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Gyroscope Control System in Wave Power Plant Using PID Controller

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***Abstract*—A wave power plant can generate sufficient electrical voltage using the wave as energy to supply electrical equipment. Nevertheless, waves become a problem to generate because it depends on the wind to obtain the generated voltage in the wave power plant. The wave power plant must be able to work optimally to produce electric power and stabilize the voltage output. It can be done by implementing a gyroscope control system in the wave power plan. In this study, the wave power plant control was designed using a PID controller with five types of controllers, namely system without controller, system with P controller, system with PI controller, system with PD controller, and system with PID controller. The results showed that the use of a PD controller with a value of KP = 5.2 and KD = 0.6 can produce a voltage value on the power take off (PTO) generator when the ocean wave occurred and made the gimbal movement unstable.**

***Keywords*—PID, Gyroscope, Wave Power Plant, Gimbal, Flywheel**

I. Introduction

Indonesia, as a maritime nation, has a coastline of 95,181 km and is the second-longest coastline in the world after Canada[1]. As the largest archipelagic country in the world, Indonesia has role in global economic growth through sea transportation. In addition, the ocean has an important role as a source of renewable energy. Ocean waves can be utilized as a form of renewable energy source[2]. They are generated by force which can be in the form of objects moving around the sea surface, wind, seismic disturbances, and waves generated by the gravitational fields of the moon and sun[3].

By utilizing ocean waves as energy, the wave power plant can generate sufficient electrical voltage to supply electrical equipment[4]. The wave power plant may depend on the wave size. If the wave size is too small, then the PTO (power take-off) generator of the wave power plant will not be able to generate voltage. To overcome it, an optimal controller is needed to maintain the stability of the voltage generated by the wave power plant.

Control system of the wave power plant has been studied in various papers. Such studies include the use of a gyroscope by utilizing a flywheel driven by a motor on the gimbal that is on the 1 DOF (degree of freedom) platform[5], and on the 2 DOF platform[6]. The use of gimbals that are on the 1 DOF platform will be efficient when it is aligned with the incoming wave. The use of gimbals on a 2 DOF platform can be more efficient because it does not depend on the direction of the wave, even though the use of PTO in the wave power plant is a pneumatic PTO.

The results obtained in [5] and [6] showed that the generated voltage by the wave power plant was not effective yet, where the output was almost zero. Thus, in this study, the gyroscope control system in the wave power plant will be discussed using a PID controller. According to Bracco, the use of a gimbal on a 1 DOF platform is sufficient to generate an output voltage[5].

In this study, the wave power plant is designed using a 1 DOF gimbal platform and a float of it using PID so that the position of the waves and the wave power plant can be aligned. The use of the PID control system is chosen because it is suitable for correcting the position of the wave power plant so that it can produce a stable voltage.

The rest of this paper is organized as follows. In Section 2, a brief literature review is presented, followed by the research method used in this study as shown in Section 3. Section 4 represents the results and discussion. Finally, the paper is concluded in Section 5.

II. Literature Review

In this research, a gyroscope control system will be designed for the wave power plant using a PID controller. Here, a brief description of the wave power plant, gyroscope, and PID controller will be discussed.

A. Wave Power Plant

The wave power plant is a power plant that uses an energy source in the form of ocean waves located in an aquatic environment or coastline[7]. The wave power plant is one of the most promising renewable energy sources with an estimated potential of around 2 MW[8].

B. Gyroscope

Gyroscope is an actuator to control attitude and stability in a system. It consists of a flywheel, gimbal, rotor motor, and gimbal motor as shown in Fig 1. Gyroscope consists of two dynamic components, namely flywheel and gimbal[9]. The flywheel rotates at high speed and the gimbal rotates at low speed. The rotation of the flywheel will affect the rotation of the gimbal through the mechanical structure of the supporting bearing. The rotation of the gimbal affects the stiffness of the bearing, resulting in a complex combined motion between the flywheel and the gimbal[10].

