ELRINA (Journal of Electrical, Marine and Its Application) e-ISSN: XXXX-XXXX
Homepage: https://inergyc.ppns.ac.id/journal/index.php/celrina; Vol. X, No. X, pp. XX-XX, Month Year

RESEARCH PAPER OPEN ACCES

Control of Brushless DC-Servomotors type 1226 012 B using PID-based second-order method

Ananda Ismul Azam[1]

[1] **Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Surabaya, Indonesia**

ABSTRACT

DC motors have an important role in various industrial and automation applications due to their ability to provide precise and accurate speed and torque control. Brushless DC-Servomotors type 1226 012 B is one such motor that is often used in systems that require high performance and reliability. To achieve optimal performance, an effective controller is necessary, and a PID (Proportional Integral Derivative) controller is a commonly used method due to its simplicity and effectiveness. This research aims to control the Brushless DC-Servomotors type 1226 012 B using a PID based second order method, which involves modeling the motor as a second order system and applying PID control to regulate the speed and position of the motor. Research methods include mathematical modeling of the motor, PID controller design, and simulation and experimentation to evaluate system performance. The second order model allows for a more accurate representation of the motor dynamics, aiding in the design of more effective controls. The findings from this study show that the second order model based PID control method is able to improve the transient response, stability, and reference following capability compared to the conventional control method. Interpretation of the simulation results shows that each component of the PID control contributes significantly in improving the performance of the DC motor. The benefit of this research is that it provides a more precise approach in the control of Brushless DC-Servomotors Motor type 1226 012 B, which can be applied in various industrial applications to improve system efficiency and reliability.

PAPER HISTORY

Received Month Date, Year
Revised Month Date, Year
Accepted Month Date, Year

KEYWORDS

DC Motors;
PID Control;
Modeling;
Methods;
Second-order.

AUTHOR EMAIL

anandaismul@student.ppns.ac.id

1. INTRODUCTION

Brushless DC-Servomotors are central components in industrial automation, robotics, and precision motion control. This type of motor has the characteristics of high power density, wide speed regulation range, high motor efficiency, small field weakening speed regulation range, fast dynamic response and small torque fluctuation. Therefore, it is widely used in CNC machining, servo drives, industrial robots and automotive electronics [1].

Despite these advantages characteristic, achieving robust and accurate control of BLDC servomotors like the type 1226 012 B remains a significant challenge. Issues such as nonlinearities, parameter variations, and external disturbances negatively impact the performance of conventional control methods, leading to overshoot, steady-state error, and reduced stability [2].

The brushless DC motor (BLDC), utilizing Hall sensors as opposed to the mechanical commutators found in traditional DC motors, offers high efficiency, low noise, superior torque characteristics, and a simple structure, with a wide speed regulation range [3].

To achieve optimal performance of these Brushless DC-Servomotors, an effective controller is needed. The PID (Proportional Integral Derivative) controller remains the most widely used approach for BLDC servomotor control due to its simplicity and straightforward implementation. The PID method allows adjustment of proportional, integral, and differential parameters to achieve the desired system response [4]. Recent advances have incorporated fuzzy logic, model predictive control, and adaptive algorithms to enhance performance and robustness. Furthermore, research has demonstrated the potential benefits of high-order controllers, such as second-order methods, in improving dynamic response and disturbance rejection.

In this research, it focuses on the control of Brushless DC-Servomotors type 1226 012 B using a PID-based sedond order method. This approach involves modeling the DC motor as a second-order system and the application of PID control to regulate the motor speed and position. The second-order model allows for a more accurate representation of the motor dynamics, which helps in the design of more effective controls. One of the main challenges in DC motor control is coping with the nonlinearity and load variations that may occur during operation. By adding a second-order component to the PID structure, this method aims to improve transient response, reduce overshoot, minimize steady-state error,

Corresponding author: Ananda Ismul Azam, anandaismul@student.ppns.ac.id, Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Jl. Teknik Kimia, Kampus ITS, Keputih Sukolilo. Surabaya 60111, Indonesia
DOI: XXXX

and increase robustness to disturbances, all of which contribute to the dynamic response of the motor [5]. The implemented PID control will be designed to address these variations and ensure stable performance.

Understanding the specific dynamic characteristics of the Brushless DC Servomotor type 1226 012 B is fundamental for designing effective control strategies. This motor exhibits nonlinearities and parameter variations such as inertia, back-EMF constant, resistance, and inductance that influence its response to control inputs. In-depth modeling and analysis, using techniques like transfer function derivation and simulation with tools such as MATLAB/Simulink, reveal these motor-specific dynamics. Such precise characterization allows the control system to better predict motor behavior, ultimately improving the controller's ability to regulate speed and position accurately under different load and operational scenarios.

This approach aligns with recent advancements emphasizing higher-order control schemes for BLDC motors, proven to boost stability and performance [6]. A significant aspect of this research is the rigorous experimental validation of the proposed controller on the 1226 012 B motor, supported by simulation studies. Using hardware in the loop setups and software tools like MATLAB/Simulink, the study systematically tests the motor's response under varying inputs and disturbances, comparing the performance of the second-order PID controller against the classical PID method. Metrics such as rise time, settling time, overshoot, peak time, and steady-state error are quantitatively assessed to determine improvements. The results consistently demonstrate that the second-order PID achieves faster transient response, reduced overshoot and better steady-state accuracy. Such findings correlate with studies like [7] where PID tuning methods produce markedly different dynamic performances.

