Chapter 7
Rudder Stock Vibration in Different Materials on Boat Hulls

Md Redzuan Zoolfakar, Nur Ashikin Ayub, and Shareen Adlina Shamsuddin

Abstract Vibration is known as one of the energy losses experienced by a ship propulsion system. Excessive vibration might occur resulting in the negative effect to the system leading responsible bodies such as the International Maritime Organization (IMO) have set a certain guidelines and requirements in reducing vibration. The rudder stock is one of the mechanisms that experiences vibration due to the energy loss in the propulsion system. This paper will discuss on the vibration level generated by the rudder stock in different materials on the boat hull. There are some parameters that have been taken into account in this research such as speed of motor, size of propeller, rudder stock position from the center of the propeller, and the 30° angle of turn for both port and starboard side. Different parameters should generate different vibration effects that will be transmitted to the rudder stock.

Keywords Vibration · Rudder stock · Hull vibration · Propeller excitation · Energy loss

7.1 Introduction

A ship propulsion system can be defined as the mechanism or system used to drive a ship or boat across the open water [1]. The ship propulsion system may be electric or mechanical. A mechanical propulsion system involves the use of a diesel engine to drive the propelling shaft of the ship, whereas an electrical propulsion is a system consisting of a prime mover such as a steam turbine, diesel engine, etc., and a generator, electrical motor, and related equipment such as measuring instruments, converters that are used to drive the system [2]. The entire energy provided by the

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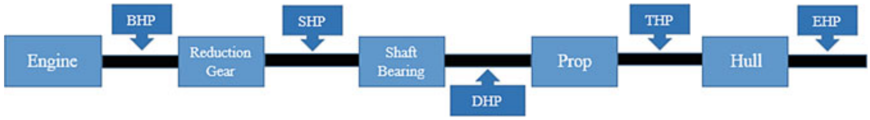

Fig. 7.1 Simplified diagram of a ship's drive train

main engine is essentially transferred to a simple rotary movement of the mechanical mechanism of the propeller shafting in an ideal propulsion system [3].

According to [4], a drive train of a ship propulsion system consists of five main components: (1) BHP-brake horsepower, (2) SHP- shaft horsepower, (3) DHP- delivered horsepower, (4) THP- thrust horsepower, and (5) EHP-effective horsepower. Figure 7.1 shows a simplified diagram of a ship's drive train. The biggest energy losses in the ship propulsion system are the thermodynamic and mechanical engine losses. These cause the loss of approximately 60 percent of the fuel energy before it becomes rotational power at the engine output or the brake horsepower [4]. As a result, additional motions, such as longitudinal, transverse, and/or torsional vibrations, are produced in response to the propeller shafting simple rotational motion. These extra motions are inefficient from the perspective of energy transfer and delivery in the whole propulsion system. These motions are responsible for the dissipation of kinetic energy in rotational motion as well as the deposition of internal energy in structural materials. Fatigue loss occurs as these energies reach critical limits, and the mechanism is characterized by residual energy processes of thermal and vibroacoustic nature [3].

Naval architects and marine engineers have long been fascinated by vibration because of its negative impact on passenger and crew comfort as well as the ship's structure [5]. Hull vibration, transmitted in the form of structural noise in all ship spaces, is induced by the action of the machinery and equipment, but the propeller is usually the main source of vibration [6, 7]. The rotation of the propeller induces differential pressure in the surrounding water, which are conveyed as hydroacoustic waves to the hull plating above the propeller and excites it [7]. Excessive vibrations can contribute to fatigue damage to the vessel's structure and mechanism sections or failure of the onboard machinery [8].

The concern about the complication between the hull and the propulsion system and the transmission of vibration via couplings and bearings are seen as something serious [9]. However, the propeller operation transmitted the vibration to the hull structure of the vessel in two different ways (1) the vibration is transferred or distributed to the hull through the shaft line and the bearing (thrust and journal bearing) and (2) the vibration oscillation is transferred directly to the hull by the water or through the vibration of the rudder stock [10].

The vibration level generates by the different rudder stock materials is observed, and the results will be measured and compare based on the parameters used in the experiment.