C. PID Control System

The control system used in the wave power plant is the PID control system. This control system is divided into two, namely the open-loop system and the closed-loop system[11].

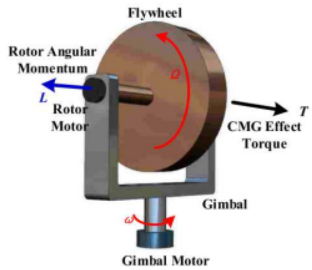

Fig 1. Gyroscope Structure and Principle

1) Proportional

The form of the equation of proportional control can be expressed as follows:

$$P_{out} = K_p e(t) \quad (1)$$

Based on the equation above, the P controller only functions as a gain and does not give a dynamic effect to the system[12].

2) Integral

The form of the equation of integral control can be expressed as follows:

$$I_{out} = K_i \int_0^t e(\tau)\, d\tau \quad (2)$$

Based on this equation, if $e(\tau)$ is close to zero, the value of I_{out} will be smaller. On the contrary, if the value $e(\tau)$ is close to constant, the value of I_{out} will be greater so that it can correct the *error*[12]. Integral control can improve response to steady-state. Nevertheless, the value of Ki must be appropriate since the unappropriated value will cause a very high transient response which can make the output oscillates or not stable.

3) Derivative

The equation form of the derivative control can be expressed as follows:

$$D_{out} = K_d \frac{de(t)}{dt} \quad (3)$$

Based on the equation above, the control D is related to the speed or rate of the error value. Value D can know the errors that exist. The D controller may reduce the value of the error[12].

III. Methods

A. Design System

A design system of this study is divided into the programming and hardware. A flowchart of the proposed control system implemented in the wave power plant can be seen Fig. 2. This flowchart contains of the simulation stages which is performed in the wave power plant.

PID parameters can be obtained by finding the constant proportional (Kp), constant integral (Ki), and constant derivative appropriate (Kd) in order to determine the success of the system. In this study, the values of Kp, Ki, and Kd were determined by trial and error. The trial and error method is the basic method for providing reinforcement values by comparing the results of the existing constants.

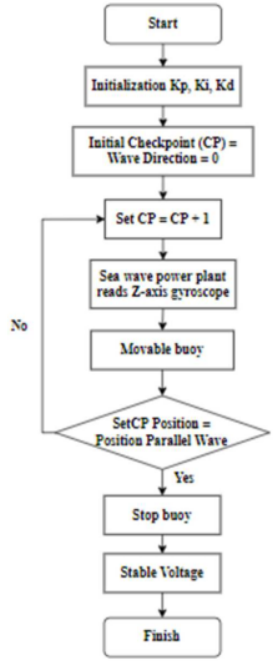

Fig 2. Flowchart Control System Gyroscope Wave Power Plant

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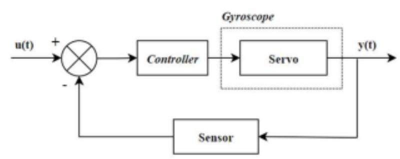

Fig 3. PID System Block Diagram

In Fig. 3, it can be seen the block diagram of PID system where $u(t)$ is the setpoint in the form of a direction parallel to the ocean waves, which is the input of the PID to be used.

Fig. 4 is a design of the power plant which was made using the SolidWorks application. The body outer and gimbal of the wave power plant use acrylic material. Meanwhile, the float is made of plastic and a combination of PVC. On the gimbal, there is a flywheel which is used to rotate the gyroscope.

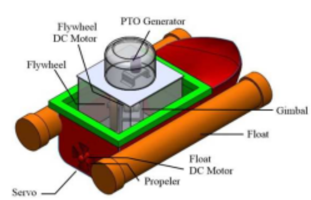

Fig 4. Design of Wave Power Plant

B. Wave Power Plant Control System

A control system used in the wave power plant is the P, I, and D controller. The controllers must have high reliability in maintaining system stability. Thus, some parameters of the controller used in this study are PD (Proportional Derivative), PI (Proportional Integral), and PID (Proportional Integral Derivative).

