

CIWS Control System

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Closed Loop Control Systems

THE CONTROLL SYSTEM FOR A CIWS TURRET

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ABSTRACT

In this study, a control system is designed to aid in the operation of a CIWS (close-in weapon system) turret with the use of a PID (Potential-Integral-Derivative) controller. This is done by designing the closed loop control system using MATLAB and Simulink then tuning the response. The aim is to obtain a transfer function of the system as a whole in order to validate the operational parameters required for a successful system, meaning the control system has an overshoot of less than 5% with a settling time of under 2 seconds. As CIWS turrets are used for anti-missile capability onboard destroyer class vessels, the requirement for the overshoot and settling time must be as low as possible.

INTRODUCTION

To understand what a control system is, the underlying theory behind PID controllers and transfer functions must be understood. For systems that gain an input from their output in order to regulate the results. This use of feedback allows the system to operate within set parameters (set point) without human intervention and this is known as a closed loop control system.

Operations of a PID controller

A PID controller works by continuously measuring the error between a setpoint and the actual process variable, then using this error to adjust the process input. The proportional component of the PID controller produces an output that is proportional to the difference between the setpoint and the process variable. The integral component accumulates the error over time and produces an output that is proportional to the integral of the error. [2] Finally, the derivative component produces an output that is proportional to the rate of change of the error. Each component separately has its advantages and disadvantages however the combined result of all 3 limit these shortfalls. The proportional component provides a quick response to changes in the process variable, while the integral component eliminates any steady-state errors. The derivative component provides damping and reduces overshoot and oscillations. The output of the PID controller is then fed back into the process input to maintain the process variable at the setpoint.

Transfer functions are mathematical expressions that describe the relationship between the input and output of a system. The transfer function of a PID controller can be derived by taking the Laplace transform of the differential equation that describes the controller's behaviour [3]. The resulting transfer function is a ratio of two polynomials in s , where s is the Laplace variable. The transfer function of a PID controller is given as:

$$G(s) = K_p + K_i/s + K_d s$$

Where K_p , K_i , and K_d are the proportional, integral, and derivative gains, respectively.

Closed-Loop Systems: Closed-loop systems are feedback control systems where the output of the system is fed back to the input. In a closed-loop system, the feedback allows the system to adjust itself to reach a desired setpoint. There are three types of closed-loop systems: proportional, integral, and derivative. [1]

Proportional Control: Proportional control is the simplest type of closed-loop system. In this type of system, the controller output is proportional to the difference between the setpoint and the process variable. The transfer function of a proportional controller is given as:

$$G(s) = K_p$$

Where K_p is the proportional gain.

Proportional control is effective in reducing steady-state errors and improving system stability. However, it can cause overshoot and oscillations if the gain is set too high.

Integral Control: Integral control is used to eliminate steady-state errors in a closed-loop system. In this type of system, the controller output is proportional to the integral of the error between the setpoint and the process variable. The transfer function of an integral controller is given as:

$$G(s) = K_i/s$$

Where K_i is the integral gain.

Integral control

Integral control is effective in reducing steady-state errors, but it can cause overshoot and oscillations if the gain is set too high. To avoid these problems, integral control is often used in combination with proportional or derivative control.

Derivative Control: Derivative control is used to reduce overshoot and oscillations in a closed-loop system. In this type of system, the controller output is proportional to the derivative of the error between the setpoint and the process variable. The transfer function of a derivative controller is given as:

$$G(s) = K_d s$$

Where K_d is the derivative gain.

Derivative control is effective in reducing overshoot and oscillations, but it can cause noise amplification if the gain is set too high. To avoid these problems, derivative control is often used in combination with proportional or integral control.

SIMULATION SETUP

In this task, a model for a CIWS turret is produced as a transfer function with the operation being shown below which represents its angular positioning system.

$$G(S) = \frac{1}{5S^2+8}$$

In MATLAB, a suitable control system is chosen for this task (being a PID controller) with the closed loop system being simulated in Simulink. The PID controller parameters is then tuned

to achieve the desired performance specifications, being settling time of 2 seconds and overshoot of less than 5%. By multiplying the transfer function of the control system with the transfer function of the positioning system, the closed-loop transfer function of the system as a whole is gained which is then used to Validate the simulation results by comparing the response of the closed-loop system with the performance specifications. This completed model Simulation show in Fig 1.

