Improvement of Azimuth Axis Position Control on Turret Gun Caliber 20 mm with Tuning PID Cohen-Coon using MATLAB Simulink

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Abstract: This research focuses on the development of defense technology centered around turret guns. A turret gun is a projectile weapon capable of moving with orientation along the axes of elevation and azimuth. A responsive, accurate, and stable system is essential for effectively targeting objectives. Therefore, simulations were conducted to control the azimuth axis position of a 20 mm caliber turret gun using MATLAB, tuning the PID parameters with the Cohen-Coon method to achieve both rapid and stable responses. In this study, the Cohen-Coon PID tuning method was compared with the Ziegler-Nichols and Root Locus methods previously explored by other researchers. Parameters compared in this study included rise time, settling time, and overshoot in the turret gun response system. The results showed that the Cohen-Coon tuning method produced the lowest overshoot value at 16.5%, compared to 64.48% with the Ziegler-Nichols method and 29.9% with the Root Locus method. A lower overshoot value indicates relatively stable control system response to input changes, reducing the risk of excessive oscillations that could damage the system or cause instability. The rise time values obtained were 0.404s for Cohen-Coon, 1.6481s for Ziegler-Nichols, and 0.3s for Root Locus. The settling time values were 2.66s for Cohen-Coon, 49.9369s for Ziegler-Nichols, and 1.74s for Root Locus. Despite Cohen-Coon having a higher settling time compared to Root Locus, it exhibited less overshoot after reaching the set point, suggesting a more stable control. In the context of turret gun applications, balancing responsiveness (rise time) and stability (settling time) is crucial. If the turret gun requires a very rapid response to changes in target position, using PID with Root Locus can provide an advantage in achieving high precision targeting in a short time. However, if the primary concern is maintaining position stability after reaching the target, the Cohen-Coon approach may be more suitable.

Keywords: turret gun; control PID; Cohen-Coon; azimuth axis

1. Introduction

The rapid evolution of technology, particularly in industrial defense sectors, necessitates continuous advancements to uphold national sovereignty. In Indonesia, ongoing efforts in defense technology enhancement include the development of turret guns. Turret guns, pivotal as projectile weapons, enable precise targeting through their ability to adjust along the elevation and azimuth axes[1)]. Achieving optimal performance in turret guns involves two critical aspects: precision and responsiveness in attaining specified angular positions[2)].

The dimensions of turret guns are meticulously tailored to operational requirements, where larger calibers correspond to increased weight. This introduces complexities in control during firing sequences. To optimize turret gun performance, the implementation of a Proportional-Integral-Derivative (PID) control system is crucial. This system aims to deliver fast, precise, and stable responses[3)].

Among various PID tuning methods, the Cohen-Coon method stands out for its capability to minimize overshoot, enhancing system stability and operational safety. Previous studies referenced have explored azimuth axis control using the Ziegler-Nichols and Root Locus methods. Building upon this foundation, the current research aims to investigate the performance of the Cohen-Coon PID control system in a similar setup[4,5)]. The primary objective is to achieve minimal overshoot values compared to previous methodologies, thereby improving turret gun control accuracy and reliability in demanding operational environments[5,6].

By employing the Cohen-Coon tuning method, this study seeks to contribute empirical insights into optimizing turret gun control systems. The research aims to validate its effectiveness in enhancing precision and responsiveness, essential for bolstering national defense capabilities. Through rigorous experimentation and analysis, this research endeavors to provide practical guidelines for implementing advanced control strategies in turret gun technology[7–14].

2. Literature Review

2.1 Turret Gun

Turret gun is a projectile weapon designed with a swivel mechanism in azimuth and elevation orientation, allowing the weapon to be fired in multiple directions. It can be mounted on a building or combat vehicle structure. Turret gun have the ability to be equipped with one or more machine guns, automatic cannons, large-caliber weapons, or missile launchers[14]. The working system of the turret gun involves two movable parts, namely the rotating base (turret) and the barrel (gun). The working system of the turret gun can be seen in Fig. 1[15–18].

