Design and Simulation of Automatic Ballast System on Catamaran Ship Based on Programmable Logic Control

Indra Ranu Kusuma[1]

***Abstract*—characteristics of catamaran ship which has deficiency to ship stability during maneuvering. to that end, this paper concerns about ballast system design in support of the safety and comfort of passengers on the catamaran boat. the discussion is done by creating a mathematical model of each component in the block diagram of the ballast system. then determine the pid value of the system and add the compensator for the system to run stable. further analyzed with the help of matlab software to get transient system response. with the automation system on the ballast system, it is expected that the motion of the ship can work automatically and provide a better response in the stability of the catamaran type ship. the ballast system begins to work against the tilt of the ship at 6.7 seconds at a certain angle, and will continue to work during the vessel maneuvering. judging from the 6.7 second system response time, the convenience of the passengers is not disturbed (the system response is not too fast). one way to reduce the rolling that occurs on the ship is to optimize the performance of the ballast system. performance optimization is done by using programmable logic controller (plc). plc used is omron cpm1a-30cdr-a-v1. the process is done by making the installation plant model of the ballast system as a control medium. followed by creating a control circuit consisting of wiring i / o, limit switch circuits, power supplies and programming languages associated with plcs. the result of the control is expected to regulate fluid flow in the ballast system automatically resulting in a rapid response to the stability of the ship.**

Keywords—ballast system, catamaran ship, PLC, ship stability

I. INTRODUCTION

Catamaran is characterized by having two hulls, when the vessel is maneuvering the catamaran boat has an unfavorable stability when compared to monohull [2], even the stability of the vessel is very less especially when the load is excessive. Even, this catamaran boat may be collaps, if in a state of sailing and exposed to a very strong wind, especially when maneuvering. And even this catamaran boat may be upside down and fall, if in a state of sailing and exposed to a very strong wind, especially when maneuvering.

An automatic ballast system will be offered in this research using pumps as a ballast water regulator, automatic valves, and also sensors against the angle of the vessel. By using the tilt sensor on the ship, the system is expected to be more precise in the stability of the vessel. The resulting module will be an automation system that can be applied to the ballast system on Catamaran type ships, as shown in figure 1.

The design offered must satisfy the crew and other passengers who are on board during the voyage [1]. This design should show seakeeping behavior that is capable of facing waves at seaand the passenger safety factor is a major concern [6].

In the event of a slope on the catamaran ship, the inclinometer of the sensor will respond and measure how much the angle of the ship's angle, which will then be transmitted to the PID control unit. In the control unit, the incoming angle is the desired angle (θ_i) minus the actual angle (θ_o).

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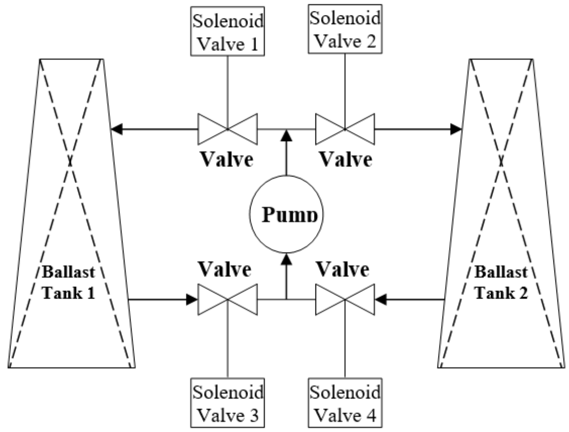

Figure. 1. Ballast Control System Design

If the positive result means the ship is tilted to the left (portside) and the water in the ballast tank will be from left to right, so also if the opposite happens [7]. In the control unit, the operator specifies the desired condition ie the condition of the ship at the time of the keel event. In this condition, the ship is at an angle position of 0^0.

If at the time of maneuver (turn left), the ship will slope to the right then the pump will light up, and valve 1 and valve 4 will open automatically, and valve 2 and valve 3 will close automatically [5]. So, the water in the ballast tank 2 will move to the ballast tank 1, until it reaches the keel position and is monitored by the inclinometer, vice versa.

The output of the PID control unit is a voltage signal (E_i) that will be the input for the starter motor and solenoid valve [4]. The starter motor is useful for moving the pump where the output is a voltage signal (E_o). While in the solenoid valve with input in the form of a voltage gain signal will be transmitted to a coil of current flow, from the coil will generate magnetic force which will push the piston and move the mass (M) as far as x, where in this mass system there is a spring component arranged in a Parallel to the constant (k) and a dashpot (B).