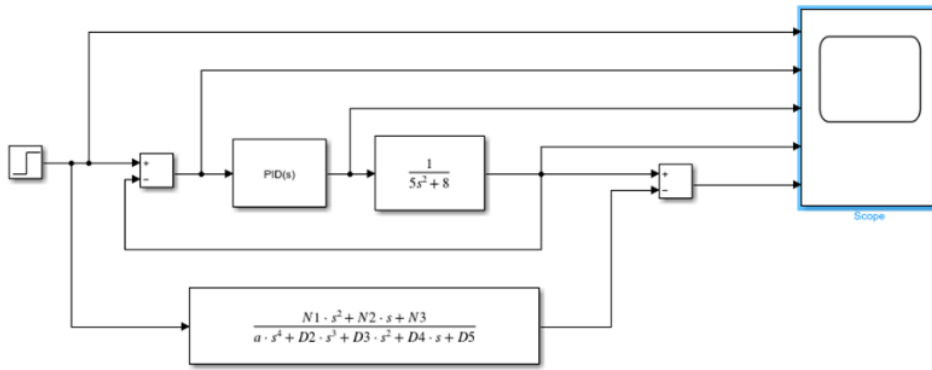
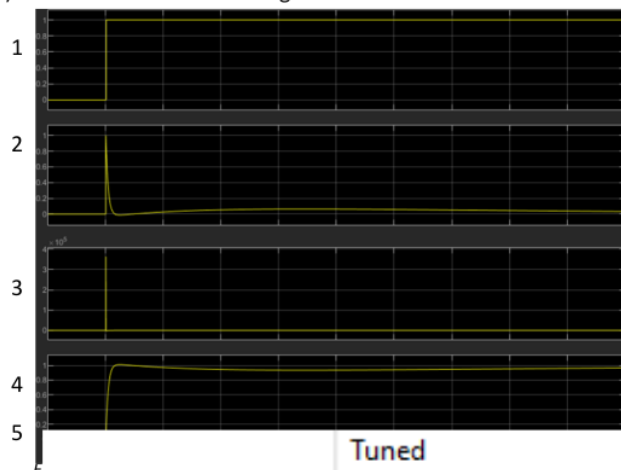


Fig 1 (Completed model simulation of Control system)

RESULTS

Once the simulation of the CIWS turret was completed, the values for each component was recorded. This included the step input (1), the output of the PID controller (2), the output of the transfer function representing the CIWS turrets angular positioning system (3), the same step input minus the output of the transfer function of the CIWS turret (4) and finally the same transfer function minus the complete transfer function of the system as a whole (5 blue line). The results are shown in figure 2.



	Tuned
Rise time	0.0984 seconds
Settling time	0.159 seconds
Overshoot	0.767 %
Peak	1.01
Gain margin	Inf dB @ Inf rad/s
Phase margin	88 deg @ 20.9 rad/s

Fig 3 (the performance of the control system)

A Nyquist plot is a system's frequency response represented in a graph. It is a polar plot of the system's complex transfer function, which describes the relationship between the input and output signals of a system in the frequency domain [5]. The Nyquist plot shows the magnitude and phase of the system's frequency response as a function of frequency. The magnitude is plotted on the radial axis, while the phase is plotted on the angular axis. The Nyquist plot can be used to analyse stability and performance of a control system. The Nyquist plot is particularly useful for determining the stability of feedback systems. By analysing the Nyquist plot, an engineer can determine the stability of the system and the amount of gain and phase margin that the system has. Gain margin refers to the amount of gain that can be added to the system before it becomes unstable, while phase margin refers to the amount of phase lag that can be introduced into the system before it becomes unstable. This is show in Fig 4