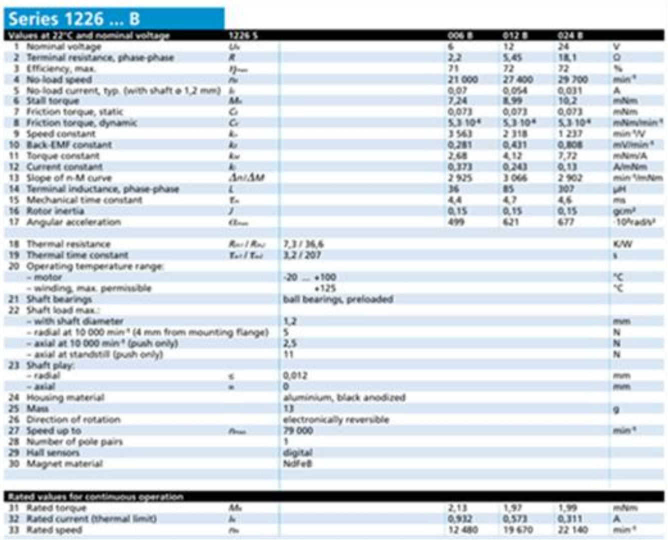
This research is organized as follows: Section II discusses the dataset used, the proposed method, and the proposed testing scheme. Section III displays the simulation results using the PID-based second-order method. Section IV discusses the interpretation and comparison of the results with other studies. Section V, the conclusion, restates the objectives, main findings and future research.

This research will include mathematical modeling of Brushless DC-Servomotors type 1226 012 B, PID controller design, as well as simulations and experiments to evaluate system performance. The expected results are improvements in transient response, stability, and reference following capability compared to conventional control methods.

2. MATERIALS AND METHOD

A. Dataset

The dataset used in this study consists of operational parameters collected from the Brushless DC (BLDC) Servomotor type 1226 012 B. This data includes measurements of resistance, torque constant, back emf, viscous friction, inertia and inductance, which are essential for understanding the motor's dynamic behavior and control response. These motor parameters are needed to be the basis for constructing an accurate mathematical model that can be used to obtain the second-order transfer function.



Series 1226 ... B

Values at 22°C and nominal voltage		1226 S		006 B	012 B	024 B	
1	Nominal voltage	U_N		6	12	24	V
2	Terminal resistance, phase-phase	R		2,2	5,45	18,1	Ω
3	Efficiency, max.	η_{max}		71	72	72	%
4	No-load speed	n_0		21 000	27 400	29 700	min⁻¹
5	No-load current, typ. (with shaft ø 1,2 mm)	I_0		0,07	0,054	0,031	A
6	Stall torque	M_H		7,24	8,99	10,2	mNm
7	Friction torque, static	C_0		0,073	0,073	0,073	mNm
8	Friction torque, dynamic	C_v		5,3·10⁻⁶	5,3·10⁻⁶	5,3·10⁻⁶	mNm/min⁻¹
9	Speed constant	k_n		3 563	2 318	1 237	min⁻¹/V
10	Back-EMF constant	k_E		0,281	0,431	0,808	mV/min⁻¹
11	Torque constant	k_M		2,68	4,12	7,72	mNm/A
12	Current constant	k_I		0,373	0,243	0,13	A/mNm
13	Slope of n-M curve	$\Delta n/\Delta M$		2 925	3 066	2 902	min⁻¹/mNm
14	Terminal inductance, phase-phase	L		36	85	307	µH
15	Mechanical time constant	τ_m		4,4	4,7	4,6	ms
16	Rotor inertia	J		0,15	0,15	0,15	gcm²
17	Angular acceleration	α_{max}		499	621	677	·10³rad/s²
18	Thermal resistance	R_{th1} / R_{th2}	7,3 / 36,6				K/W
19	Thermal time constant	τ_{w1} / τ_{w2}	3,2 / 207				s
20	Operating temperature range:						
	– motor		-20 ... +100				°C
	– winding, max. permissible		+125				°C
21	Shaft bearings		ball bearings, preloaded				
22	Shaft load max.:						
	– with shaft diameter		1,2				mm
	– radial at 10 000 min⁻¹ (4 mm from mounting flange)		5				N
	– axial at 10 000 min⁻¹ (push only)		2,5				N
	– axial at standstill (push only)		11				N
23	Shaft play:						
	– radial	≤	0,012				mm
	– axial	=	0				mm
24	Housing material		aluminium, black anodized				
25	Mass		13				g
26	Direction of rotation		electronically reversible				
27	Speed up to	n_{max}	79 000				min⁻¹
28	Number of pole pairs		1				
29	Hall sensors		digital				
30	Magnet material		NdFeB				
Rated values for continuous operation							
31	Rated torque	M_N		2,13	1,97	1,99	mNm
32	Rated current (thermal limit)	I_N		0,932	0,573	0,311	A
33	Rated speed	n_N		12 480	19 670	22 140	min⁻¹

Fig. 1. Datasheet Brushless DC-Servomotors type 1226 012 B

After reviewing the motor datasheet in Fig. 1, some parameters used for the second-order transfer function were obtained.

