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SIMULATION STUDY OF P, PI, AND PD CONTROLLERS FOR DC MOTOR POSITION

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Abstract— DC motor is a direct current motor which converts electrical energy to mechanical energy. It is widely used in industry such as in transportation, robotic control system and other fields. Position control is an important for system which include precision control. The performance of the DC motor for position control also can be influenced by a controller as well as the DC motor itself in providing outstanding performance. Therefore, this paper will discuss the performances of the DC motor for position control which applied varies controllers that tuned by the Ziegler-Nichols tuning method. P, PI and PD controller will be implemented in this work and will be conducted by using the software of MATLAB/Simulink. To validate the performance of the DC motor position control derived from the circuit of DC motor as well as the different controllers and no controller, it will be compared in terms of the transient response characteristics which are rise time, settling time and percentage overshoot. At the end of the study, it shows that the DC motor for position control with the P controller obtained an outstanding performance compared to the DC motor position control without and other controllers.

I. Introduction

DC motors change electrical energy into mechanical energy and have been used in many different ways. For example, in guided vehicles, heating, ventilation, and air conditioning (HVAC) systems, electrical transportation devices, elevators and other mechanism where it have reasonable sizes and could be used in a robotic positioning device for installing pipelines made from composite material [1-2]. Amini et al., in [3] mentioned that DC motors are often used in control systems because they are easy to adjust for position or speed and work well in a wide range of conditions.

Other than that, DC motors with separate excitation are useful due to the ability to control the speed and position of the motor independently of the flux and torque. DC motors are usually modelled as linear systems, and linear control approaches are then used to control them. However, most of them do not work well because the load and motor dynamics change, and the armature reaction where it causes nonlinearities [3].

One problem with designing motor controllers is that the parameters of the system under control can change, and the way to fix this is to use robust controls. As mentioned by previous researchers, the goal of the controller design is to make a process become more stable and shorten the time it takes to get to the desired state when things go wrong. In addition, to enhance the system performance of the DC motor itself especially in this project, different controllers have been implemented and being compared. Controllers that being used are proportional (P) controller, proportional-integral (PI) controller and proportional-derivative (PD) controller.

P-only controller is the most elementary of the PID-based algorithms. This control method employs a control framework that functions to maximise control exertion in proportion to mistake. What distinguishes a proportional frameworks from others is that the degree of control exerted is proportionate to the amount of inaccuracy [4].

Next, PI controller is a type of controller that combines the proportional and integral controllers. In [5], the authors said that this controller is used to make power distribution less likely to go wrong. Aside from that, it is always looking for an error signal, which is the difference between a measured process variable and the desired set point. The proposed controller also speeds up response and makes the system less unstable. It can also bring things back into line with the values that were set before.

PD controller is a controller that merged proportional and derivative controller together. The derivative term in the PD controller is used to forsee the character of error and hence reduce the impact of any sudden shifts in error [6]. Referring to [7], mentioned controller is a simple controller structure that is both globally stable and capable of responding to rapid changes in process loss with a minimum of overshoot. By improving the control, this controller helps make the system more reliable.

The main objective of this paper is to explore the performance of the DC motor position control by using different controllers which are

P controller, PI controller, PD controller as well as the DC motor position only without any controller. The parameters of the proposed controllers will be tuned by the Ziegler-Nichols tuning technique. After that, to justify the performance of the DC motor position, it will be analyzed by comparing between these controllers that have been proposed and the DC motor position without any controller in terms of transient response aspects.

II. Methodology

In this study, a mathematical model for DC motor position control was developed. Architectures of P, PI, and PD controller have been built up in MATLAB/Simulink software where transfer function of DC motor position will be implemented together.

A. General Equations of DC Motor Mathematical Modelling

Figure 1 shows the DC motor circuit. The circuit of DC motor mathematical modelling consists of two parts: the electrical part and the mechanical part. In the electrical component, it will consist of input voltage, resistor, and inductor, while in the mechanical part, it will just consist of the rotor.