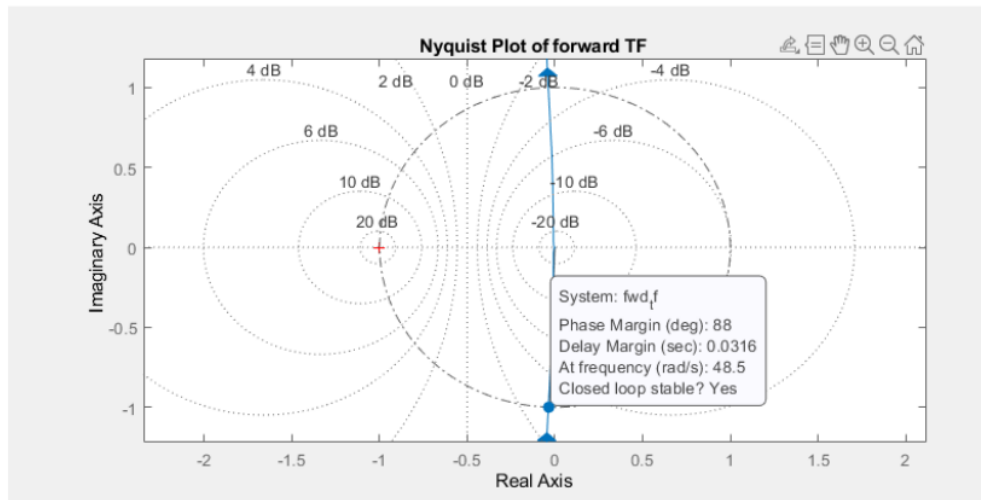


Fig 4 (The Nyquist plot of the forward Transfer function)

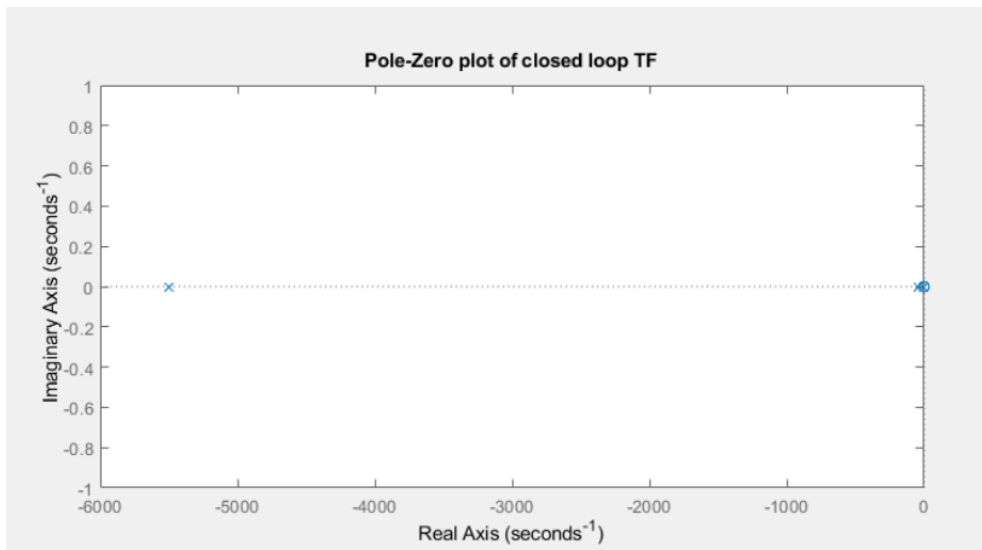


Fig 5 (Pole Zero diagram for the closed loop transfer function)

A pole-zero diagram is a graphical representation of the factors that make up the system's transfer function. The poles and zeros of the transfer function are plotted on the complex plane, with the real axis representing the frequency of the input signal and the imaginary axis representing the phase shift [4]. A zero is a value of the input signal where the output of the system is zero. It is represented by the circle on the pole-zero diagram. The pole is a value of the input signal where the output of the system is infinite or undefined. It is represented by the cross on the pole-zero diagram. The location of the poles and zeros on the diagram give insight into the behaviour of the system. The distance between the poles and zeros can also affect the frequency response of the system. This is shown in Figure 5.

