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Optimization of Propulsion Efficiency to Reduce Fuel Consumption of a Marine Vessel

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Abstract- ***Operators can use techniques like slow steaming, hull maintenance, optimum weather routing, and cutting-edge technologies like wind-assisted propulsion systems to reduce fuel usage in ships. In addition to lowering operating expenses, these strategies assist in lowering emissions and complying with ever-tougher environmental standards. Here, we look at some of the most important tools, techniques, and factors for more environmentally friendly sailing. The aim of the research is to optimize the propulsion efficiency of a marine vessel for reduced fuel consumption. Static analysis was performed in a medium water medium at rest while a hydrostatic force was applied using either concentrated or uniformly distributed loads in order to determine pressure. As a result, the concentric pressure created over the propeller creates stress, strain, and deformation in the propeller blade, which results in vibration and lowers the safety factor of the propulsion system. A model of the propeller shaft was created using CAD. Alloy Steel material was selected, knowing the material properties, the model information was generated, which includes the weight, volume, density. A linear dynamic study analysis was performed to determine the effect of torque and vibration on the shaft, two end faces were fixed and a torque was applied across the section of the shaft. Meshing was carried out to effect check the force distribution as it is paramount in FEA. The effect of the torque and the vibration can be seen in the analysis result. As indicated in figure 3 and 4, shows that the nuclear power plant will be grossly underutilized at the cruise speed. Hence, this power plant should rarely be used during cruise period. The resistance and power graph shows a continuous rise in power and resistance with RPM with the graph peaking at 3750kW and 150kN for 250RPM respectively. The graph of P_E against R_T as in figure 5 shows that as the ship resistance increases it causes a corresponding increase in the effective power and vice versa. This shows that a proportional relationship exists between the ship resistance and the effective power with the peak values at 120kN and 2.4×10^4kW respectively. It was observed that vibration effect is higher in solid propulsion shaft when compared with the hollow propulsion shaft. With the same shaft diameter of 0.78 meters and length of 3 meters, solid propulsion shaft has a frequency of 407.02 Hz while the hollow shaft has a frequency of 248 Hertz. The amplitudes of vibration are in phase relative to the frequency. High amplitudes with a phase angle of 180° or π rad are produced by misalignment which occurs when the shaft length of two directly mating parts meet at an angle. It was concluded that solid propulsion shaft contributed about 39.06% increase in frequency as compared to the hollow propulsion shaft. Hence vibration effect is higher in solid propulsion shaft, and that about 21.72% error in the manual value of the natural frequency calculated and the value obtained from the numerical analysis, therefore it's advisable to avoid the frequency range of 318.63Hz and 407.02Hz.***

Index Terms- ***RPM, Shaft Power, Shaft Vibration, Fuel Consumption, Propeller Blade***

I. INTRODUCTION

The marine industry accepts that it can no longer be confident about the future availability, price, and environmental acceptability of the heavy fuel oils upon which it has so long relied. This situation does not provide a secure foundation for planning major capital investment in new ships, many of which would have an expected life of 20-30 years. Ship owners and operators therefore need to be prepared with more efficient ship designs and technical solutions in anticipation for higher fuel prices or emissions trading schemes adopted in the future, [1]. The relatively optimistic view taken by the International Maritime Organization forecasters of demand for the world fleet to 2020 carries with it an ongoing pressure to reduce fuel costs and the emission of greenhouse gases [2]. Shipping is already one of the most carbon-efficient forms of commercial transport: it accounted for less than 3% of the world's carbon emissions, transporting 90% of world trade. Nevertheless, pressures on its environmental performance are likely to increase. This is largely because the shipping industry's greenhouse gas emissions (about 800 million tonnes of CO_2 annually) are set to grow significantly, through the sheer growth in trade and the limited potential for improving the carbon efficiency of marine transport compared with land-based transport [3].

The conditions under which marine engines operate have a direct impact on fuel usage. Larger container ships often have a two-stroke marine engine that powers the propeller at a speed of less than 130 rpm. Additionally, all onboard power and off-loading equipment is powered by an auxiliary four-stroke marine engine. In this study, differential equations are used in conjunction with a cycle mean value model approach to model the marine engine in order to quickly calculate the engine crankshaft speed and delivered power [4].

The operating conditions of marine engines have a direct impact on fuel consumption. Larger container ships typically include a two-stroke marine engine that can run at less than 130 rpm as the main engine, providing power to the propeller. Additionally, a four-stroke marine engine serves as an auxiliary engine that powers all equipment on board or while offloading. In order to calculate the engine crankshaft speed and delivered power for the quick transient power plant performance, this study models the marine engine utilizing a cycle mean value model approach in combination with differential equations. [4].