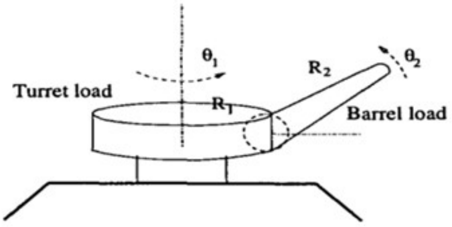

Fig. 1: Working System and Design of Turret Gun[19].

Based on Fig. 1, working system The turret gun has 2 axes of movement, namely the azimuth axis and the elevation axis. The azimuth axis includes 360° horizontal rotation of the turret, while the elevation axis includes vertical rotation of the gun[19].

2.2 System Dinamics

From Fig. 1, the dynamic system equation of the turret gun can be written as follows.

$$T_{turret} = D(\theta)\ddot{\theta} + C(\theta,\ \dot{\theta})\theta \quad + G(\theta) \tag{1}$$

Where,

$$D(\theta) = \begin{pmatrix} D_{11} & 0 \\ 0 & D_{22} \end{pmatrix} \tag{2}$$

$$C(\theta,\ \dot{\theta}) = \begin{pmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{pmatrix} \tag{3}$$

$$G(\theta) = \left(\left(0, \tfrac{1}{2} m_2 g R_2 \cos(\theta_2)\right)\right)^T \tag{4}$$

$$D_{11} = \frac{1}{2} m_1 {R_1}^2 + m_2 {R_1}^2 +$$

$$m_2 R_1 R_2 \cos(\theta_2) \tfrac{1}{3} m_2 {R_2}^2 cos^2(\theta_2) \tag{5}$$

$$D_{22} = \tfrac{1}{3} m_2 {R_2}^2 \tag{6}$$

$$C_{11} = (-m_2 R_1 R_1 \sin(\theta_2)\theta_2) \tag{7}$$

$$C_{12} = \left(-\tfrac{1}{3} m_2 {R_2}^2 \sin(2\theta_2)\dot{\theta}\right) \tag{8}$$

$$C_{21} = \left(\tfrac{1}{2} m_2 R_1 R_2 \sin(\theta_2) + \tfrac{1}{6} m_2 {R_2}^2 \sin(\theta_2)\right) {\dot{\theta}_2}^2 \tag{9}$$

$$C_{22} = 0 \tag{10}$$

Where D(θ) is the inertia of the system, C($\theta,\ \dot{\theta}$) is the coriolis vector, and the effect of centrifugal torque and $G(\theta)$ is gravity. Then the following equation is obtained.

$$\ddot{\theta}_1 = \frac{T_{turret} - C_{11}\dot{\theta}_{11} - C_{12}\dot{\theta}_2}{D_{22}} \tag{11}$$

The input of the dynamic system is the turret angular position ($\theta 1$), turret rotational speed ($\dot{\theta}_1$), and turret angular acceleration ($\ddot{\theta}_1$), as well as the gun position (θ_2), and gun rotational speed ($\ddot{\theta}_2$). Where $\ddot{\theta}_1$ is used in the turret gun azimuth system and $\ddot{\theta}_2$ is used for the turret gun elevation system[20,21].

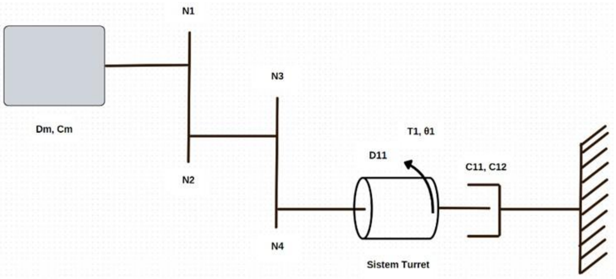

Fig. 2: Illustration of Motor, Transmission and turret circuit[4].