By using Kirchhoff's voltage law, the electrical equation of the DC motor can be described as

$$E_a = R_a . I_a + L_a \, d_{ia}/d_t + E_b \qquad (1)$$

where I_a is the armature current, E_b is the back emf voltage and E_a which act as the voltage source.

$$E_b = K_b \, d\theta/dt \qquad (2)$$

where K_b is a constant of back emf.

From the mechanical part can be derived as

$$J_m \, d^2\theta/dt + B_m \, \theta/dt = T_m \qquad (3)$$

where, J_m is the rotor moment of inertia, B_m is the frictional coefficient and Tm is motor torque.

$$T_m = K_t . I_a \qquad (4)$$

K_t is a torque constant.

By substituting Equation (2) into Equation (1), Equation (4) into Equation (3) and rearranging, converting it to Laplace transform, a new equation was formed as below.

$$E_a(s) - K_b s\theta(s) = (R_a + sL_a) I_a(s) \quad (5)$$

$$J_m s^2 \theta(s) + B_m s \theta(s) = K_t I_a(s) \quad (6)$$

After some calculation, the general transfer function was generated as below.

$$\frac{\theta(s)}{E_a(s)} = \frac{K_t}{J_m L_a s3 + (J_m R_a + B_m L_a) s2 + K_t K_b s} \quad (7)$$

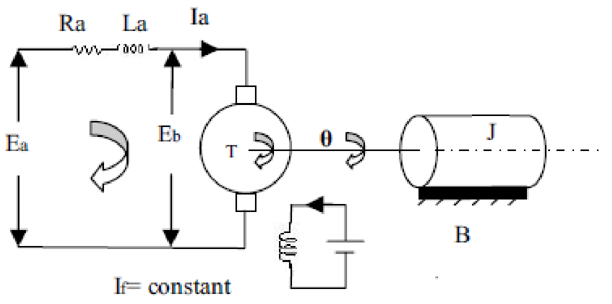

Figure 1: DC motor circuit

B. Tuning Method for *Kp, Ki, Kd*

A controller's *Kp*, *Ki*, and *Kd* parameters can be adjusted in a variety of ways. The Ziegler-Nichols approach, the Cohen-Coon method, bio-inspired computation and swarm intelligence, a subset of artificial intelligence are the most popular tuning techniques [8]. The Ziegler-Nichols approach will be used to tune the parameters and to compare the performance of a DC motor and suggested controller.

Patel in [9] said that, Ziegler-Nichols (ZN) rules are frequently used to fine-tune PID controllers for plants whose precise dynamics are unknown, however, they can also be utilized with plants whose dynamics are known. Based on the transient response properties of a particular plant, Ziegler and Nichols provided criteria for calculating the values of proportional gain, *Kp*, integral time, *Ti*, and derivative time, *Td*.

Figure 2 below is the curve of step input response or known as the S-shaped step response of a plant. Two constants, delay time, L and time constant, T can be used to describe an S-shaped curve. The delay time and time constant can be figured out by drawing a tangent line at the point where the S-shaped curve changes direction and finding where the line meets the time axis and the line y(t) = K [10].

In this work, as the step response illustrate the S-shaped curve and there is no any oscillations occurred, thus the first method of Ziegler-Nichols can be implemented. After the parameters' value of delay time and time constant is known, the value for each gains' controller can be calculated by using the formula that is tabulated as Table 1 below.

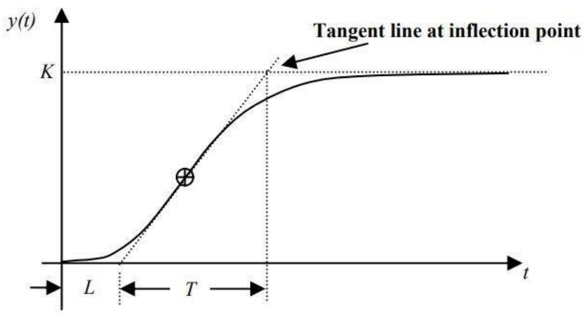

Figure 2: Step input response curve

Table 1: Ziegler-Nichols Tuning

Type of controllers	Gains' value		
	Kp	Ki	Kd
P	$\frac{T}{L}$	0	0
PI	$0.9\frac{T}{L}$	$\frac{0.3}{L}$	0
PD	$1.2\frac{T}{L}$	0	*0.5L*