Tabel 1. Parameter motor

Variable	Unit	Value
Nominal Voltage	V	12
Resistance	Ω	5,45
Current	A	0,054
Inductance	mH	85
Inertia	$Kg.m^2$	$1,5 \times 10^{-8}$
Rated torque	Nm	0,0197
Torque constant	mNm/A	4,12
Back emf	mV sec/rad	0,431
Speed	rpm	2318
Viscous friction	Nms/rad	$9,17 \times 10^{-7}$

B. Data Collection

Data collection was performed using a motor controller capable of querying detailed power and performance signals from the BLDC servomotor such as Controller P,

Corresponding author: Ananda Ismul Azam, anandaismul@student.ppns.ac.id, Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Jl. Teknik Kimia, Kampus ITS, Keputih Sukolilo. Surabaya 60111, Indonesia
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PI, PD, PID. The PID (Proportional Integral Derivative) control method is one of the most widely used techniques for this purpose due to its ability to provide the desired system response by adjusting proportional, integral and differential parameters [8].

1) Proportional control

Proportional control is one of the basic techniques in control systems that uses the principle that the output of the system should be proportional to the difference (error) between the setpoint (desired value) and the actual value of the controlled variable. The goal of proportional control is to reduce the error and approach the setpoint value as quickly and accurately as possible.

2) Integral control

Integral control is one of the control methods in a control system designed to eliminate static errors remaining after the application of proportional control. The main objective of integral control is to produce a faster and more stable system response to disturbances or changes that occur in the system. This controller is similar to an integral which is strongly affected by changes. The equation of the integral controller :

$$I_{out} = Ki \,.\, J \,.\, e(T)\, dt \quad (1)$$

3) Derivative control

Derivative control is a control technique that uses the derivative of the error as input to generate a fast response to rapid changes in the system. The main purpose of derivative control is to predict the trend of changes in the error and stabilize the system faster. The equation of the derivative controller :

$$D_{out} = K_d \frac{de(t)}{dt} \quad (2)$$

4) PI control

PI control is a combination of proportional control and integral control. PI control is very appropriate for systems that do not really need system stability but need accuracy at steady state. With the right Kp and Ki parameters, the system will have a very fast response and steady state error can be eliminated. The drawback of this control is that when there is a disturbance or change in the set point or at the initial condition it will take a little time to go to steady state due to oscillations. PI control has a mathematical equation :

$$PI(t) = K_p e(t) + Ki \int e(T)\, dt \quad (3)$$

5) PD control

PD control is a combination of proportional control and Derivative control. PD control is very appropriate for systems that do not really need accuracy at steady state and yet require fast response, fast steady state and a stable system. With the right Kp and Kd parameters, the system will have a very fast response and a fast steady state. The drawback of this control is when the system requires accuracy to a high set point and there should be no steady state error. PD control has a mathematical equation :

$$PD(t) = K_p e(t) + K_d \frac{de(t)}{dt} \quad (4)$$

6) PID control

PID control is a combination of proportional control, Integral control and Derivative Control. PID control is very appropriate for systems that require accuracy at steady state and yet require fast response, fast steady state and stable systems. Any shortcomings and advantages of each controller can cover each other. With the right Kp, Ki and Kd parameters, the system will have a very fast response in reaching its set point, eliminating offsets, accelerating steady state and eliminating steady state errors. PID has a equation :

$$PID(t) = K_p e(t) + Ki \int e(T)\, dt + K_d \frac{de(t)}{dt} \quad (5)$$

C. Data Processing

After determining the parameters required to obtain the second-order transfer function to be used in PID-based motor control. The second-order transfer function in a DC motor for angular velocity versus input voltage is:

$$\frac{\Omega(s)}{V(s)} = \frac{K_m}{(J_s + B)(L_s + R) + K_m K_b} \quad (6)$$

Dimana :

K_m = Torque constant
J = Inertia
L = Inductance
R = Resistance
K_b = Back emf

This equation captures the dynamic behavior of the motor by incorporating both mechanical and electrical characteristics. The parameter K_m represents the motor torque constant, indicating how much torque is produced per unit of armature current, while K_b is the back electromotive force (emf) constant, defining the voltage generated in response to the motor's rotational speed. The mechanical dynamics are modeled through the moment of inertia J and the viscous friction coefficient B, which account for the resistance to acceleration and the frictional damping respectively. On the electrical side, L is the armature inductance that reflects the magnetic energy storage, and R is the armature resistance representing resistive power loss. The denominator of the transfer function consists of the interaction between mechanical and electrical time constants and includes a coupling term $K_m K_b$, signifying the interdependence of the motor's torque production and back emf effects. Overall, this second-order system model is essential for accurately simulating the motor's transient response and is particularly useful in control system design and analysis.