Further, the distance change from mass (x) is proportional to the magnitude of the pressure difference that occurs in the cylinder system (ΔP), where this pressure signal will be the input signal of the butterfly valve [3].

The output of the pump and the butterfly valve is the desired fluid flow capacity (Q). Both devices run in parallel where the magnitude of the outflow capacity of the pump will be adjusted to the magnitude of the valve angle opened by the butterfly valve [8]. With the operation of the pump and the opening of the valve, the water in the ballast tank will move from right to left or vice versa, depending on the angle read by the PID control unit, positive or negative [9].

The moment caused by the ballast tank and outside interference will be the input for the dynamic ship which is a description of the ship's rolling motion due to the ballast control system. As the output of the dynamic ship is the true angle of the ship's inclination to be responded by the inclinometer.

II. METHOD

A. Block Diagram Ballast System Design

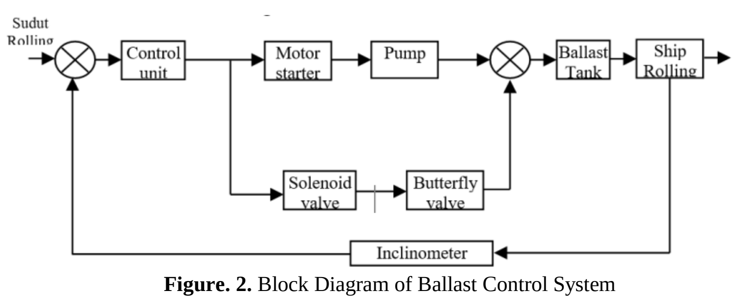

Figure. 2. Block Diagram of Ballast Control System

Ballast system on this catamaran boat is modeled two ballast tanks and 4 solenoid valves (2 valve systems) open and closed, port and starboard section. Each valve (open and closed) connects one tank. Because in the event of rolling, the flow of water that occurs only one direction, then here described only one tank and one valve (open or closed). The mathematical model of the ballast system control component is solved using the frequency domain and in obtaining the whole system block diagram shown in Figure 3.

The block diagram, see figure 3, can be solved by finding the coefficients of each of the control components. Which later will be known the stability of the system using Simulation. By knowing the mathematical functions of each component, the new block diagram is shown in figure 4:

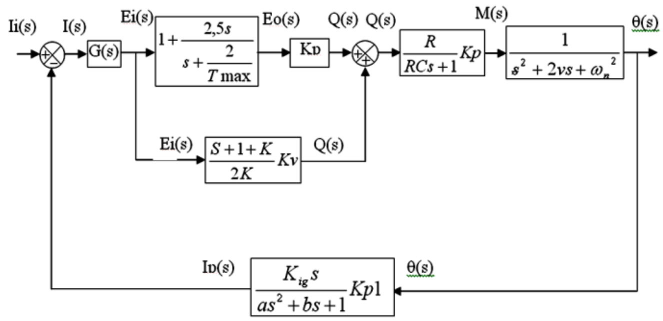

Figure. 3. Block Diagram of Ballast Control System

Where :

G (s) = Control unit

I_i (s) = The current that is converted from the desired angle is 00 (current)

Θ (s) = The actual angle of the ship's tilt (degree)

E_i (s) = Voltage from output of control unit (volt)

E_o (s) = Voltage coming out of starter motor (volt)

Q (s) = The same pump capacity as the butterfly valve capacity (m3 / hr)

M (s) = Rolling motion caused by the motion of the ship itself

Ip (s) = Current converted from inclinometer sensor

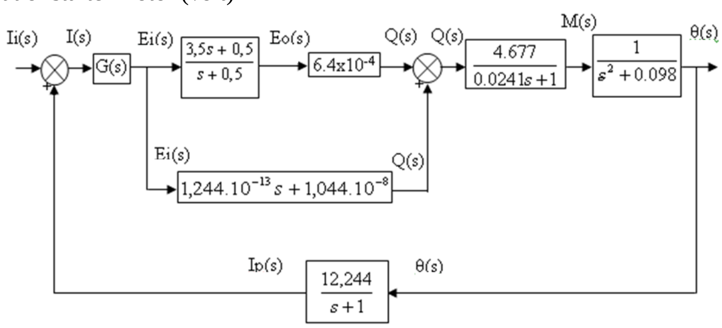

Figure. 4. Ballast Control System in Frequency Domain

B. Prototype Ballast System Design with PLC

This ballast system model is supplied by one centrifugal pump with valves as actuator. In this installation, it is planned that the pump can move the fluid from the right-side tank to the left side or vice versa. This can be done by controlling the valve opening system which is intended to automate the open the valve cover is controlled by the control equipment Programmable Logic Controller. In addition, the control equipment also controls the operation of the pump.