The set point used in the control method is a variable value which is obtained from the HMC5883L compass sensor reading.

C. System Testing

At this stage, the previously designed system will be tested. The purpose of this test is to find out errors and the performance of the system that has been designed. At this stage, the wave power plant will be placed in the water that has high waves to determine whether the generated voltage is stable or not using the PID control system and without a controller. In addition, the errors of using the PID control system will be found through this test. The error obtained shows the failure rate of the wave power plant in getting a stable voltage value. Experiments are carried out in the high wave location by providing a value offset to the wave power plant so that the direction of the arrival of the waves will always be the same as the direction of the setpoint that has been given to the wave power plant. The success of this experiment can be seen from the ability of the wave power plant to produce a stable voltage.

Fig. 5 is the wave power plant that has been designed and made of acrylic and plastic. Some components, such as microcontrollers, sensors, and propulsion were arranged in the wave power plant.

IV. Result And Discussion

A. Simulation Testing PID

The simulation test is divided into five, namely system without controller, system with P controller, system with PI controller, system with PD controller, and system with PID controller.

The closed-loop performance test is obtained from the response of the close-loop transfer function switching to the unit step input. The parameters to determine the closed-loop performance in the time domain include rise time, peak time, peak, overshoot, settling time

1) System Without Controller

Table 1 shows the simulation results of a closed-loop system without control system.

Fig 5. Wave Power Plant

TABLE I. Closed-Loop Performance System Without Controller

Criteria	Values
Rise Time	8,9191 s
Peak Time	42,8113 s
Peak	1,0000
Overshoot	0 %
Settling Time	15,8973 s

The response of a feedback control system without control system to a unit step can be seen in Fig. 6.

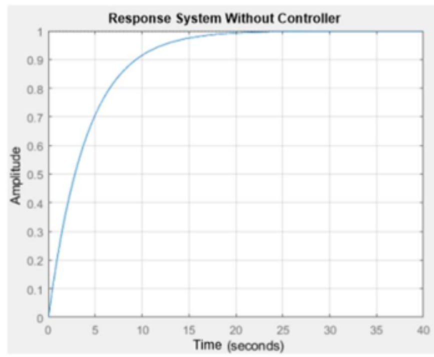

Fig 6. Response System Without Controller

As shown in Table 1, the performances of the closed-loop system in the time domain did not the criteria of good one since the value of rise time, peak time and settling time need long duration. Thus, to improve the performance of the closed-loop system, it is necessary to have faster rise time, peak time, and settling time, as well as lower peak and overshoot values. These can be done by adding controller.

2) System With P Controller

The performance of the closed-loop system in time domain using P controller with a constant value of Kp = 5 can be seen in Table 2. The response system with controllers P using the unit step is shown in Fig. 7.

TABLE II. Closed-Loop Performance System With P Controller

Criteria	Values
Rise Time	1,7552 s
Peak Time	5,8488 s
Peak	0,9993
Overshoot	0 %
Settling Time	3,1416 s

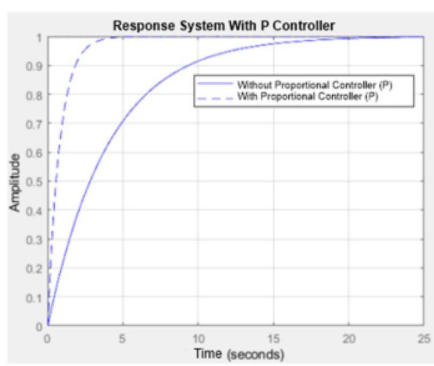

Fig 7. System Response With P Controller

As shown in the figure, the performance of closed-loop in the time domain did not meet the desired criteria even though the P controller has been used. The results obtained from MATLAB simulation using the P controller showed that the values of the rise time, peak time, and settling time have decreased compared to the the value of the system without using a controller. So it is necessary to add another controller.