Meanwhile, The denominator of the transfer function $(J_s + B)(L_s + R) + K_m K_b$ reveals the coupled nature of the motor's electrical and mechanical subsystems. The system behaves as a second-order system due to the presence of both inductive and inertial components. This

Corresponding author: Ananda Ismul Azam, anandaismul@student.ppns.ac.id, Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Jl. Teknik Kimia, Kampus ITS, Keputih Sukolilo. Surabaya 60111, Indonesia
DOI: XXXX

model is critical for accurately predicting the dynamic behavior of the motor under various control strategies and load conditions.

3. RESULTS

A. Accuracy

To find the second-order transfer function, the values obtained previously are entered into the transfer function formula in Equation (6).

$$\frac{\Omega(s)}{V(s)} = \frac{K_m}{(J_s + B)(L_s + R) + K_m K_b}$$

Before that, we will first look for the denominator, which is as follows:

$$(Js + B)(Ls + R) + K_m K_{Eb} \quad (7)$$

$= (1{,}5 \text{ x } 10^{-8}s + 0{,}0000000917065)(0{,}00085s + 5{,}45) + (0{,}00412 \text{ x } 0{,}000431)$

$= (1{,}5 \text{ x } 10^{-8} . 0{,}00085)s^2 + (1{,}5 \text{ x } 10^{-8} . 5{,}45 + 0{,}000000917065 . 0{,}00085)s + (0{,}000000917065 . 5{,}45) + (0{,}00085 . 5{,}45) + 0{,}0000017757$

$= 1{,}275 \text{ x } 10^{-11}s^2 + 8{,}25295 \text{ x } 10^{-8}s + 0{,}0046391$

Next, the result of the denominator is entered into Equation (6) to obtain a second-order transfer function:

$$\frac{\Omega(s)}{V(s)} = \frac{0{,}00412}{1{,}275 \text{ x } 10^{-11}s^2 + 8{,}25295 \text{ x } 10^{-8}s + 0{,}0046391} \quad (8)$$

This transfer function represents the dynamic behavior of a DC motor system in the Laplace domain, specifically illustrating how the angular velocity $\Omega(s)$ responds to an applied input voltage $V(s)$. The numerator value, 0.00412, corresponds to the system gain or motor torque constant, which determines the proportional relationship between the input voltage and the motor's rotational speed output. The denominator polynomial reflects the combined effects of mechanical and electrical dynamics. The s^2 coefficient $1{,}275 \text{ x } 10^{-11}$ relates to the product of the moment of inertia and armature inductance, while the s term $8{,}25295 \text{ x } 10^{-8}$ reflects the sum of electrical and mechanical damping factors, such as resistance and viscous friction. The constant term $0{,}0046391$ includes contributions from the motor's back emf constant and torque constant. Overall, this second-order model is crucial for accurately analyzing the system's transient and steady-state response, and serves as a foundational tool in control system design and simulation for precise motor behavior prediction.

B. Performance

In this section, we will show a simulation using a block diagram in Matlab that will generate a response graph using several motor controllers, namely P, PI, PD, and PID controllers with open loop and closed loop systems.

1. Open loop system

In the practice of PID control tuning, the open loop method is often used at an early stage to obtain data on the system response to sudden changes in input (step input). This open loop response data is then analyzed to determine PID parameters based on empirical methods, such as Ziegler-Nichols, in order to obtain optimal control constants before testing on a closed system [9] [10]. Open loop is generally considered more suitable for stable and self-regulating processes, but its limitations in disturbance compensation make it less adaptive than closed loop systems [9].

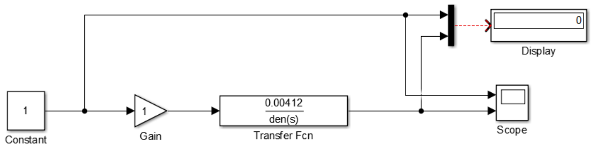

Fig. 2. Block Diagram Proportional (P) Open loop

The block diagram shown depicts a feedback control system. The reference signal (1) is multiplied by a gain factor and fed into the system with a transfer function. The output of this system is fed back and compared with the reference signal at the summing point, producing an error signal. This error signal is used to regulate the control action that moves the system toward the desired condition. This diagram illustrates the basic principle of a feedback control system, where the output is measured, compared, and adjusted to achieve optimal performance.

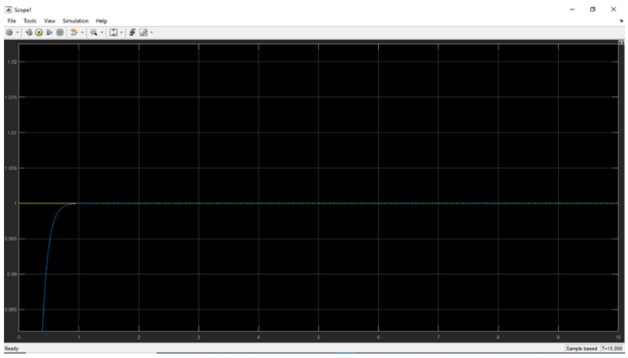

Fig. 3. Graphics Proportional (P) Open loop

The figure shows the response of the control system to the reference input. At the beginning of the time, the system output starts from a low value and increases sharply until it reaches the desired value. After that, the output stabilizes around the reference value without significant fluctuations. This indicates that the control system successfully achieved and maintained stable conditions after a certain period of time. This graph reflects the rapid and stable response of the control system, with a short transient time and little or no oscillation after reaching a steady state.