The equipment specifications used in the model installation are as follows, see figure 5:

1. Tank, using glass with size (90 cm x 80 cm x 30 cm).
2. Pump 1 piece. - Type: Centrifugal. - Head suct: 9 m. - Capacity: 32 l / min. - Brand: Sanwa.
3. PVC pipe diameter 0.5 ".
4. Valve, used type of solenoid valve and manual valve. For Solenoid Valve: - Voltage: 24 DC. - Cycles: 50 Hz / 60 Hz. - Pipe sizes: ½ "- Brand: UNI-D UW 15.
5. Limit switch 2 pieces.
6. Accu 2 pieces - Voltage: 12 volts - Ampere: 5 Ah
7. PLC (Programmable Logic Controller).

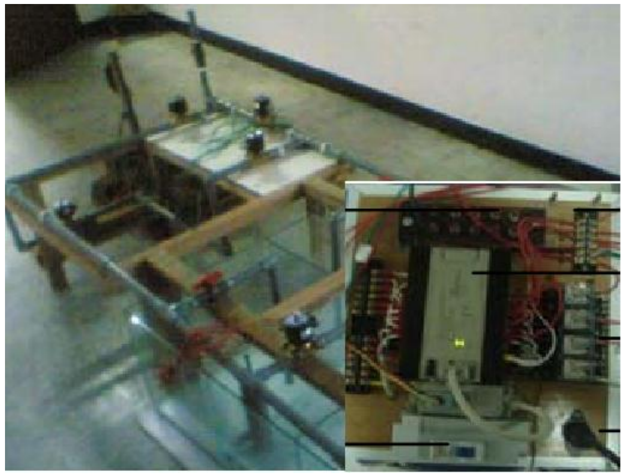

Figure. 5. Ballast Control System Based PLC

III. Analysis and Result

A. Simulation of Ballast System Design

Response of anti-heeling control system can be simulated with input in the form of roling motion measured by gyroskop. For input of the motion rolling vessel measured by the gyroscope can be written with the equation:

$$\theta_o(t) = \theta m \sin \omega \tag{1}$$

where :

θm = amplitude of gyroscope output motion

ω = the measured rolling frequency of the gyroscope, assumed to be the same as the rolling frequency experienced by the vessel.

Type of passenger ship with rolling period T = 20 s then ω = 0.413 rads-1. If the gyroscope angle is 900 in accordance with the maximum motion of the vessel on the axis axis, then θm = 900 = 1.57 rad, so the input equation is:

$$\theta o(t) = 1{,}57 \sin 0{,}413t \tag{2}$$

$$\theta o(t) = \frac{0{,}648}{s^2 + 0{,}17} \tag{3}$$

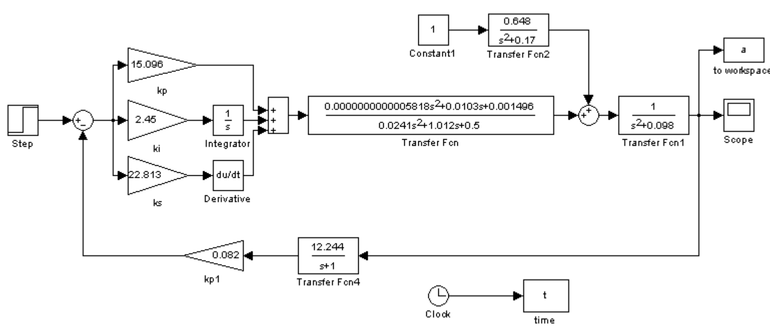

Figure. 6. Ballast Control System with Disturbance

Figure 7 shows that the ship is still wobbling because it is caused by a distortion, the abscissa axis for the slope of the vessel (but the numbers do not reflect the actual angular value as it is searched in domain (s) and horizontal for time (seconds), then responded by the system so The ship will return to a stable condition, because in theory the motion of the ship's rolling can not be completely removed from the ship because of the disturbance.