7.2 Methodology

Generally, the study required the researcher to develop an experimental rig to run the experiment. This rig is important to help the researcher to collect data from the testing before analyzing it. A sensitive analysis method is used in the tabulation of the data in this project. The methodology used for this study is arranged accordingly so that it can produce a result within the time given. It also defines the project's series flow and the design proposed to achieve the desired outcome. It contains a flow chart that shows the data collection procedure from project parameters as well as data analysis processes. The flowchart in Fig. 7.2 indicates all the stages that need to be done by the researcher to obtain the results that are parallel with the aim and objectives of the project.

The experiment is conducted by following all the procedures starting from the experiment planning, project implementation, and the data collection process. The data will be recorded by adhering to all the variables and translated into a graph form for analysis purposes.

7.2.1 Experimental Planning

Experimental planning in this project shows all the parameters that need to be measured leading to the development of the experiment. This includes all the details of the parameters and the materials and equipment required in the project. With this experiment planning, the researcher will get a clear picture of how to conduct the experiment.

There are mainly five parameters which have been considered to conduct this experiment. First, the experiment in this project will be conducted by using three different types of rudder stock. The materials selected for the rudder stock are stainless steel, aluminum, and carbon composite.

Second, different diameters of the 3-blade propeller will be used in this experiment. An even increase of diameter from 40, 44, and 48 mm will be used. The aim of using the different diameters of propeller is to observe the different vibrations induced from the trust produced by the propeller toward the rudder stock.

Third, the experiment will be carried out by running the motor at three different revolutions which are 900, 1200, and 1500 rpm. The next variable is regarding to the position of the rudder stock. The vibration of the rudder stock will be measured at different locations. The location is calculated by the percentage of the propeller diameter (%Dp). The location will be set at 59% Dp, 65% Dp, and 71% Dp.

Lastly, the vibration of the rudder stock will be measured at different turning angles. The angle will be measured from 0°, 10°, 20°, and 30° for both port and starboard side.

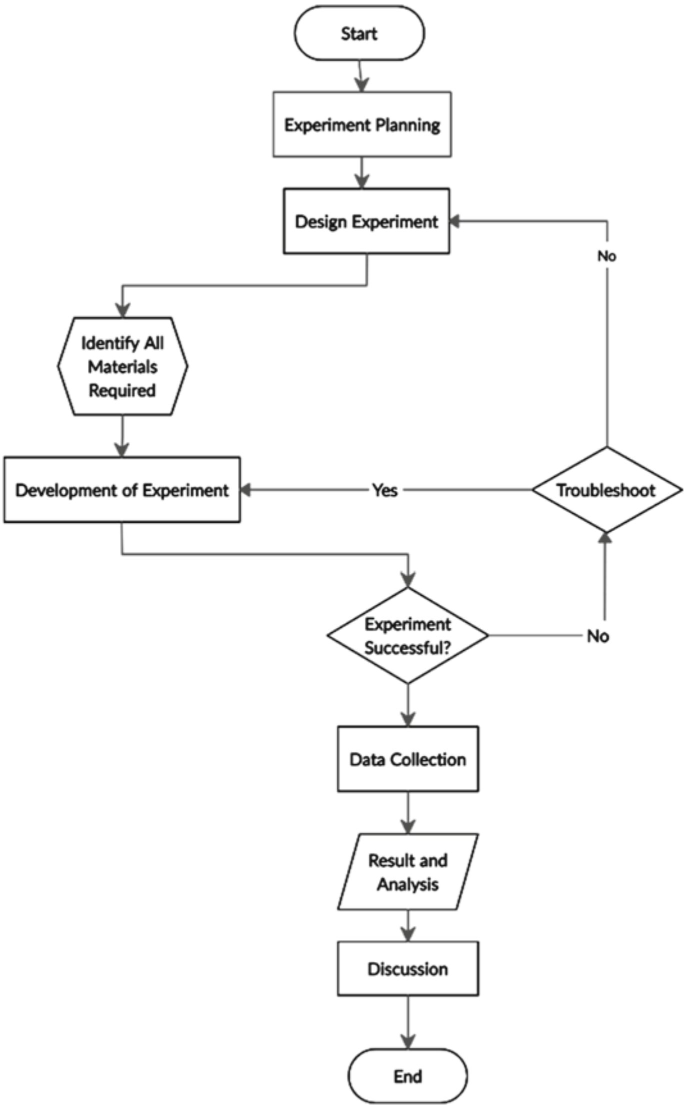

Fig. 7.2 Flowchart of experiment

7.2.2 Development of the Experiment

The flowchart in Fig. 7.3 is important to ensure that the flow of the research is correct, and the experiment can be carried out according to the schedule. The development of the experiment is carried out after all the materials and the equipment required is identified.