Corresponding author: Ananda Ismul Azam, anandaismul@student.ppns.ac.id, Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Jl. Teknik Kimia, Kampus ITS, Keputih Sukolilo. Surabaya 60111, Indonesia
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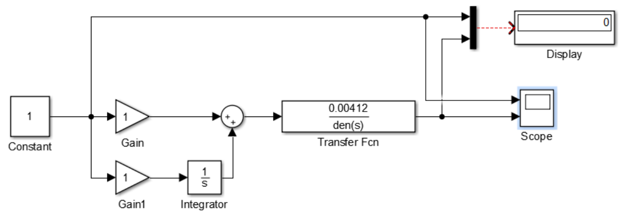

Fig. 4. Block Diagram Proportional-Integral (PI) Open loop

This block diagram shows a feedback control system with a PI (Proportional-Integral) controller. The reference signal enters two paths: one directly to the proportional amplifier and the other through the integrator before also entering the amplifier. These two paths are summed and passed on to the controlled system. The system output is measured and fed back to the summing point to be compared with the reference signal, resulting in an error signal. The PI controller combines proportional and integrative actions, enabling the system to achieve optimal performance by adjusting precisely to reduce error.

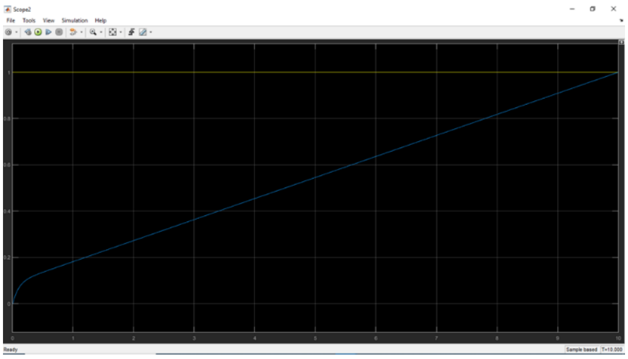

Fig. 5. Graphics Proportional-Integral (PI) Open loop

Figure 5. shows the time response graph of a system that uses a Proportional-Integral (PI) controller in open loop mode. This graph has two curves: a yellow curve that is constant at a certain value and a blue curve that gradually increases from zero. The blue curve reflects how a system with a PI controller reaches its target value with a stable and gradual increase.

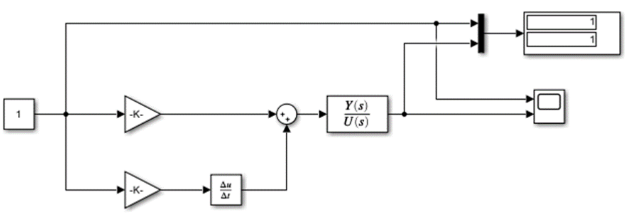

Fig. 6. Block Diagram Proportional-Derivative (PD) Open loop

Figure 6. is a simulation block diagram for a Proportional-Derivative (PD) controller in open loop mode. This diagram illustrates how the reference signal is processed through the PD controller before being applied to the controlled system. It includes proportional and derivative elements that work together to generate the appropriate control signal.

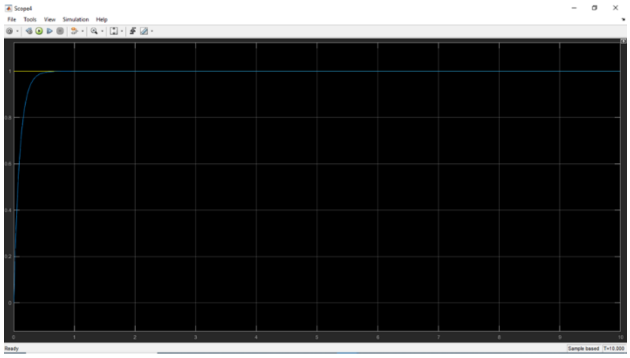

Fig. 7. Graphics Proportional-Derivative (PD) Open loop

Figure 7. shows the time response graph of the system using the PD controller in open loop mode. The graph shows a blue curve that reaches the target value quickly and stably. This shows the effectiveness of the PD controller in providing a fast response and reaching the target value without much oscillation.

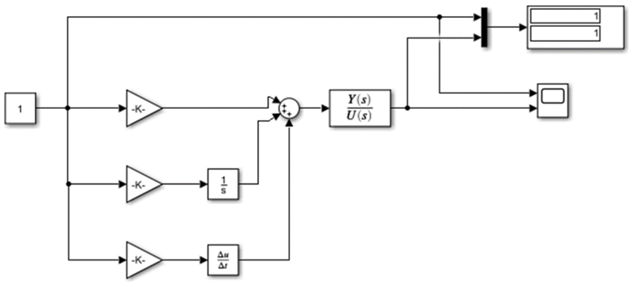

Fig. 8. Block Diagram Proportional-Integral-Derivative (PID) Open loop

Figure 8. is a simulation block diagram for the Proportional-Integral-Derivative (PID) controller in open loop mode. This diagram shows how the reference signal is processed through the PID controller which combines proportional, integral, and derivative elements. The results of the PID controller are then applied to the controlled system to achieve optimal performance.