DISCUSSION

Findings

Based on the results obtained, the rise time of the closed-loop system was found to be 0.0984 seconds, while the settling time was 0.159 seconds. The overshoot of the system was 0.767% and the phase margin was 88 degrees at a frequency of 20.9 rad/s. This is in line with our original aim of a maximum of 2 second settling time and 5% overshoot. These results indicate that the closed-loop system is stable and responsive. The Nyquist plot (Fig 4), which shows the relationship between the frequency response and the stability of the system, also supports the conclusion that the closed-loop system is stable. The pole-zero diagram (Fig 5) of the system also provides important information about the stability and performance of the system. In this case, all of the crosses on the pole-zero diagram are on the left of the complex plane, which indicates that the system is stable. As for the error of the closed loop

system, the difference between the transfer function as a whole and the output were taken. On Fig 2 indicated by the blue line, it can be observed that the error value for the closed loop system is negligible being in the values of 10^{-14} .

Explanation

The rise time is the time it takes for the system output to rise from 10% to 90% of its steady-state value, and the settling time is the time it takes for the system output to settle within 2% of its steady-state value. These values indicate that the system responds quickly and settles to its steady-state value within a reasonable amount of time. The overshoot value of 0.767% indicates that the designed control system was able to bring the angular positioning system under control without overshooting the desired output by more than 5%. The phase margin of 88 degrees at 20.9 rad/s indicates that the designed control system is stable and has a good level of robustness against disturbances. In this study, the designed control system was able to meet the requirements because it was designed to have a high gain and a fast response time. The high gain ensured that the system was able to respond quickly to any changes in the input, while the fast response time ensured that the system settled to its steady-state value within a reasonable amount of time without overshooting the desired output.

CONCLUSION

In conclusion, the closed-loop control system designed for the angular positioning system of the automatic CIWS turret was successfully able to achieve the desired performance specifications of settling within two seconds with overshoot less than 5%. The simulation results showed that the closed-loop system was stable and able to track the reference input with high accuracy. The phase margin indicated that the system was robust and less susceptible to disturbances. The pole-zero diagram indicated the stability of the system a whole. The Nyquist plot of the closed-loop transfer function showed that the system was stable.

Overall, the findings of this study demonstrate the effectiveness of the designed control system in achieving the desired performance specifications for the angular positioning system of the automatic CIWS turret.

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- [4] P. A. Lynn, "The Laplace Transform and the z-transform," in Electronic Signals and Systems, Macmillan Education UK, London, 1986, pp. 225-272, doi: 10.1007/978-1-349-18461-3_6.
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FINAL GRADE

GENERAL COMMENTS

Instructor

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GRADING FORM: SMU GENERIC_SMOSEY

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ENGAGEMENT WITH LITERATURE

including reading, referencing, academic conventions and academic honesty



You need to do in-text referencing from relevant and diverse academic and industry sources for the PID controllers which is limited.

6

KNOWLEDGE & UNDERSTANDING

Knowledge of the basic underlying concepts and principles of a subject.



Its good that you have explained the concepts of PID controller. You should also use resource statements to show how turrets will make use of PID Controllers to turn its positions.

21

COGNITIVE & INTELLECTUAL

Evaluate underlying concepts and principles of a subject and interpret qualitative and quantitative data in order to develop lines of argument and make sound judgements.



Settling time and the overshoot values are up to the expectation.
The graphs are captured but limited.
Needs more points on interpreting the results.

21

PRACTICAL APPLICATION SKILLS

Different approaches to solving problems in particular contexts.



Proper simulation tool is used. Discussions on findings are satisfactory.

14

TRANSFERABLE SKILLS

Communicate the results of their study/work accurately and reliably, and with structured and coherent arguments; the qualities needed for employment requiring the exercise of some personal responsibility within a structured and managed environment.



To score high you need to ensure that the document is of high quality and professionally done. There should be a good flow of ideas , with evidence of proper use of the spelling and grammar tool and a complete and neat presentation of work. Marks for the structure of the document were also considered in this section.

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