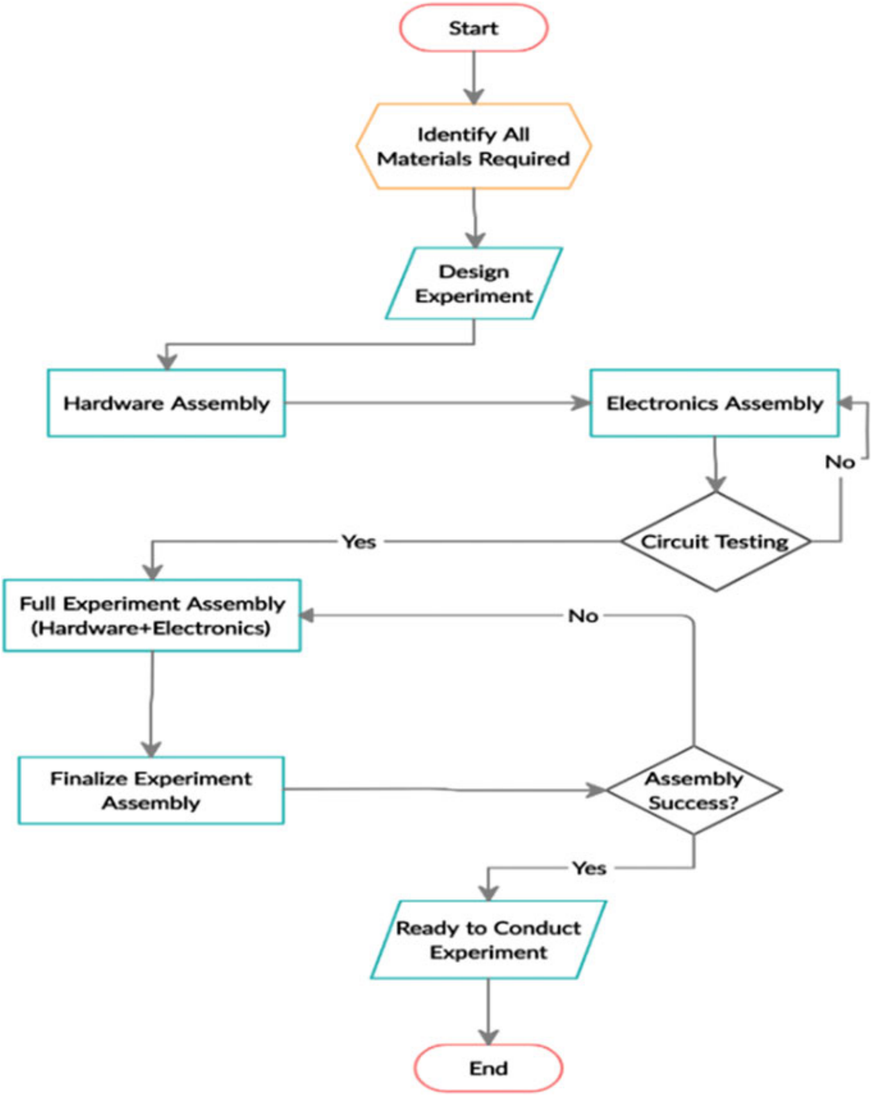

Fig. 7.3 Development of experiment flowchart

Hardware assembly is the first part in the development of the experiment. Figure 7.4 shows the design of the experiment. During construction of the rig, a rubber sheet is used as the shock or vibration absorber between the plate and the tank to absorb excessive vibration when running the experiment. Bolts and nuts are also used to secure and tightened the plate with the tank top.