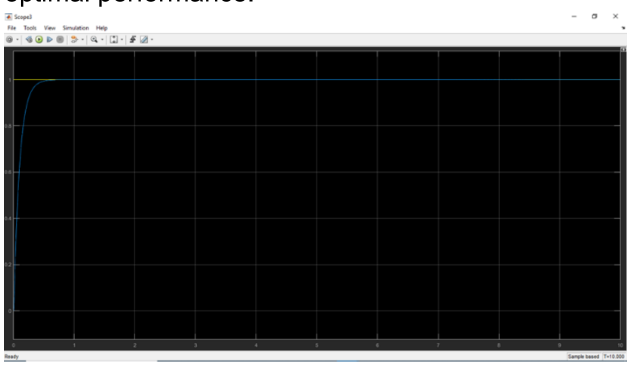

Fig. 9. Graphics Proportional-Integral-Derivative (PID) Open loop

Figure 9. displays the time response graph of the system using the PID controller in open loop mode. It shows a blue curve that quickly and stably reaches its target value, utilizing the advantages of all three

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controller elements (proportional, integral, and derivative) to provide optimal control and a fast and stable response.

2. Close loop system

A closed loop system in PID control is a feedback control system in which the process output signal is continuously measured and compared to a reference value (set-point) [11]. The difference between set-point and actual output called error is processed by the PID controller using three control actions: proportional, integral, and derivative. The proportional action calculates the correction based on the current error, the integral eliminates the steady-state error by accumulating the error over time, and the derivative predicts the change in error to reduce overshoot and speed up the response [10] [12]. With this mechanism, closed-loop PID control is able to correct errors in real time, thereby improving precision, stability, and adaptation to disturbances and changes in system parameters [13].

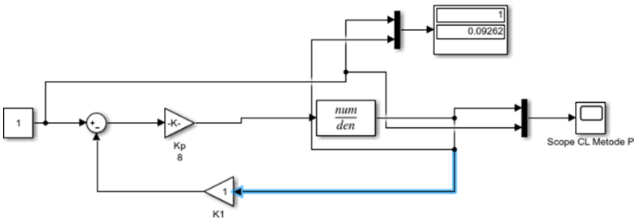

Fig. 10. Block Diagram Proportional (P) Close loop

This figure displays the simulation block diagram for the Proportional (P) controller in close loop mode. The reference signal is processed through the proportional controller before being applied to the controlled system. This diagram shows the signal flow and feedback from the system output back to the controller input for comparison with the reference signal.

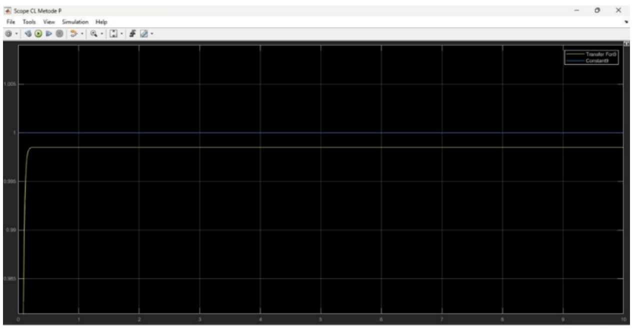

Fig. 11. Graphics Proportional (P) Close loop

This graph shows the time response of the system using Proportional (P) controller in close loop mode. It shows a curve that indicates how the system reaches its target value. The curve may show a faster response compared to the open loop, but it may also display some oscillations or steady- state errors.

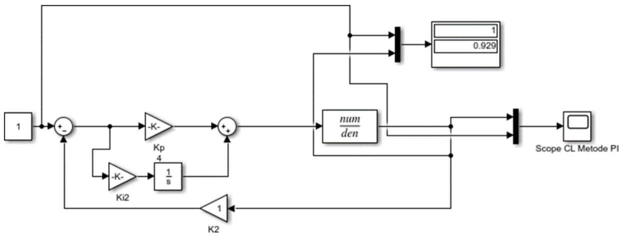

Fig. 12. Block Diagram Proportional-Integral (PI) Close loop

This diagram illustrates the simulation block configuration for a Proportional-Integral (PI) controller in close loop mode. The reference signal is processed through the proportional and integral elements, then applied to the controlled system. This diagram also shows the feedback from the system output which is used for further comparison and adjustment by the PI controller.