Based on Fig. 2, it explains that the torque output from the DC motor above is the torque entering the system which is influenced by the gear transmission[4,22].

$$T_{turret} = T_{motor} x\ N \tag{12}$$

It is known that N comes from the gear ratio of the entire drive transmission and Tmotor is the torque produced by the DC motor. Therefore, from Equation (4) and Fig. 2, the equation can be concluded as follows.

$$\theta 1^{\ddot{}} =$$

$$\frac{\mathrm{KtEaN} - [((\mathrm{Ram2R1R2}\ \sin(\theta 2\ )) + \mathrm{Ra}\ 1\ 3\ \mathrm{m2R2}\ 2\ \sin(2\theta 2\ ))\theta 2^{\dot{}} - \mathrm{NKtKb}]\theta\ 1}{\mathrm{Ra}(\ 1\ 2\ \mathrm{m1R1}\ 2 + \mathrm{m2R1}\ 2 + \mathrm{m2R1R2}\ \cos(\theta 2\ )\ 1\ 3\ \mathrm{m2R2}\ 2\ \cos 2(\theta 2\ ))} \tag{13}$$

From Equation (6), it is then linearized using the jocobian method to produce the following matrix Equation.

$$A = \begin{pmatrix} 0 & 1 \\ 0 & \frac{NKtKb}{Ra(\frac{1}{2}m1R1^2+m2R1^2+m2R1R2\cos(\theta 2)\frac{1}{3}m2R2^2cos^2(\theta 2))} \end{pmatrix} \quad (14)$$

$$B = \begin{pmatrix} 0 & 0 \\ 0 & \frac{NKtEa}{Ra(\frac{1}{2}m1R1^2+m2R1^2+m2R1R2\cos(\theta 2)\frac{1}{3}m2R2^2cos^2(\theta 2))} \end{pmatrix} \quad (15)$$

$$C = (1\ 0) \quad (16)$$

$$B = (0) \quad (17)$$

2.3 PID Control

PID control is one method that is often used in industry. The simple structure of PID control is the main reason why this method is widely used[19,23–27].

$$u(t) = K_p e(t) + \frac{K_p}{T_i}\int_0^t e(t)dt\ + K_p T_d \frac{de(t)}{dt} \quad (18)$$

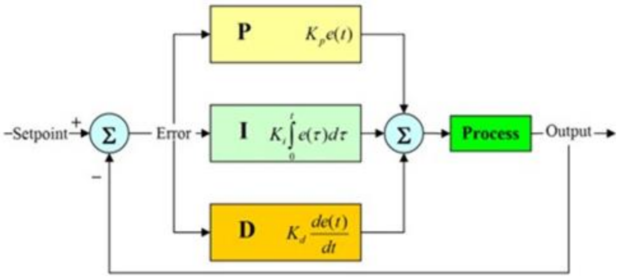

Fig. 3: Block diagram of PID Control[28].

Based on Fig. 3, The PID controller uses three components, namely proportional (P), integral (I), and derivative (D), to generate appropriate control signals. The proportional (P) component handles current errors, the integral (I) component addresses static errors, and the derivative (D) component anticipates sudden changes in the system[29–31].

2.4 Cohen-Coon Tuning Method

PID control parameters are determined based on the plant's or system's physical characteristics. Therefore, parameter tuning methods are carried out to produce system performance following the design specifications[7,32,33].

The Cohen-Coon tuning method uses the first-order response, which is then added to the dead time derived from the system response by modeling it to a step change. Based on the response, the parameters can be known as the output steady state divided by the input step change, while τ is the effective time constant derived from the first-order response, and td is the dead time. For an explanation, please refer to Fig. 4[34–36].

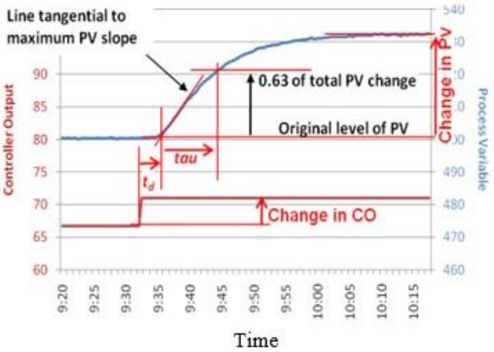

Fig. 4: Step Test for Cohen-Coon Tuning Process[10].