C. Development and Combination of DC Motor with Controllers

In this part of study, there will be three different development of DC motor with each of the proposed controller that are P, PI and PD controller. The development portrayed as Figure 3, Figure 4 and Figure 5 below. Then, a combination block diagram will be created as in Figure 6 to make it simple and the system diagram is more systematic.

Controller's gain that included in this work is proportional gain, *Kp*, integral gain, *Ki,* and derivative gain, *Kd.* Each of the gains has its own advantage and purposes that will influence how the system will be responds. As for the *Kp*, it is a measure of how stiff a system is. It shows how much force is needed to correct for position errors.

At the same time, the static torque demand on the system is inversely proportional to the integral gain, *Ki*. At the end of the step, value of *Ki* "pushes" the system to zero positioning error. This value is called as integral due to it grows over time. Then, comes *Kd*, which shows the system's damping effects, which work with *Kp* in stopping the oscillations as well as overshoot [11].

Even so, each of the benefits will change how the system works in a different ways. Jenkins [12] says that *Kp* will help reduce the steady-state error and rising time while making the system overshoot more. *Ki* will take less time to rise than *Kp*, but it will take more time to overshoot and settle. Last but not least, *Kd*'s rising time will be moved a little bit to help cut down on overshoot and settling time.

After that, all of these block diagram will be created a subsystem in order to combine all of the controllers. It will be included with the subsystem of DC motor without using any controller as well as the step input which acts as the reference point. Three different value for step input has been applied during this simulation for a linear position which are 5m, 10m, and 20m.