The shaft is mounted on a wooden stand in horizontal position as shown in Fig. 7.5. The end of the shaft is connected with a shaft connectors where the connector are

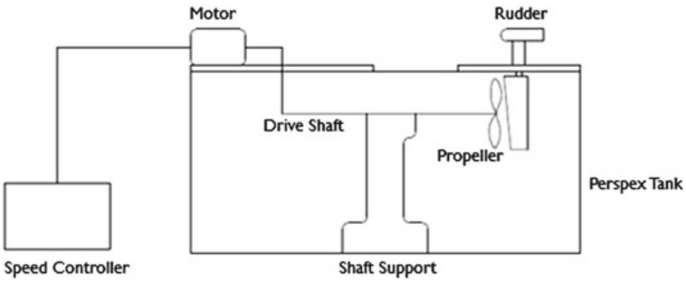

Fig. 7.4 Design of experiment

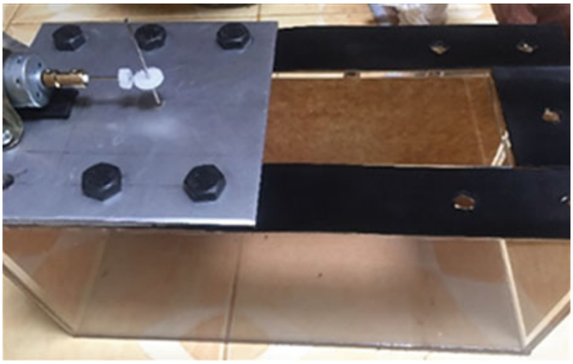

Fig. 7.5 Installation of rubber sheet, bolts, and nuts on the experiment rig

used to connect different diameters of shaft rod. The gear connector is used at the shaft rod to connect the gear shaft with the vertical shaft rod. Figure 7.6 shows that after all the process, motor and rudder will be installed to the plate. A bracket is used to secure the motor on the flat from moving. A rubber sheet also placed between the DC motor and the plate to avoid excessive vibration.

On the electronic part of the experiment rig, an Arduino board acts as a micro-controller, along with other components such as a diode, capacitor, resistor, and

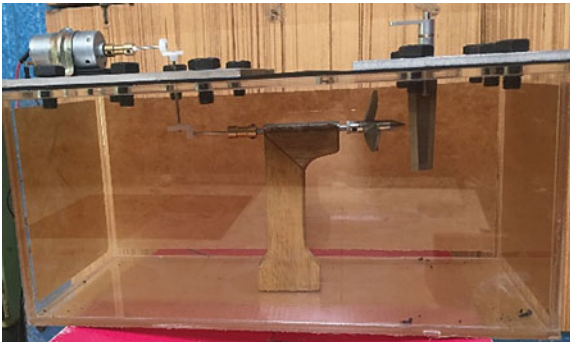

Fig. 7.6 Installation of motor, propeller, and rudder

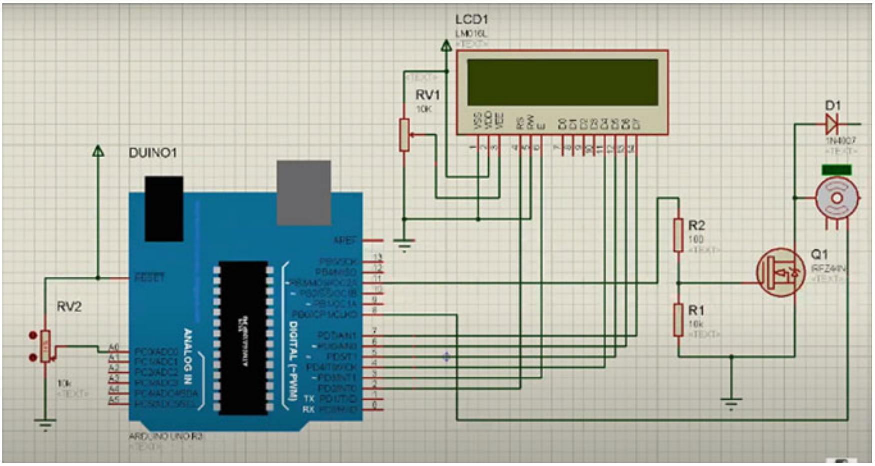

Fig. 7.7 Schematic diagram for speed controller

connecting cable, which are connected on a solderless bread board. This experiment employs a 12 V DC motor and a 9 V rechargeable battery to power the electronic module. The LCD panel is used to display the desired rpm value set on the microcontroller. The electronic connection is carried out by following the schematic diagram in Fig. 7.7. Finally, testing on the speed controller is conducted to ensure that the controller is correctly connected and functioning to run the experiment.