3) System With PI Controller

The performance of the closed-loop in time domain using PI controller with constant value Kp = 8, and Ki = 2,3 can be seen in Table 3. The response system of PI controller to input of a unit step can be seen in Fig. 8.

By using the PI controller, the performance of the closed-loop in the time domain as shown in the response system did not meet the desired criteria. Based on the results obtained using the PI controller, the values of the rise time, peak time, and settling time have shown decreasing values compared to the system without using a controller. On the other hand, the value of overshoot has increased compared to the system without a controller.

4) System With PD Controller

Based on the results obtained using PD controller with constant values of Kp = 5.2, and Kd = 0.6, the performance of closed-loop can be seen in Table 4. Meanwhile, the response system with PD controller to unit step input is shown in Fig. 9. Using a PD controller, the performance of closed-loop in the time domain, the system response has met the desired criteria. Based on the designed criteria, it is expected that the system output response should be better than the system without a controller. The results obtained using the PD controller, the values of the rise time, peak time, and settling time have decreased in the value of the system without using a controller.

5) System With PID Controller

The performance of closed-loop using PID controller with constant values of Kp = 13.36, Ki = 1 and Kd = 0.4 in the time domain can be seen in Table 5. The response system with PID controller to unit step input can be seen in Fig. 10. As shown in the figure, the performance of closed-loop in the time domain did not meet the criteria needed as a good performance. The value of rise time, peak time, and settling time has a longer duration. In order to have a good performance closed-loop, it is necessary that the rise time, peak time, and settling time values have a faster duration, lower peak and overshoot values.

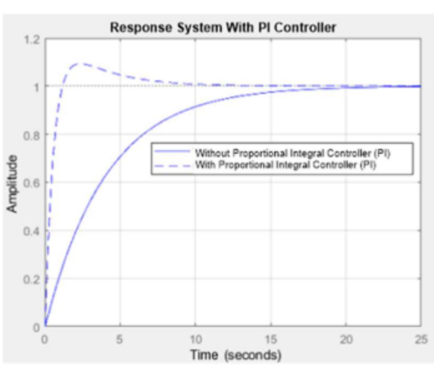

Fig 8. System Response with PI Controller

TABLE III. CLOSED-LOOP PERFORMANCE SYSTEM WITH PI CONTROLLER

Criteria	Values
Rise Time	0,8058 s
Peak Time	2,3431 s
Peak	1,0937
Overshoot	9,3730 %
Settling Time	7,4620 s

TABLE IV. CLOSED-LOOP PERFORMANCE SYSTEM WITH PD CONTROLLER

Criteria	Values
Rise Time	1,4053 s
Peak Time	4,7024 s
Peak	0,9992
Overshoot	0 %
Settling Time	2,5578 s

TABLE V. CLOSED-LOOP PERFORMANCE SYSTEM WITH PID CONTROLLER

Criteria	Values
Rise Time	0,8386 s
Peak Time	2,8094 s
Peak	1,0490
Overshoot	4,8982 %
Settling Time	NaN

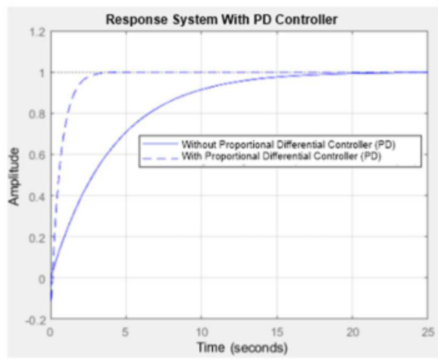

Fig 9. System Response with PD Controller

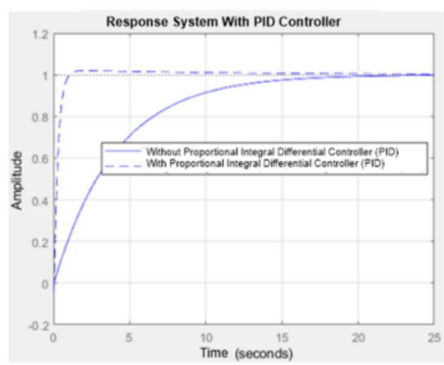

Fig 10. System Response with PID Controller

B. *Wave Power Plant Movement Testing*

This study was carried out to obtain the value of the digital compass (heading), heading error, and target heading which was driven by a servo to adjust the direction of the buoy movement. The display values were stored in the serial monitor using five controllers, namely the P controller