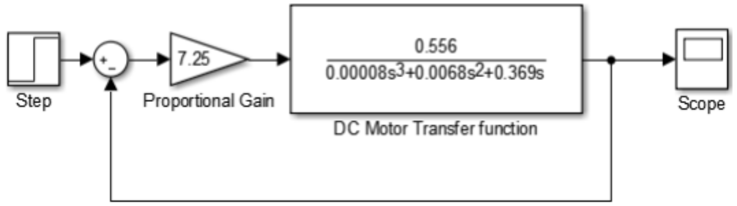

Figure 3: Block diagram of DC motor with proportional controller

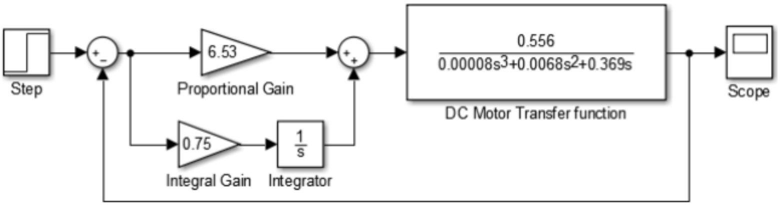

Figure 4: Block diagram of DC motor with proportional integral controller

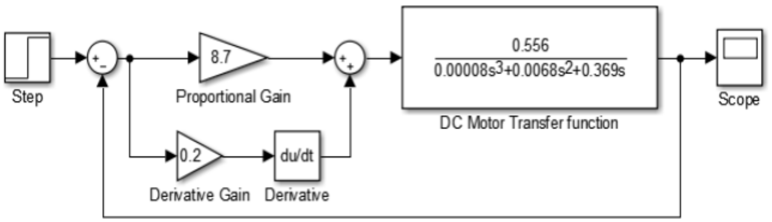

Figure 5: Block diagram of DC motor with proportional derivative controller

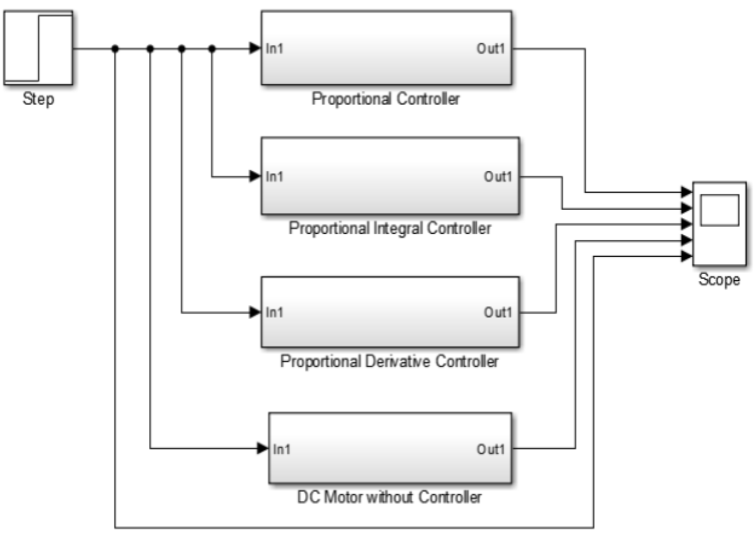

Figure 6: Block diagram of combination controllers

D. Performance Evaluation

In this phase, the performance of the controllers will be measured and compared between a few characteristics. For example, the rise time, Tr, is the amount of time it takes for the system's reaction to grow from 10% to 90% of its final value. The settling time, Ts, is the amount of time it takes for the system to stabilise. The percentage overshoot, OS, is the percentage of the difference between the peak and steady-state.

This will be done for each type of controller, as well as for a DC motor that doesn't have any controllers. This procedure was done to figure out which controller works best with the DC motor for position control to make it move quickly and stay in place.

III. Result and Discussion

A. Ziegler Nichols Tuning Method

Parameters of Ziegler-Nichols tuning, which are Kp, Ki, and Kd, can be obtained by some calculation based on Table 1. These parameters being used in the block diagram along with the mathematical model of DC motor based on the type of controller that is used.

Table 2 below is the result of the Ziegler-Nichols tuning method that has been obtained.

Table 2: Ziegler-Nichols Tuning

Type of controllers	Gains' value		
	Kp	Ki	Kd
P	7.25	-	-
PI	6.53	0.75	-
PD	8.7	-	0.2

B. Simulink Result of Simulation

During the simulation, there are three different step input that has been implemented during the simulation which are 5m, 10m and 20m as it is for linear position purposes. By using these varies values of step input, different simulation graphs were obtained and displayed as below.

Figure 7, Figure 8 and Figure 9 above shows that the system response for these three different positions or step input provide a similar pattern. Different values being applied in this study is for the purposes of verifying the performance of the DC motor position with suggested controllers.

As we can see from the figures above, for all of the linear position, the performance of the DC motor without using any controller are in stable condition. This can happen due to the precise derivation of mathematical model that have been made earlier. Next, to improve the performance of the DC motor position, thus, controllers being implemented. DC motor position with P controller portrayed a fast response compared to the other DC motor position with their own controller.

Comparison between the DC motor position with controller will be discussed in detail in terms of transient response characteristics.