7.2.3 Method to Collect Data

A sensitive analysis method will be used for the data collection process of the experiment. The data recorded throughout the experiment will be tabulated by referring to Table 7.1. The data will be recorded by following to all the variables and transformed into a graph form for analysis purpose.

7.3 Results and Discussion

The results obtained will be discussed according to the parameters that have been set from the beginning of the research. The data will all be recorded by using the sensitive analysis method in Table 7.2 and transformed into the graph form. The aim of using this method is to get clearer information related to the results that have been obtained. The graphs in Figs. 7.8, 7.9, 7.10, 7.11 and 7.12 show the results of the experiment.

Table 7.1 Tabulation of data

No.	Types of RS Materials	RPM	Diameter (mm)	Position of Rudder Stock (% Dp)	Angle of Turn (°)	Vibration level (m/sˆ2)
1	Carbon composite	900	40	59	P,0	
2	Carbon composite	900	40	59	P,10	
3	Carbon composite	900	40	59	P,20	
4	Carbon composite	900	40	59	P,30	
5	Carbon composite	900	40	59	S,0	
6	Carbon composite	900	40	59	S,10	
7	Carbon composite	900	40	59	S,20	
8	Carbon composite	900	40	59	S,30	
9	Carbon composite	900	40	65	P,0	
10	Carbon composite	900	40	65	P,10	
11	Carbon composite	900	40	65	P,20	
12	Carbon composite	900	40	65	P,30	
13	Carbon composite	900	40	65	S,0	
14	Carbon composite	900	40	65	S,10	
15	Carbon composite	900	40	65	S,20	
16	Carbon composite	900	40	65	S,30	
17	Carbon composite	900	40	71	P,0	
18	Carbon composite	900	40	71	P,10	
19	Carbon composite	900	40	71	P,20	
20	Carbon composite	900	40	71	P,30	

(continued)

Table 7.1 (continued)

No.	Types of RS Materials	RPM	Diameter (mm)	Position of Rudder Stock (% Dp)	Angle of Turn (°)	Vibration level (m/s^2)
21	Carbon composite	900	40	71	S,0	
22	Carbon composite	900	40	71	S,10	
23	Carbon composite	900	40	71	S,20	
24	Carbon composite	900	40	71	S,30	
25	Carbon composite	900	44	59	P,0	
26	Carbon composite	900	44	59	P,10	
648	Stainless steel	1500	48	71	S,30	

The vibration level is measured in units of acceleration (m/s^2) because acceleration is commonly used as a method of treating objects rotating at high speeds and is considered a useful parameter for measuring the probability of dynamic fracturing. As for the negative value on the graph, it is used as the indication of the angle of turn for the port side of the propeller.

Based on Fig. 7.8, the graph shows that the vibration level generated by the rudder stock increased because as the rpm of the motor increased, the faster the rotation of the propeller. The rotation of the propeller induced differential pressure in the surrounding water which contributed to the vibration of the rudder stock. The faster rotation of the propeller creates higher differential pressure in the surrounding water. The graph also shows that the vibration level of the rudder stock increased gradually when the angle of turn of the rudder blade increased. When the rudder blade is turned, one side of the rudder blade has higher tendency to be exposed to the water pressure that is created by the rotation of the propeller than the other side.

Figure 7.9 shows that the vibration level of the carbon composite rudder stock is higher when the rudder stock is placed to the nearest position from the propeller. There is no vibration detected when the distance of the rudder stock to the propeller is 71% of the propeller diameter while the vibration starting to present when the distance is 59% of the diameter. This is due to the direct influence of the water pressure created by the rotation of the propeller that reaches the rudder plate increased when the rudder location is approaching the propeller. As it had been stated earlier in this chapter, the graph shows that the vibration level is slightly different where the port side is higher than the starboard side. The difference appears because the type of propeller used in this experiment is a positive displacement propeller where the rotation takes place in a clockwise direction. Thus, this rotation causes higher water pressure created on the port side of the propeller.