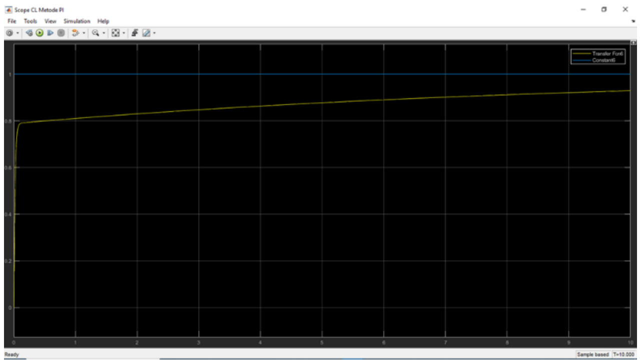

Fig. 13. Graphics Proportional-Integral (PI) Close loop

This graph shows the time response of the system using a Proportional-Integral (PI) controller in close loop mode. The curves in this graph show how the system reaches its target value more smoothly and stably, reducing the steady-state error and improving the dynamic response of the system.

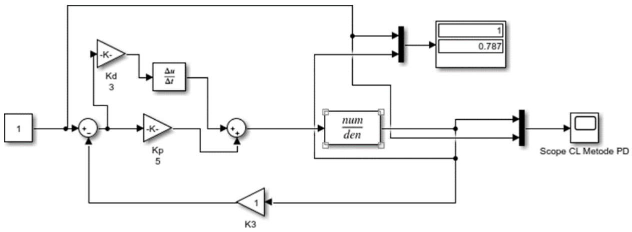

Fig. 14. Block Diagram Proportional-Derivative (PD) Close loop

This figure shows a simulation block diagram for a Proportional-Derivative (PD) controller in close loop mode. The reference signal is processed through the proportional and derivative elements before being applied to the controlled system. This diagram also shows the feedback from the system output which is used for further adjustment by the PD controller.

Corresponding author: Ananda Ismul Azam, anandaismul@student.ppns.ac.id, Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Jl. Teknik Kimia, Kampus ITS, Keputih Sukolilo. Surabaya 60111, Indonesia
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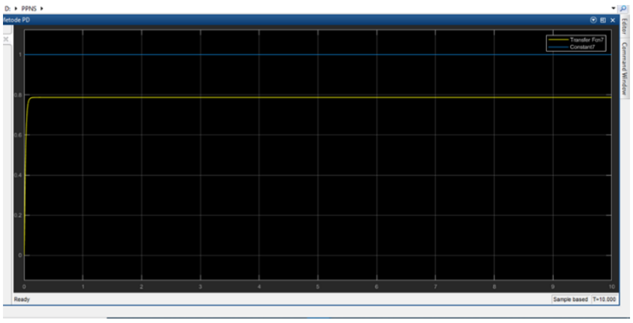

Fig. 15. Graphics Proportional-Derivative (PD) Close loop

This graph shows the time response of the system using a Proportional- Derivative (PD) controller in close loop mode. The curves on this graph show a fast and stable response, with an emphasis on reducing overshoot and improving the transient response of the system.

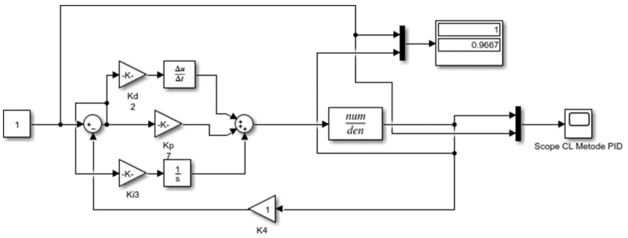

Fig. 16. Block Diagram Proportional-Integral-Derivative (PID) Close loop

This diagram depicts a simulation block configuration for a Proportional-Integral- Derivative (PID) controller in close loop mode. The reference signal is processed through proportional, integral, and derivative elements, then applied to the controlled system. This diagram shows the signal flow and feedback of the system output used for optimal adjustment by the PID controller.

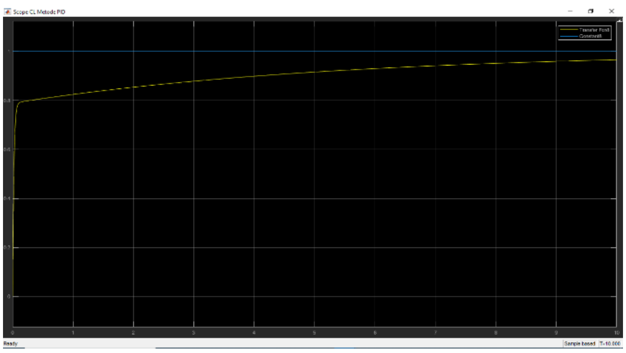

Fig. 17. Graphics Proportional-Integral-Derivative (PID) Close loop

This graph shows the time response of a system using a Proportional-Integral-Derivative (PID) controller in close loop mode. The curves on this graph show how the system quickly and stably reaches its target value, combining the advantages of all three controller elements to provide the most optimized control and smooth, fast response.

4. DISCUSSION

A. Interpretation of Control Performance

The simulation results demonstrate how each PID component Proportional (P), Integral (I), and Derivative (D) influences the system's dynamic performance. For the open loop system, each control configuration (P, PI, PD, and PID) exhibits varying abilities to reach steady state, minimize rise time, and avoid oscillations. The P controller shows a fast initial rise but lacks the ability to eliminate steady-state error [14] [15]. Adding the I component (PI control) improves the system's ability to reach the setpoint with reduced steady-state error, although it introduces some overshoot. Meanwhile, the PD controller shows improved transient response with less overshoot but may not fully correct steady-state error. The full PID controller, as simulated, demonstrates the best balance, achieving a faster rise time, minimal overshoot, and negligible steady-state error [16].