The engine and propeller work together as a tightly connected system to control the speed of the vessel. Therefore, when assessing fuel consumption and emissions during the real voyage, it is important to consider the engine response in waves. A fixed pitch propeller system and a two-stroke marine engine were included in the model of maritime propulsion. A container ship could be operated under various engine responses along the intended trajectory when combined with a vessel voyage model. It would thus be possible to forecast how much fuel will be used under various sailing situations. It offers a fresh viewpoint for researching the best sailing routes. [5]. Tadros [6] choose the propeller with the best efficiency to operate at the engine load diagram's minimum brake specific fuel consumption (BSFC). To compare a trawler vessel's propeller performance based on fuel consumption and propeller efficiency, Tadros [6]created an optimization process to make it simple to choose the propeller's ideal properties. When the propeller is optimized at the smallest fuel consumption, as opposed to maximizing propeller efficiency or decreasing the BSFC along the engine load diagram, the calculated results demonstrate a considerable reduction in fuel consumption. Fuel efficiency may be greatly increased by properly cleaning, polishing, or even applying the right coating. Port States should acknowledge and support the necessity for ships to maintain efficiency through in-water propeller and hull cleaning. Emissions and lifecycle costs are decreased by increasing ship efficiency overall. The aim of this project is to optimize propulsion efficiency to reduce fuel consumption of a marine vessel.

Yang [7] suggested that Shipping companies work hard to increase the energy efficiency of their current ships. Such operational improvements require an accurate fuel consumption prediction model. A genetic algorithm-based gray-box model was presented to anticipate the ship's fuel consumption based on ship operation data, in addition to existing grey-box models (GBMs). A GA-based estimation approach, a performance evaluation procedure, and a ship's fuel consumption modelling procedure based on the fundamentals of the ship's propulsion make up the model creation methodology.

The authors of the research claim that compared to current models, the suggested model offers a more trustworthy relationship between the ship's fuel consumption rate and the variables influencing it. Regretfully, this model has two significant flaws: it has only been tested on a single ship and ignores the effects of propeller and hull biofouling.

Szłapczyński and Ghaemi [8] noted that a single-objective optimization approach is used almost entirely in the majority of published research on ship shipping route optimization, making it nearly impossible to successfully accomplish goals linked to economy and safety. Their approach is an attempt to create such solutions by using evolutionary multi-objective optimization to achieve three goals: reducing the likelihood of a collision, reducing the amount of fuel used for collision avoidance manoeuvres, and reducing the additional time spent on collision avoidance manoeuvres for autonomous surface ships.

Vesting and Bensow [9] outlines concept and evaluates two approaches that optimize the marine propeller from the perspective of cavitation using evolutionary algorithm techniques. The multi-objective optimization was carried out using the particle swarm optimization (PSO) algorithm. To improve four marine propeller design options for various ship types, three PSO algorithms were created and put to the test. A study of the generation medians and the Pareto front development was used to assess the results.

Lewis and Mirjalili [10] stated that ship's propeller's effective shape was attained by the use of multi-objective particle swarm optimization. As partial optimization goals, efficiency maximization and cavitation minimization were selected.

Gaggero [11] suggests a high-speed ship propeller design option. Utilizing a newly created optimization process, the required data was gathered from reduction model experiments conducted in the towing tank. The Boundary Elements Method, a viscous flow solver based on the Reynolds-Averaged Navier-Stokes Equations approximation, a parametric 3D description of the blade, and a genetic algorithm are all used in the multi-objective numerical optimization process to solve the propeller design. In order to attain high levels of energy efficiency and reduce fuel consumption and CO2 emissions, the maritime industry needs to investigate several journey optimization techniques. Studies have looked into solutions like weather-routed speed optimization and trip planning, and the findings show an overall increase in energy efficiency that lowers emissions and fuel consumption. [12]