Table 7.2 Tabulation of result

No.	Types of RS Materials	RPM	Diameter (mm)	Position of Rudder Stock (% Dp)	Angle of Turn (°)	Vibration level (m/s^2)
1	Carbon composite	900	40	59	P,0	0.3
2	Carbon composite	900	40	59	P,10	0.5
3	Carbon composite	900	40	59	P,20	0.7
4	Carbon composite	900	40	59	P,30	0.9
5	Carbon composite	900	40	59	S,0	0.3
6	Carbon composite	900	40	59	S,10	0.4
7	Carbon composite	900	40	59	S,20	0.5
8	Carbon composite	900	40	59	S,30	0.7
9	Carbon composite	900	40	65	P,0	0.2
10	Carbon composite	900	40	65	P,10	0.4
11	Carbon composite	900	40	65	P,20	0.5
12	Carbon composite	900	40	65	P,30	0.7
13	Carbon composite	900	40	65	S,0	0.2
14	Carbon composite	900	40	65	S,10	0.3
15	Carbon composite	900	40	65	S,20	0.4
16	Carbon composite	900	40	65	S,30	0.6
17	Carbon composite	900	40	71	P,0	0
18	Carbon composite	900	40	71	P,10	0.2
19	Carbon composite	900	40	71	P,20	0.3
20	Carbon composite	900	40	71	P,30	0.5

(continued)

Table 7.2 (continued)

No.	Types of RS Materials	RPM	Diameter (mm)	Position of Rudder Stock (% Dp)	Angle of Turn (°)	Vibration level (m/s^2)
21	Carbon composite	900	40	71	S,0	0
22	Carbon composite	900	40	71	S,10	0.1
23	Carbon composite	900	40	71	S,20	0.2
24	Carbon composite	900	40	71	S,30	0.4
25	Carbon composite	900	44	59	P,0	0.5
26	Carbon composite	900	44	59	P,10	0.7
648	Stainless steel	1500	48	71	S,30	0.5

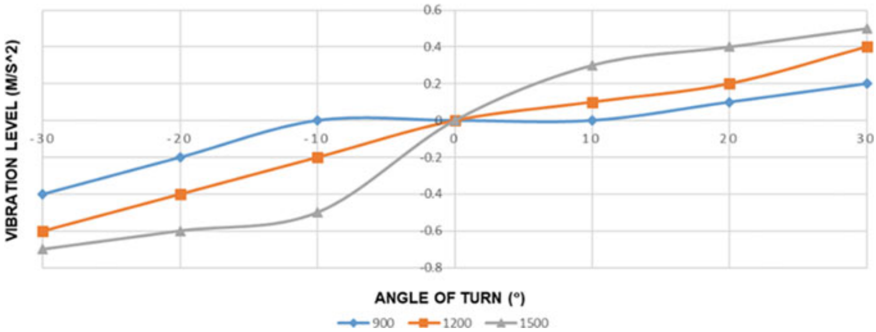

Fig. 7.8 Rpm of motor vs the angle of turn of the rudder blade for stainless steel rudder stock with 48 mm of propeller diameter at 71% of rudder stock position of the propeller diameter

Referring to Fig. 7.10, the graph shows that when the rpm of the motor increases, the vibration level produced by the rudder stock increases. As mentioned in Fig. 7.8, the vibration level generated by the rudder stock increased because as the rpm of the motor increases, the faster the rotation of the propeller. The faster rotation of the propeller creates the higher differential pressure in the surrounding water. As for the angle of turn, the vibration level produced by the rudder stock increases when the angle of turn increases. This is because the higher the angle of turn causes a bigger surface area of the rudder blade to be exposed to the water pressure produced by the rotation of the propeller. However, as mentioned in Fig. 7.9, the vibration level generates on the port side is slightly higher than the starboard side because the propeller used in this experiment is a positive displacement propeller where the rotation takes place in a clockwise direction.

