. In Figure 4, it was seen that the maximum overshoot did not occur in the graph obtained as a result of using the I-PD control method. Looking at the angular motor error graph, it was seen that the motor reached a settling time of about 0.2 seconds. In Table 2, the error results were obtained according to Root Mean Square Error (RMSE) and Mean Absolute Error (MSE) performance criteria. Equations of RMSE and MSE performance criteria are given below.

$$RMSE = \sqrt{\frac{1}{N}(\sum_{j}^{N} y_{j} - y_{j})^2} \quad (12)$$

$$MSE = \frac{1}{N}(\sum_{j}^{N} y_{m_j} - y_{s_j})^2 \quad (13)$$

y_{dj} robot requested j. If the value is y_j, the robot j. shows its true value. y represents the angular position (θ) of the motor. j = 1,2,3,4… .N. Table 2 shows the error results obtained by using the results of the PID, I-P and I-PD control methods against a constant input value to the performance criteria RMSE and MSE.

Table 2. The error results according to performance criteria.

Control Methods	RMSE	MSE
PID Control	0.0984	0.0097
I-P	0.1640	0.0269
I-PD	0.0596	0.0063

Table 2 shows the error results obtained by using the results of the PID, I-P, and I-PD control methods against a fixed input value to the performance criteria RMSE and MSE. The lowest error rate was obtained using the I-PD control method and the MSE criterion against a fixed input value given in Table 2, and the result is 0.0063 radians. According to the RMSE criterion, the lowest error rate was obtained using the I-PD control method and its value was 0.0596 radians. The PID control method given in the table has a larger error rate than the I-PD control method. These are 0.0097 and 0.0984 radians according to the MSE and RMSE criteria, respectively. I-P control method performed worse than I-PD and PID control methods. The values obtained using the I-P control method, MSE, and RMSE criteria are 0.0269 and 0.1640 radians, respectively.

5. DISCUSSION AND CONCLUSION

In this study, modeling and position control of DC motor was performed using Proportional-Integral-Derivative(PID), Integral-Proportional (I-P), and Integral-Proportional-Derivative (I-PD) control methods. The control performance of the system was evaluated using RMSE and MSE criteria. When the results obtained with the I-PD control method are observed, the best performance result was obtained in terms of both maximum overshoot and settling time. Among the control methods are given in the table, PID and I-P control methods did not give as good results as the I-PD control method. In general, it is seen that the I-PD control method shows superior performance. In future studies, the control coefficients can be obtained by using optimization methods and applied in a real-time laboratory environment.

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APPENDİX

Nomenclature	
i_a	Motor current
R_a	Motor resistance
e_b	emf
T_L	Load torque
ϕ	Magnetic flux
J_m	Moment of inertia
B_m	Viscous damping coefficient
L_a	Motor inductance
e_a	Motor voltage
K_b	emf constant
θ_m	Angular rotation of the rotor
K_i	Torque constant
w_m	Angular velocity of the rotor