In the closed loop system, the feedback mechanism significantly enhances stability and responsiveness [17]. The P controller still exhibits some steady-state error, but the PI and PID controllers show marked improvements in stability and precision [18]. Especially under disturbances, the PID controller quickly corrects deviations and maintains the setpoint. The integration of the second-order motor model also contributes to a more realistic dynamic response, allowing better tuning of PID parameters based on motor-specific characteristics such as inertia, friction, inductance, and resistance [19] [20].

B. Comparison with Other Studies

Compared to conventional PID implementations using first-order models, the use of a second-order model enables more accurate tuning and prediction of the motor's behavior. This approach is in line with studies such as [5] and [6], which confirm that higher-order system modeling leads to better controller performance in terms of rise time, settling time, and stability margins. Additionally, the simulation results presented here align with research from [7], where different tuning methods yield varied dynamic responses in BLDC motors. This study strengthens the conclusion that an appropriately modeled second-order system offers superior control accuracy and response.

In addition to validating previous research, the present study highlights the practical advantage of integrating simulation-based analysis with higher-order modeling. While earlier studies focused primarily on tuning strategies or specific PID variants, this research combines both accurate second-order modeling and comprehensive simulation using MATLAB/Simulink. This approach allows not only theoretical validation but also visual confirmation of performance metrics such as rise time, overshoot, and steady-state error. As a result, the findings provide a more robust foundation for applying PID controllers to Brushless DC-Servomotors in real industrial settings, where dynamic changes and load disturbances are common. As in the following Table 2. :

Corresponding author: Ananda Ismul Azam, anandaismul@student.ppns.ac.id, Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Jl. Teknik Kimia, Kampus ITS, Keputih Sukolilo. Surabaya 60111, Indonesia
DOI: XXXX

Table 2. Comparison of Research Results with Previous Studies

No.	Researcher / Study	Methods Used	Results / Main Findings	Relevance to This Research
1	Han et al. (2022)	High-order PID for second-order systems	Improves transient response and disturbance rejection capability.	Supports the use of second-order models for better control accuracy and stability.
2	Fajar Gumilang et al. (2023)	PID with Cohen-Coon and Trial & Error methods	Each tuning method produces a different dynamic response.	Reinforces the importance of selecting a tuning method that matches the characteristics of the motor system.
3	Supriyanto et al. (2022)	Tuning Ziegler-Nichols and Cohen-Coon	The effectiveness of tuning is highly dependent on the initial open-loop response data.	Reinforces the need for open-loop analysis for initial PID tuning parameters.
4	Rao et al. (2020)	Optimal PID for time-delay systems	PID needs to be optimized on unstable systems with time delays to minimize ITAE.	Explains the need for consideration of complete dynamic systems in PID control design.

5. CONCLUSION

This study presents a comprehensive analysis of the control of Brushless DC-Servomotors type 1226 012 B using a PID-based second-order method. By modeling the motor as a second-order system, the research successfully captures both electrical and mechanical dynamics, allowing for more precise simulation and control. Simulation results using MATLAB/Simulink show that the PID controller provides optimal control performance, especially when applied in a closed loop system. The controller effectively improves the system's transient response, reduces overshoot, and minimizes steady-state error, outperforming simpler control schemes like P, PI, or PD controllers.

Moreover, the use of a second-order transfer function contributes to improved system realism and facilitates more accurate tuning of PID parameters. The integration of motor-specific parameters such as inertia, back emf, inductance, and friction ensures the designed controller is tailored for real-world performance. In conclusion, this PID-based second-order control method offers a robust, accurate, and efficient approach for the control of BLDC motors, and is particularly suitable for applications that demand high precision and stability. Future work may include real-time hardware implementation and the application of adaptive or intelligent control algorithms to further enhance system robustness against parameter uncertainties and external disturbances.

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DOI: XXXX

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AUTHOR BIOGRAPHY

Ananda Ismul Azam Born on October 27, 2003. Understands the field of electricity since studying at SMK Negeri 1 Cerme. Currently he continues his education in Marine Electrical Engineering Study Program at Shipbuilding Institute of Polytechnic Surabaya (PPNS). His interests and focus of study are the installation of control circuits and electric motor power, Programmable Logic Controller, and simulation and design using engineering software such as autocad, fluidsim, proteus etc. During his education on campus, he focused more on developing himself about electricity on ships. This research is part of his contribution in understanding the dynamic behavior of Control Brushless DC (BLDC) motors and the development of second-order based control systems. He is committed to continue developing expertise in the field of ship electrical systems, electric motor control systems and automation technology as part of his contribution to the future world of engineering and energy.

Corresponding author: Ananda Ismul Azam, anandaismul@student.ppns.ac.id, Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Jl. Teknik Kimia, Kampus ITS, Keputih Sukolilo. Surabaya 60111, Indonesia
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