After obtaining τ and td, the next step is to find the value of the PID parameters with the Cohen-Coon tuning rule formula, explained in Fig. 5.

Table 1. Cohen-coon Tuning Rule Formula[37].

	Controller Gain	Integral Time	Derivative Time
P	$K_c = \frac{1.03}{g_p}\left(\frac{\tau}{t_d} + 0.34\right)$		
PI	$K_c = \frac{0.9}{g_p}\left(\frac{\tau}{t_d} + 0.092\right)$	$T_I = 3.33\ t_d \frac{\tau\ + 0.092\ t_d}{\tau\ + 2.22\ t_d}$	
PD	$K_c = \frac{1.24}{g_p}\left(\frac{\tau}{t_d} + 0.129\right)$		$T_D = 0.27\ t_d \frac{\tau - 0.324\ t_d}{\tau\ + 0.129\ t_d}$
PID	$K_c = \frac{1.35}{g_p}\left(\frac{\tau}{t_d} + 0.185\right)$	$T_I = 2.5\ t_d \frac{\tau\ + 0.185\ t_d}{\tau\ + 0.611\ t_d}$	$T_D = 0.37\ t_d \frac{\tau}{\tau\ + 0.185\ t_d}$

3. Methods

3.1 Identify the Problem

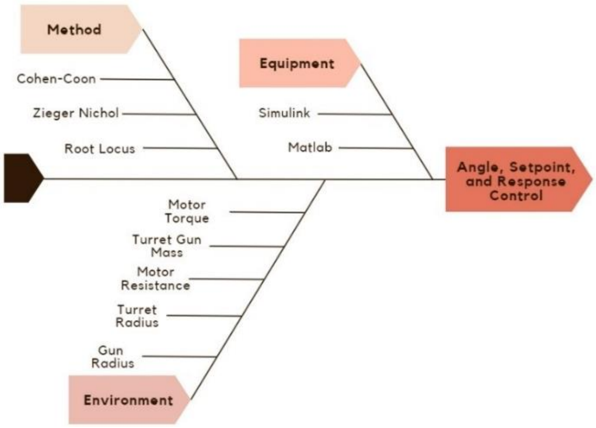

Fig. 5: Fishbone Diagram.

Based on Figure 5, important points were obtained to identify the problem. The problem at hand is that the position of the azimuth axis on the turret gun is unstable and difficult to control. This impacts the inability of weapons to target accurately and effectively. Therefore, it is necessary to do proper control to keep the position of the azimuth axis stable and controllable. This research can be done using MATLAB simulation. In this simulation, a mathematical model of the azimuth axis position control system on the turret gun will be made, and the Cohen-Coon PID tuning will be carried out to find the optimal parameters[38–40].

3.2 Experimental Steps

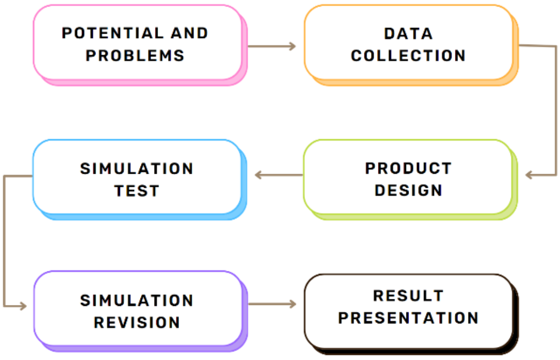

Fig. 6: Diagram of Design Steps.