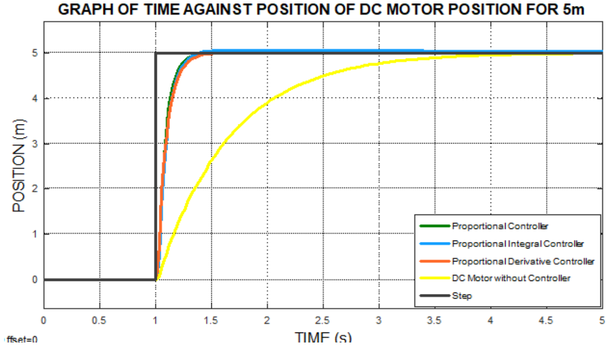

Figure 7: Combination graph of the different controllers for 5m

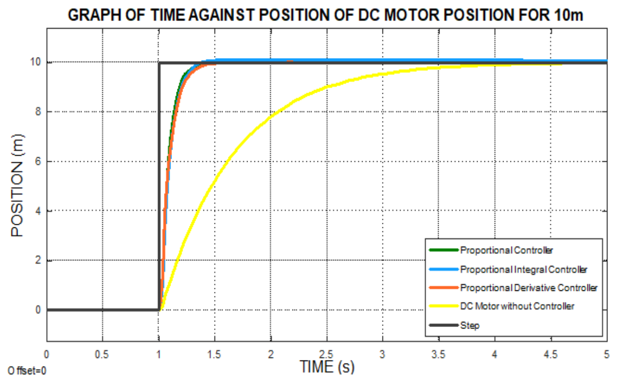

Figure 8: Combination graph of the different controllers for 10m

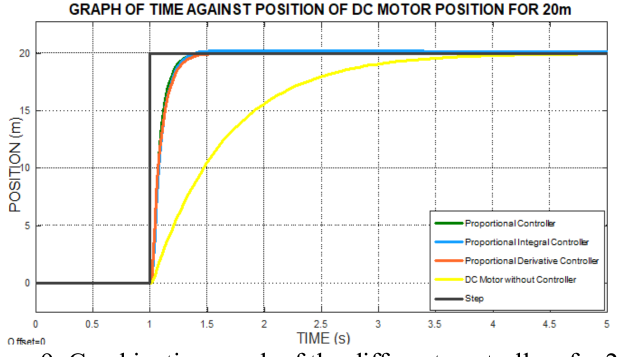

Figure 9: Combination graph of the different controllers for 20m

C. Transient Response of DC Motor with Each Controller

By referring to step response graph in Figure 7, Figure 8 and Figure 9, transient response for each controller can be carried out and the data will be displayed in Table 3, Table 4, and Table 5 below. The performances of the combination controller with DC motor position will be compared and discussed based on the transient response table.

From the step response simulation graph in Simulink and transient response results for step input 5m, 10m and 20 m, the proportional controller shows better performances than the DC motor without a controller. According to Table 3 until Table 5, it shows that proportional controller has the shortest rise time, Tr which are 0.142s, 0.153s and 0.155s for

5m, 10m and 20m accordingly compared to other controllers.

In terms of rising time required by system response from an initial value of 10% to reach 90% of steady-state response, DC motor without using any controller has the longest time for each position, which are 1.373s, 1.409s and 1.441s.

For settling time, Ts which is the time needed to reach and stay 2% of steady-state values, again, proportional controller required a short time to reach it to compare with other controllers. It required 1.302s for 5m, 1.300s for 10m, and 1.291s for 20m while comparing it to the second-longest time required, which is proportional derivative, this controller needed 1.340s for 5m, 1.359s for 10m and 1.388s for 20m.

In terms of overshoot that defined percentage of the difference between the peak and steady-state, all controller has a small overshoot and is the same for all positions. The smallest overshoot in the system response is 0.449% for the proportional derivative controller, and the system is still stable since the overshoot is under 10%.

Thus, after analysing all the transient response parameters for all controllers, it shows that proportional controller has better performances as it required the shortest time from an initial value of 10% to reach 90% of steady-state response, to reach and stay 2% of steady-state response and lastly small value of overshoot that is still in range of 10% which will make the system stable.

Table 3: Transient Response Position for 5m

Type of controllers	Transient response $Tr(s)$	$Ts(s)$	$OS(\%)$
DC motor position without controller	1.373	3.537	0.500
P	0.142	1.302	0.458
PI	0.180	1.312	0.505
PD	0.190	1.340	0.449

Table 4: Transient Response Position for 10m

Type of controllers	Transient response		
	$Tr(s)$	$Ts(s)$	$OS(\%)$
DC motor position without controller	1.409	3.576	0.500
P	0.153	1.300	0.458
PI	0.184	1.310	0.505
PD	0.174	1.359	0.449

Table 5: Transient Response Position for 20m

Type of controllers	Transient response		
	$Tr(s)$	$Ts(s)$	$OS(\%)$
DC motor position without controller	1.441	3.612	0.500
P	0.155	1.291	0.458
PI	0.194	1.320	0.505
PD	0.184	1.388	0.449

IV. Conclusion

In this project, different controllers which are proportional controller, proportional-integral controller and proportional-derivative controller, were successfully developed via simulation by using MATLAB/Simulink software for DC motor position control.