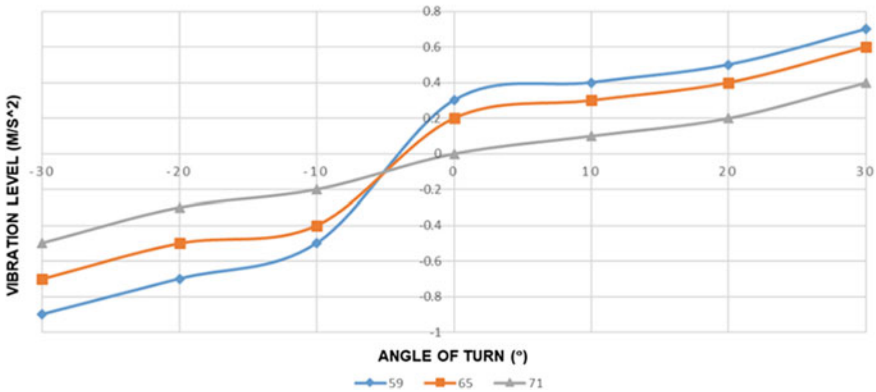

Fig. 7.9 Rudder stock position at different percentage of propeller diameter versus the angle of turn of the rudder blade for carbon composite rudder stock at 900 rpm with 40 mm of propeller diameter

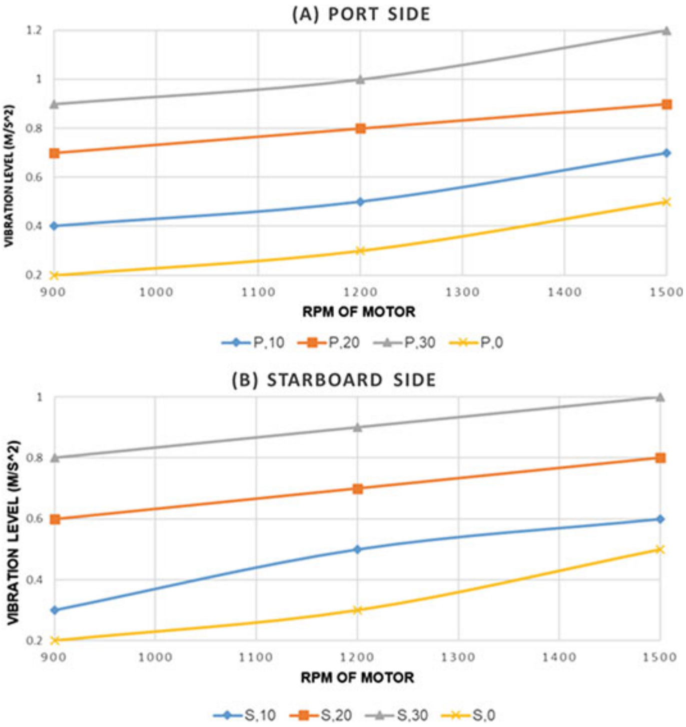

Fig. 7.10 Angle of turn versus rpm of motor for aluminum rudder stock positioned at 59% of propeller diameter with 44 mm propeller diameter at both **a** Port side and **b** Starboard side of propeller

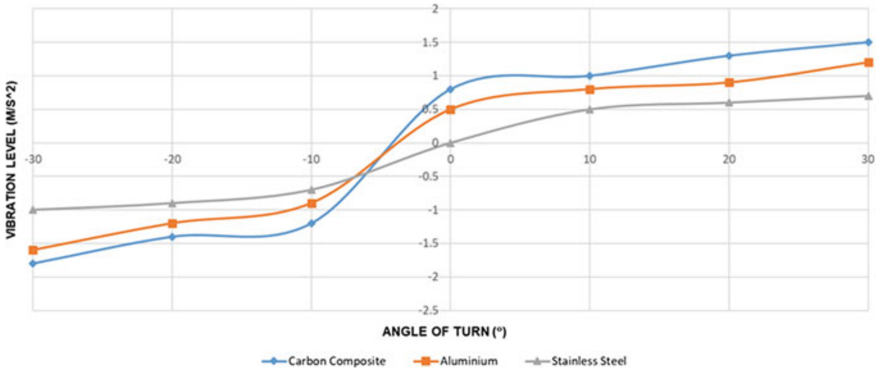

Fig. 7.11 Types of rudder stock materials versus the angle of turn of the rudder blade for rudder stock positioned at 65% of 48 mm propeller diameter at 1500 rpm of motor