Based on the diagram shown in Figure 6, this research begins with identifying the potential and common issues that often arise in controlling the azimuth axis position of a 20 mm caliber turret gun using a PID control system. Through an extensive literature review, we identified the common challenges associated with the PID control system's response in the context of turret gun applications. Subsequently, we collected data on the performance of existing PID control systems in turret guns, including their response to changes in target positions, levels of overshoot, rise time, and settling time. Based on the gathered data, we developed a simulation model using MATLAB Simulink[41-43] that incorporates the specific characteristics of a 20 mm caliber turret gun. The PID Cohen-Coon tuning method was applied in this simulation model to optimize the azimuth axis position control. We conducted rigorous simulation tests to evaluate the performance of the newly developed control system across various scenarios, ensuring stable and precise response in turret gun aiming. The simulation results served as the basis for designing improved products, with adjustments made to turret gun dimensions and parameters based on research findings. The simulation was also revised based on initial test results, with PID Cohen-Coon parameters readjusted to improve the control system's response to identified issues. Finally, the research findings are presented through in-depth analysis of significant improvements in azimuth axis position control for 20 mm caliber turret guns using the PID Cohen-Coon tuning method. We also discuss the potential applications of this technology in enhancing precision and stability in turret gun control across various defense applications.

4. Result and Discussion

The initial stage is to develop a mathematical model of the turret gun system. Next, a transfer function search is carried out based on the physical parameters of the 20 mm caliber turret gun as in Table 2.

Table 2. Physical Parameters of 20 MM Caliber Turret Gun[37].

Parameters	Symbol	value
Motor Torque	*Kt*	0.072 Nm/A
Constant Voltage	*Kb*	7.5 V/Krpm
Motor Resistance	*Ra*	0.45 ohm
Turret Mass	*m1*	1500 Kg
Gun Mass	*m2*	110 Kg
Turret Fingers	*R1*	0.5 m
Gun Fingers	*R2*	2.76 m
Motor Voltage	*Ea*	12 V

By entering the parameters contained in Table 2 into the linearized equation using the Jacobian method. From Equation (14) and Equation (15), the following values are obtained:

$$A = \begin{pmatrix} 0 & 1 \\ 0 & -0.39705 \end{pmatrix} \tag{19}$$

$$B = \begin{pmatrix} 0 \\ 0.05241 \end{pmatrix} \tag{20}$$

Variables A and B contained in Equation (14) and Equation (15) are then converted into a state space model using MATLAB with math script function as in the Equation (21).

$$State\ Space = ss(A, B, C, D) \tag{21}$$

This result of transfer function as in the Equation (22).

$$TF = \frac{0.05241}{s^2 + 0.3971s} \tag{22}$$

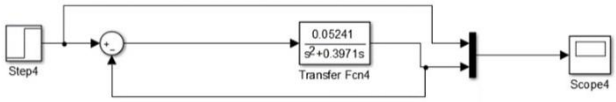

Fig. 7: Block Diagram of Closed Loop Simulation.

After obtaining the transfer function equation of the plant, the transfer function is then simulated to see the response. The simulation is carried out in a closed loop as shown in Fig. 7.

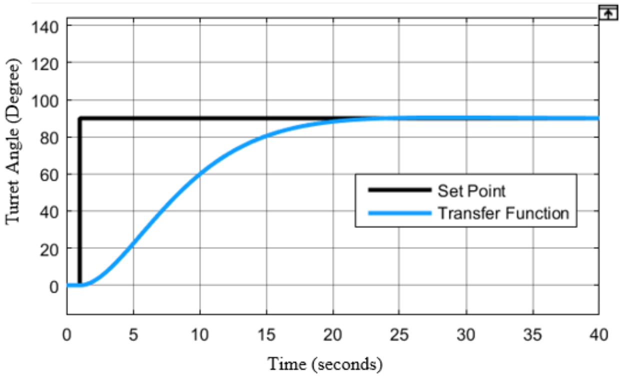

Fig. 8: System Response Result Graph without Controller (Closed Loop).

From Fig. 7 the closed loop simulation block diagram above after being simulated, the graph of the system response results with a 90° setpoint can be seen in the Scope block, the response result graph is as shown in Fig. 8. The system response shows low overshoot values but high values of rise time and settling time.