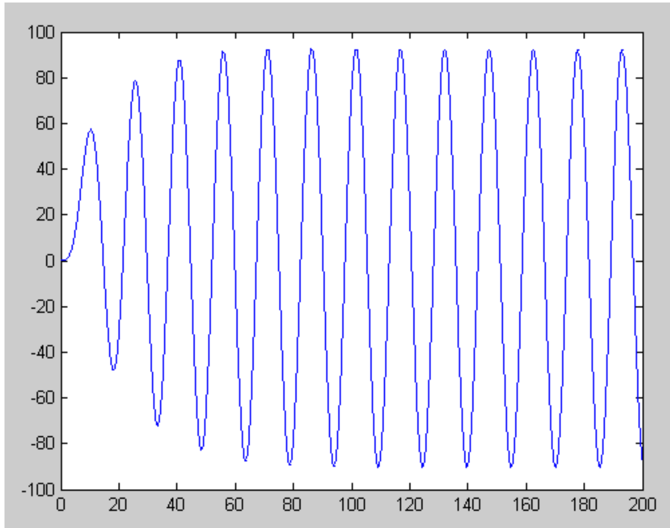

Figure. 7. Response Ballast Control System with Disturbance

The above control system is not in a stable state. To overcome this problem the system must be modified which means modifying the dynamics of the plant so as to change the overall behavior of the system in such a way that the system is stable with adequate response. One common method used in modifying the dynamic behavior of a system is to insert a compensator. Compensator is an enhancement that is inserted into the system to compensate for imperfect system behavior. From the above components seen Inclinometer is one that must be paired compensator for the system can be stable.

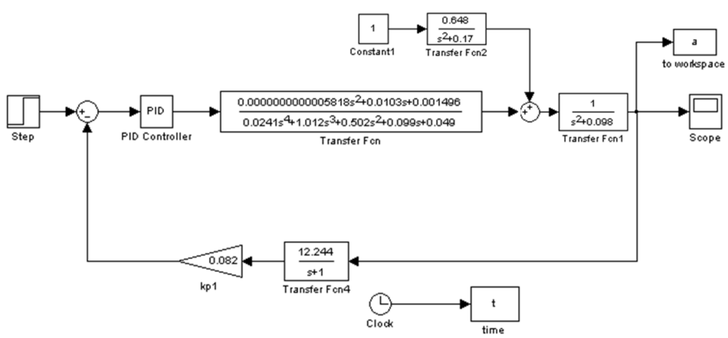

Figure. 8. Auto Tuning PID Compensator

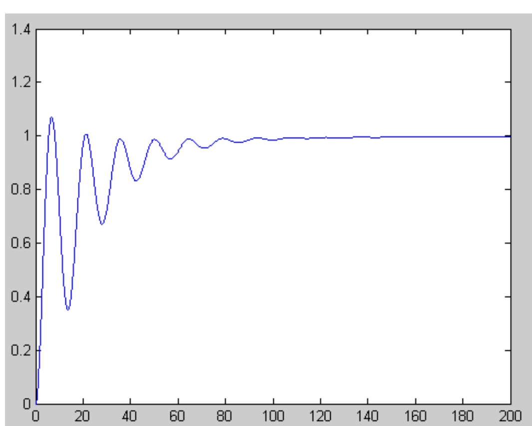

Figure. 9. Response System with Auto Tuning PID Compensator

In Figure 9 the transiet response graph, it can be seen that the ship begins to fight the slope of the ship at t = 6.7 seconds. The abscissa axis for the slope of the vessel (but the numbers do not reflect the actual angular value because it is searched in the domain (s) and horizontal for time (sec.) In the figure above the graph goes from zero to point 1 (close to point 1). Zero is the point where the ship is sloped but does not reflect how big the angle of the slope is then responded by the system so that the ship will return to a stable condition that is point 1 which is the point of balance of the ship, slowly with a certain time.

B. Ballast System Design based PLC

Simulation is needed to visualize the program. The program was built based on the theory and the formula to get the output value. From this simulation can be known the behavior and characteristic movement of the object which is appropriate with the input parameter. The result of simulation not only can be used to analysis system but also capable to prediction the next condition will be held.

Tests on the installation model of the ship's stability control system are focused on the control components including centrifugal pumps, solenoid valve, and piping installations. For testing on the pump and piping installation is done by looking at the performance, the solenoid valve generated with the parameters according to the specifications.

Based on the fact above, simulation is appropriate choice to get the solution about the automation ballast system. From visualization of the object can be analysis the condition of the ship based on the input parameter with variation on scenario draft. Input parameter which used on the simulation is draft of the ship. Draft is represented the value which read by the trim heeling meter. Trim heeling meter installed on the bow, stern and also on the midship section on starboard and portside. Below are mentioned the component which is support the simulation.