From this simulation, DC motor position control with any controller provide a better performance compared to DC motor position control without any controller being implemented. In terms of transient response aspects, DC motor position with proportional controller shows enhanced performance than other DC motor with different controller.

By implementing the proportional controller, it required the shortest time, 0.142s, 0.153s and 0.155s for 5m, 10m and 20m linear position respectively for the system to reach 90% from 10% of the steady-state response. It is the same result for the second aspect of transient response, DC motor position with proportional controller need shortest time to reach and stay within 2% of steady-state response and it does have the small value of overshoot that is still in a range of 10% which will make the system to be in stable state.

To sum up, important part in having an outstanding performance is the derivation for the mathematical model itself and implementation of some controller.

V. Acknowledgement

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VI. References

[1] E. Flores-Moran, W. Yanez-Pazmino, L. Espin-Pazmino, I. Carrera- Manosalvas, and J. Barzola-Monteses, “Particle Swarm Optimization and Genetic Algorithm PID for DC motor position controllers,” in 2020 IEEE ANDESCON, Oct. 2020, pp. 1–6.

[2] Z. M. Naing, S. Anatolii, Y. H. Linn, and K. Soe Win, “Modeling and Controlling of DC Motor Positioning in the Installation of Pipelines Based on Composite Materials,” in 2019 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), Jan. 2019, pp. 2139–2141.

[3] S. Amini, H. Golpira, and H. Bevrani, “Robust H2 and H∞ controller design for DC position motor control under uncertainties,” in 2019 6th International Conference on Control, Instrumentation and Automation (ICCIA), Oct. 2019, pp. 1–6.

[4] H. S. Hameed, “Brushless DC Motor Controller Design Using Matlab Applications,” 2018, no. 3, pp. 44–49.

[5] S. Singh, V. K. Tayal, H. P. Singh, and V. K. Yadav, “Performance Enhancement of Solid Oxide Fuel Cell by Employing PI Controller and PID Controller with Filter Derivative,” in 2021 IEEE International Power and Renewable Energy Conference (IPRECON), 2021, pp. 1–4.

[6] S. Misra, V. Kumar, and K. P. S. Rana, “Comparative Study of Conventional PD and Fuzzy PD Controllers for a Non-linear Active Suspension System,” in 2019 International Conference on

Computing, Power and Communication Technologies (GUCON), 2019, pp. 713–718.

[7] F. A. Salem and A. A. Aly, “PD Controller Structures : Comparison and Selection for an Electromechanical System,” Int. J. Intell. Syst. Appl., vol. 7, no. 2, pp. 1–12, 2015.

[8] J. M. S. Ribeiro, M. F. Santos, M. J. Carmo, and M. F. Silva, “Comparison of PID controller tuning methods: Analytical/classical techniques versus optimization algorithms,” in 2017 18th International Carpathian Control Conference, ICCC 2017, 2017, pp. 533–538.

[9] V. V. Patel, “Ziegler – Nichols Tuning Method,” Resonance, vol. 25, pp. 1385–1397, 2020.

[10] F. Isdaryani, F. Feriyonika, and R. Ferdiansyah, “Comparison of Ziegler- Nichols and Cohen Coon tuning method for magnetic levitation control system,” J. Phys. Conf. Ser., vol. 1450, no. 1, p. 012033, 2020.

[11] D. Collins, “FAQ: What are PID gains and feed-forward gains?,” 2016 https://www.motioncontroltips.com/faq-what-are-pid-gains-and-feed- forward-gains/ (accessed Sep. 05, 2022).

[12] Jenkins, “Tuning for PID Controllers,”2014.http://faculty.mercer.edu/jenkins_he/documents/TuningforPIDControllers.p df (accessed Sep. 05, 2022).