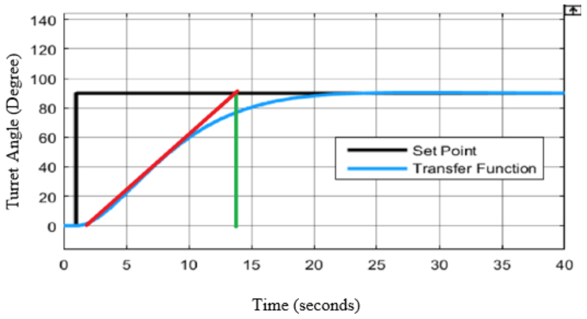

Fig. 9: Step Test of System Response without Controller (Closed Loop).

Based on Figure 9, After getting the graph of the closed loop system response results as above, to get the value of τ and td, the next step can do a step test, namely by looking for the tangent line (red line) on the closed loop system response results graph. The green line is the intersection between the tangent line and the set point line. The results of this step obtained a τ value of 12, td of 1.8, and the value of g_p obtained is 0.1.

By obtaining the values of τ and td, the next step is to find the value of the PID parameters, namely the values of Ti and Td, by entering the PID equation according to the Cohen-Coon tuning method rule formula in Table 1. Based on calculations with the rule formula, it can be seen that the parameter value is 92.4975, the Ti parameter value is 4.2366, and the Td parameter value is 0.6480, so the value is 92.4975, the value is 21.8330, and the value is 59.9400. These PID parameters are simulated with a PID control circuit, as shown in Fig. 10[44].

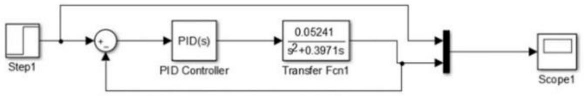

Fig. 10: Block Diagram of PID Control Simulation.

From the simulation results, the system response graph is obtained as shown in Fig. 11.

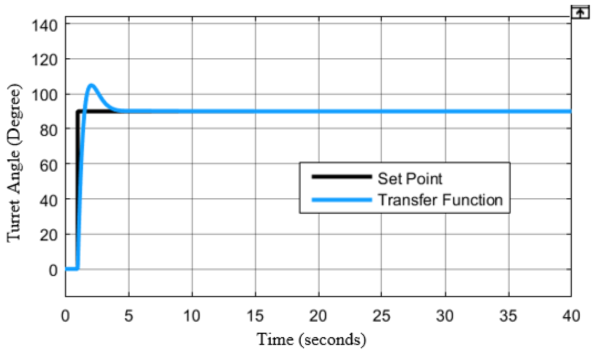

Fig. 11: System Response Result Graph of Cohen-Coon Tuning Method.

PID turret gun control with Cohen Coon method gives the system response shown in Fig. 11. The rise time value is 0.404 seconds, the settling time value is 2.66 seconds and the overshoot value is 16.5%.

To compare[45-46] the graph of the response results of the control system that has been made using the Cohen-Coon tuning PID control, the authors compare it with previous research[1], namely using a PID control system with the Ziegler Nichols and Root Locus tuning methods because it uses the same plant, namely a 20 mm caliber turret gun with an azimuth axis position.

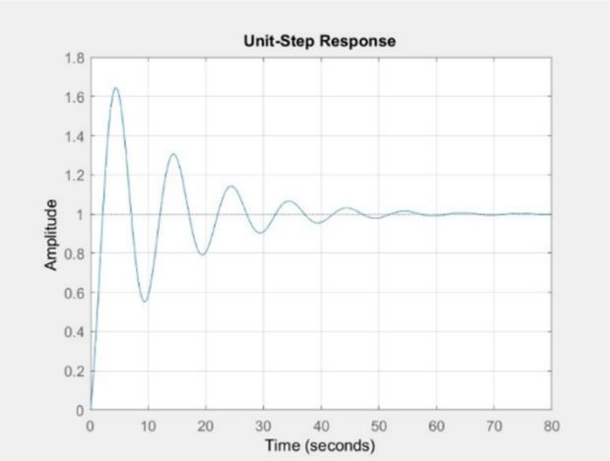

Fig. 12: System Response Result Graph of Ziegler Nichols Tuning Method.