(Kp = 5), the PI controller (Kp = 8, Ki = 2,3), the PD controller (Kp = 5.2, Kd = 0, 6), PD controller (Kp = 2, Kd = 1,2) and PID controller (Kp = 13.36, Ki = 1, Kd = 0.4). the parameter values used in these five controllers were taken from the tests that have been carried out previously using MATLAB. Tests were conducted to determine which controller is better using P controller, PI controller, PD controller, or PID controller. So far, based on the simulation result, the best controllers used were PD and PID controllers.

Fig. 11 shows the comparison of movement obtained by changing the P controller, PI controller, PD controller, and PID controller. As shown in Fig. 11, it is found that the value is target heading given 70° when the use of the P controller with Kp value = 5 got the error of 2° - 4°. Meanwhile, the PI controller with a value of Kp = 8, Ki = 2,3 had the error of 1° - 2°. PD controller with Kp = 5.2, Kd = 0.6, the error is quite stable. The use of a PD controller with a value of Kp = 2, Kd = 1.2, the value of error was 2° - 4°. As for the PID controller with Kp = 13.36, Ki = 1, and Kd = 0.4, the error was 1° - 3°. Based on these results, the PD controller with a value of Kp = 5.2, Kd = 0.6 is quite stable for the movement of the wave power plant buoy compared to the four other controllers.

The use of PD controller with Kp = 5.2, Kd = 0.6 was tested on three different values of target heading, such as 0°, 70°, and 100°. Tests on the PD controller are carried out to see the stability of the movement of the buoy when the waves come from an unexpected direction. Fig. 12 is a graph of the stability of the movement of the wave power plant buoy using a PD controller. Based on the graph, buoy stability using the PD controller obtained a fairly good value. The value of Kp = 5.2, Kd = 0.6 was used for the movement of the wave power plant buoy with a servo motor as the actuator.

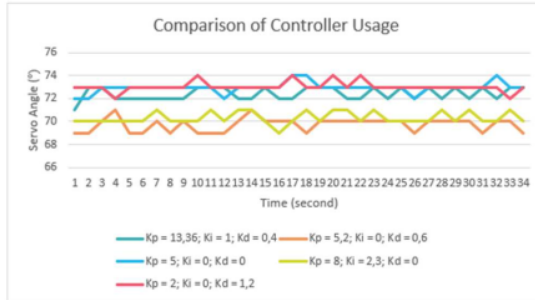

Fig 11. Comparison Graph of Controller Usage

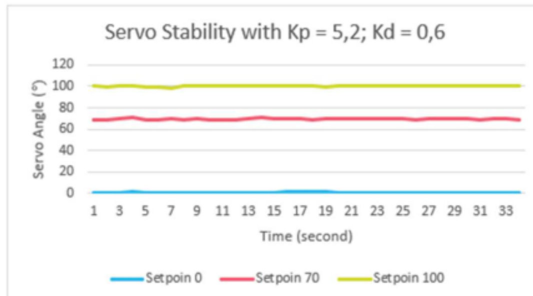

Fig 12. Graph of Buoy Stability Using PD Controller

V. Conclusion

Based on the research that has been done, it was found that the implementation of the PID control system on the wave power plant was successfully carried out to move the buoy. The movement of the wave power plant buoy using the PD controller on a digital compass and servo motor is good enough with Kp = 5.2 and Kd = 0.6.

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