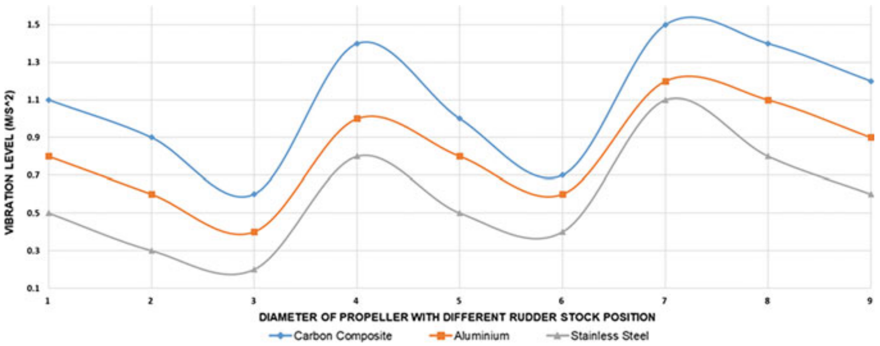

Fig. 7.12 Types of rudder stock material vs diameter of propeller with different rudder stock position at 1200 rpm measured at 30° angle of turn on port side of propeller

Based on Fig. 7.11, the graph shows that stainless steel rudder stock generates the least vibration level compared to carbon composite and aluminum rudder stock. This is because the properties of the stainless steel make it comparatively powerful than the other rudder stock materials. Comparing the vibration level generated by the rudder stocks at different angles of turn, the stainless steel rudder stock generates no vibration when the rudder is at 0° while carbon composite generates the highest. However, the vibration started to increase as the angle of turn increases. As mentioned in Fig. 7.10, this is because when the rudder blade is turned, a higher angle of turn causes a bigger the surface area of the rudder blade to be exposed to the water pressure produced by the rotation of the propeller.

Figure 7.12 shows that an increase in the diameter of the propeller causes the increase in the vibration level generated by the rudder stock. The details representing the diameter of the propeller with different percentage of rudder stock position on the graph are listed in Table 7.3. Here, the best rudder stock materials with the least

Table 7.3 Details of the diameter of propeller with different percentage of rudder stock position for Fig. 7.12

No.	Diameter (mm)	Position of Rudder Stock (%Dp)
1		59
2	40	65
3		71
4		59
5	44	65
6		71
7		59
8	48	65
9		71

vibration effect are the stainless steel rudder stock, while the highest is the carbon composite stock. As mentioned in Fig. 7.11, this is due the properties of the stainless steel, which makes it comparatively powerful than the other rudder stock materials. The characteristic of the carbon composite stock where it is lower in weight tends to vibrate more than stainless steel and aluminum stock. Comparing the vibration level produced by the stock with the diameter of the propeller at different percentage of stock position, the graph shows that the bigger the diameter of propeller, the higher the vibration level. Bigger diameter of propeller generated higher surrounding water pressure. However, the vibration decreased as the rudder location is away from the propeller because the hydroacoustic waves produced by the propeller decrease as they move away from the propeller. All types of rudder stock generate their highest vibration level at variable number 7 where the propeller diameter is 48 mm, and the stock is place 59% of the diameter.

7.4 Conclusion

This paper presented an experiment of rudder stock vibration in different materials on boat hull. Three different types of rudder stock material were used in the experiment. The rudder stock had the same diameter and blade area. Particularly, the vibration level generated by different rudder stock materials at different parameters has been studied.

During the experiment, the rudder stock was placed at three different locations in the distance from the center of the propeller equal to 59, 65, and 71% of the diameter of the propeller. The vibration level for all types of rudder stock material increases as the distance of the rudder stock is approaching the propeller.

As for rpm of the motor, the result shows that the increase in rpm of motor causes the increase in the vibration level generated by the rudder stock. The faster rotation of the propeller creates the higher differential pressure in the surrounding water.

A big difference of the rudder stock vibration can be observed when the diameter of propeller used in the experiment increases. Bigger diameter of propeller creates bigger water pressure that is transmitted to the rudder blade that generated vibration on the stock.

The experiment is conducted at different angles of turn for both port and starboard side of the propeller. As the angle of turn is gradually increased, the increase of vibration level is observed. This is because the higher angle of turn causes a bigger surface area of the rudder blade to be exposed to the water pressure produce by the rotation of the propeller.

Based on all the parameters, all types of rudder stock vibration experience different vibration levels as the parameters are changed. However, during the experiment, stainless steel stock generated the least vibration level compared to aluminum and carbon composite stock while carbon composite stock has the highest tendency to experience vibration. Here, it can be concluded that the stainless steel stock is the best rudder stock material with the least vibration effect.

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