The Turret gun using Ziegler Nichols method gave response results show in Fig. 12 where, the rise time value is 1.6481 seconds, the settling time value is 49.9369 seconds and the overshoot value is 64.4859%.

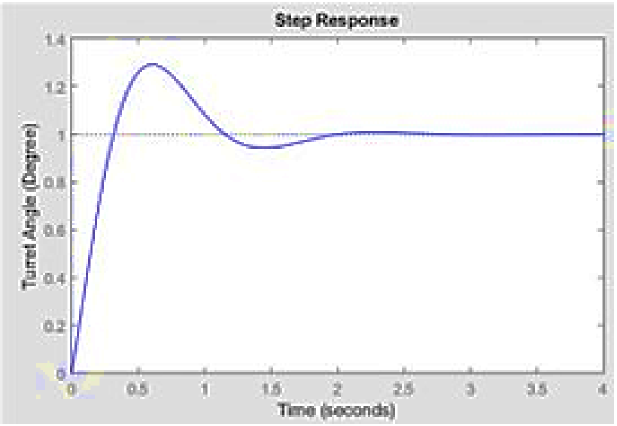

Fig. 13: Response Result Graph of Root Locus Tuning Method[4].

The Turret gun using Root Locus method gave response results show in Fig. 13 where, the rise time value is 0.3 seconds, the settling time value is 1.74 seconds and the overshoot value is 29.9%.

Based on the simulation results in Fig. 11, Fig.12, and Fig. 13, shows that at a setpoint of 90°, the results of the system response graph comparison with the maximum variables of rise time, settling time, and overshoot are obtained as in Table 3.

Table 3. Comparison of System Response Characteristic Variables.

Method	Cohen - Coon	Ziegler Nichols	Root Locus
Rise Time (s)	0.404	1.6481	0.3
Settling Time (s)	2.66	49.9369	1.74
Overshoot (%)	16.5	64.4859	29.9

It can be seen from Table 3 above that using PID control with the Cohen-Coon tuning method produces a smaller maximum overshoot compared to Ziegler Nichols PID control and Root Locus PID control. The results showed that the Cohen-Coon tuning method produced the lowest overshoot value at 16.5%, compared to 64.48% with the Ziegler-Nichols method and 29.9% with the Root Locus method. A lower overshoot value indicates relatively stable control system response to input changes, reducing the risk of excessive oscillations that could damage the system or cause instability. The rise time values obtained were 0.404s for Cohen-Coon, 1.6481s for Ziegler-Nichols, and 0.3s for Root Locus. The settling time values were 2.66s for Cohen-Coon, 49.9369s for Ziegler-Nichols, and 1.74s for Root Locus. Despite Cohen-Coon having a higher settling time compared to Root Locus, it exhibited less overshoot after reaching the set point, suggesting a more stable control. In the context of turret gun applications, balancing responsiveness (rise time) and stability (settling time) is crucial. If the turret gun requires a very rapid response to changes in target position, using PID with Root Locus can provide an advantage in achieving high precision targeting in a short time. However, if the primary concern is maintaining position stability after reaching the target, the Cohen-Coon approach may be more suitable.

5. Conclusion

PID control using the Cohen-Coon tuning method is effectively employed to regulate the movement of the turret gun along the azimuth axis. Following the search for PID parameters using the Cohen-Coon method, we obtained values of Kp, Ki, and Kd is 92.4975, 21.8330, and 59.9400. Despite Cohen-Coon having a higher settling time compared to Root Locus, it exhibited less overshoot after reaching the set point, suggesting a more stable control.

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Nomenclature

$m1$	turret mass (kg)
$m2$	gun mass (kg)
$R1$	turret radius (cm)
$R2$	gun radius (cm)
$\theta 1$	azimuth angle (°)

$\theta 2$	elevation angle (°)
$u(t)$	controller output signal
K_p	proportional gain
T_i	integral time
T_d	derivative time
$e(t)$	error signal generated

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