The fluid displacement system will automatically work if the sensor (a limit switch) that exists in the A tank is suppressed due to the addition of fluid, in figure 6.a. When the sensor is suppressed in this case the sensor acting as the input of the PLC will instruct the PLC to provide the output response in the form of opening the solenoid valve Va, V1, V2, Vb. This has been adjusted to the pre-inserted program into the PLC memory (in this case the fluid displacement from tank A to tank B). After the solenoid valve is open, the next command step corresponds to the program that has been made is to run the pump to move the fluid. In the program that has been made given time delay of 3 seconds between open valve condition with pump work. The fluid displacement system will die if the limit switch sensors available in tank B are depressed due to the addition of the A tank. When the sensor is pressed, the next command is to turn off the pump and close the solenoid valve that was opened. The sensors in the B tank are depressed if the water level in both tanks is the same.

The manual fluid transfer system is shown in figure 6.b. The intended manual in this case is no use of the sensor on the tank that becomes the input for the PLC. Caused on tank 1 and tank 3 not installed solenoid valve but manual globe valve. The experiment is to move the fluid from tank B to tank A. To provide input on PLC manual switch is used. Solenoid valve V3 and V4 will open if the manual switch is pressed then the next process, PLC will give instructions to turn on the pump. The fluid will move from tank B to tank A. When manually visually the water level of the two tanks is equal. The manual switch to stop the displacement is suppressed, so the PLC will respond to shut down the pump and close the solenoid valve

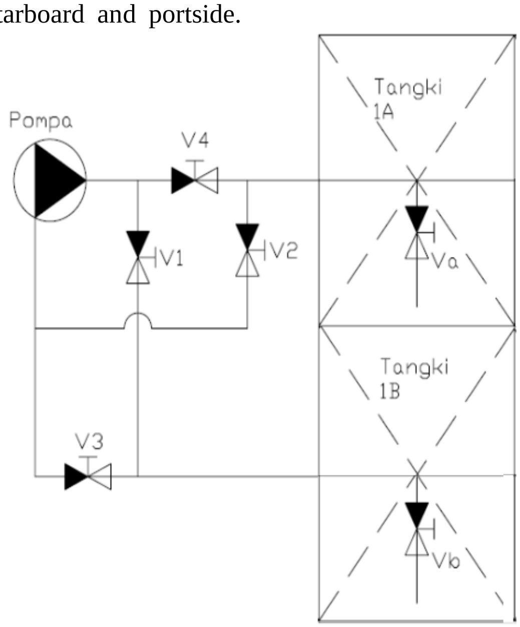

Figure. 10. Instalation Model with Selenoid Valve

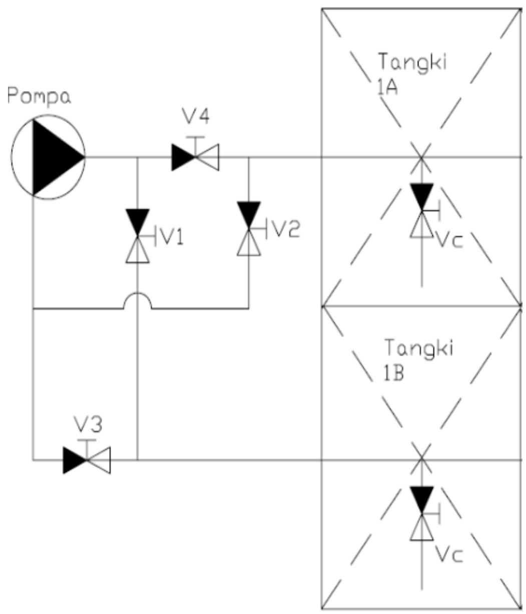

Figure. 11. Instalation Model with Manual Valve

IV. Conclusion

Overall the ballast control system on the catamaran boat is stable, which is shown in the graph of the transient response of the system. The ballast system equipment starts working against the ship's tilt at 6.7 seconds at a certain angle, and will continue to work as long as the ship is maneuvering. Judging from the time response system 6.7 seconds, then the comfort on the passengers are not disturbed (the system response is not too fast). By knowing the stability of the system, the empty tank on this ship can be made automatic ballast control so more efficient in the utilization of empty space on the ship.

From the test results can be seen that the control has been able to run well in accordance with the expected operation. PLC has been able to control the plant well in accordance with the operational fluid movement between tanks is expected. In addition to taking into account the recorded response time, PLC is able to give a quick reaction when the ship is in trim conditions. So, the stability of the ship can be well maintained. In Instalation model with manual valve is required more time than model with selenoid. Because the operator is still needed in the control process. Although PLC can run well.

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