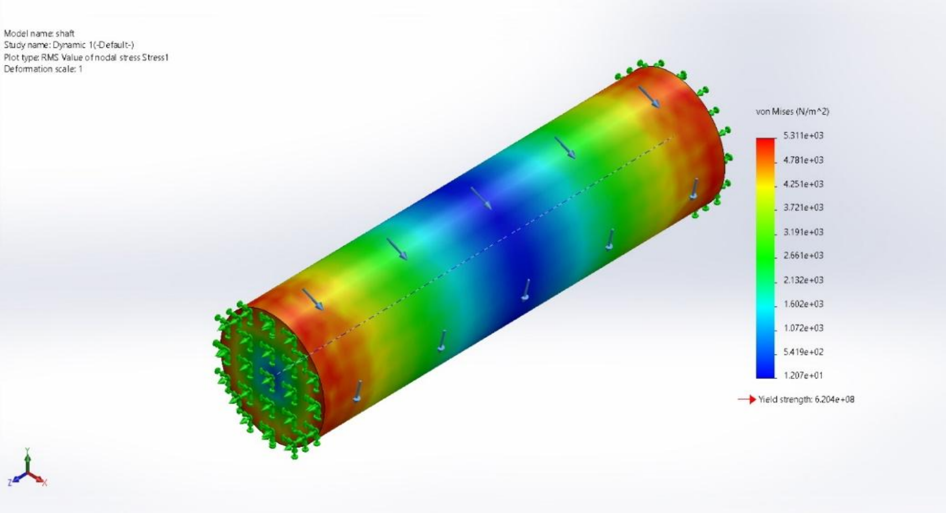
Bialystocki [13]used polynomial regression analysis to illustrate the relationships between sensor technologies, and the types and volumes of SFC data being gathered are expanding quickly. However, such unstructured data is difficult for the current SFC models to comprehend, particularly those that use on machine learning approaches. The variability and multisource nature of new fuel usage.

There are different solutions offered by the research community, such as Zhao, [14] which aims to improve the efficiency of a ship with a focus on ship navigation and performance. It involves the application of convolutional neural networks for image recognition and data compression. While in [15], energy efficiency is aimed to be achieved with the primary focus being on fuel consumption. It involves using an artificial neural network (ANN) to predict ship fuel consumption based on operational data, and then it compares the performance with multiple regression analysis.

II. MATERIALS AND METHODS

Hydrostatic Analysis using Solidworks simulation software

In order to calculate pressure, static analysis involves maintaining the water medium in its rest state while applying a hydrostatic force to it using either concentrated or uniformly dispersed loads. Consequently, the propeller blade experiences stress, strain, and deformation as a result of the concentric pressure generated over the propeller, which causes vibration and reduces the propulsion system's safety factor.



Model name: shaft
Study name: Dynamic 1(-Default-)
Plot type: RMS Value of nodal stress Stress1
Deformation scale: 1

Fig. 1: The interfaces of SolidWork Software for a Propulsion Shaft

Description of Processes

- Modeling Information: Here after creating the CAD model of the propeller shaft, Alloy Steel material was selected, knowing the material properties, the model information was generated, which includes the weight, volume, density.
- Loads and Fixtures: In creating a linear dynamic study to determine the effect of torque and vibration, two end faces were fixed and a torque was applied across the section of the shaft
- Mesh Information: Since meshing is paramount in FEA, mesh information can be found in the analysis result
- Study Result: The effect of the torque and the vibration can be seen in the analysis result.

Ship Propulsion System Model

The fuel consumption of a vessel proportionally depends on the power developed. Specific fuel consumption is the amount of fuel consumed to produce 1 Kw for 1 hour. It varies depending on the rpm of the engine but is constant over the normal service speeds of the vessel that we consider.

Improving the efficiencies of reduction gear, shaft and propeller in the propulsion system will ensure that power generated by the prime mover is transmitted for ship propulsion with minimal losses, therefore overall propulsion efficiency is improved and as a result the specific fuel consumption is reduced.

The overall efficiency of the propulsion system (η_sys) can be expressed as:

$$\eta_{sys} = \eta_{prop} \times \eta_{trans} \times \eta_{engine} \tag{1}$$

Where:

- η_{prop} = Propeller efficiency
- η_{trans} = Transmission efficiency
- η_{engine} = Engine efficiency

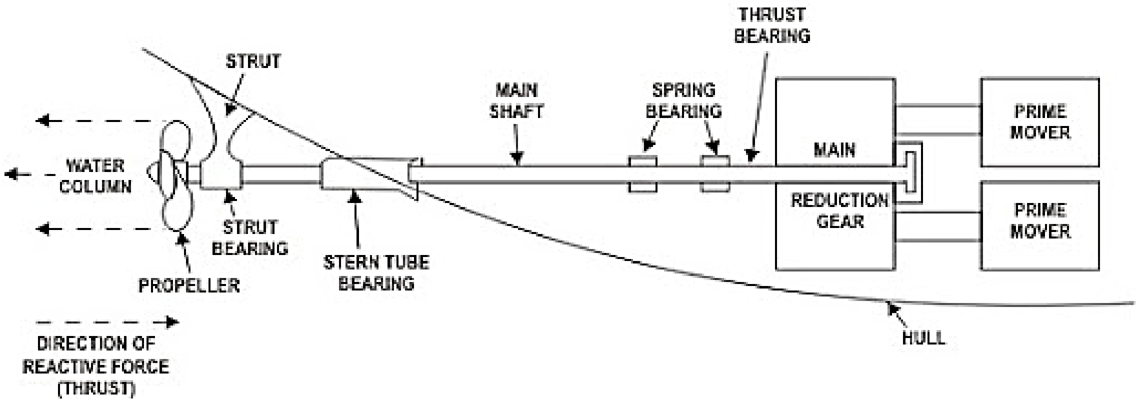


Fig. 2: Ship Propulsion System

The load condition during navigation affects the ship's engine power requirement. To determine the optimal engine power for a given load condition, the following formula is used:

$$P = R_T \times V \tag{2}$$

Shaft and Vibration Reduction

Using an appropriate shaft diameter that aligns with the required thrust is essential, this will help reduced torsional stresses and vibration. The use of vibration dampers as well as flexible couplings is key to reducing vibration and increase efficient transmission along the shaft.

Torsional vibration induces significant shaft stresses at critical speeds. Using a torsional vibration damper can reduce, alter, or entirely eliminate a restricted speed range.

The use of elastic couplings and vibration dampers will greatly reduce torsional vibration thereby optimizing the propeller efficiency, and this will enhance the overall plant efficiency of the system. A torsional vibration damper will be fitted at the free end of the engine and may be of the viscous damping type for low energy vibrations, or the spring-loaded type for high energy vibration.

However, the speed will be such that it is optimal for both the diesel engine and the propeller respectively, thus optimizing the total propulsion efficiency, for a given propeller thrust and power. The amount of power available at the engine output shaft should be determined.

$$\text{Shaft power (Kw)} = \frac{\Delta^2/\,3V^3}{Admiralty\ coefficient} \tag{3}$$

The shaft diameter, angular speed and torque are related by the following expressions;

$$P = T \times \omega \qquad (4)$$

Where,
P = effective power
T = Torque
ω = angular speed.

$$\frac{T}{J} = \frac{\tau}{R} = \frac{G\theta}{L} \qquad (5)$$

where
J = polar 2nd moment of area (m^4)
T = Torque
τ = Shear stress (N/m^2)
R = Radius of shaft
G = modulus of elasticity (N/m^2)
θ = to angle of shaft twist (Radians)
L = Length of shaft twisting (m)

From the above equation, we obtained

$$T = \frac{G\theta J}{L} \qquad (6)$$

As G,J,L are constant if the angle of twist is measured over a certain length, it follows that the torque transmitted by the shaft is directly related to the angle of twist in the shaft.

Propeller Efficiency ($\eta_{\_prop}$)

The propeller efficiency (η_{prop}) is crucial in determining the effectiveness of converting engine power into thrust. It can be calculated using the following formula:

$$\eta_{prop} = \frac{Thrust \times Ship\ Speed}{Engine\ Power} \qquad (7)$$

Where:

- *Thrust* = Thrust produced by the propeller (N)
- *Ship Speed* = Speed of the ship (m/s)
- *Engine Power* = Engine power (W)

Advanced hydrodynamic theories, real-world experience, and several model experiments conducted at different hydrodynamic institutes provide the fundamental data used in propeller design. The overall propeller efficiency, reduced noise level, and vibrations are the main design goals. Each blade is specifically made for a ship's hull and operating conditions [16].

Propeller efficiency is predominantly determined by the propeller diameter, the corresponding optimum speed, pitch and thickness and blade surface area.

In propeller design, the flow conditions around the propeller are necessary for consideration, e.g. wake coefficient (w), and thrust-deduction coefficient (t), as well as the propeller dimensions i.e. diameter, number of propeller blades, disk-area coefficient and pitch/diameter ratio of the propeller.

The power needed at normal condition will be determined using;

$$\left(\frac{P_D}{n^3}\right)_{MCR} = \left(\frac{P_D}{n^3}\right)_{SCR} \qquad (8)$$

The delivered power at the propeller can be estimated as:

$$P_D = \frac{P_E}{\eta_D} \qquad (9)$$

Where the quasi-propulsive coefficient, η_P can be taken from published data.

The shaft power Ps will be:

$$P_S = \frac{P_D}{\eta_S} \qquad (10)$$

The speed of advance V_A is obtained from V by model tests or by using approximation data.

The charts consist of colours of constant propeller efficiency η_O and of constant advance coefficient (that delta sign) plotted on a grid of Bp and pitch ratio P/D.

The value of Bp can now be estimated from the charts and the value of (delta sign) and pitch ratio can be found to give maximum efficiency, the latter being indicated on the charts, after which the actual delivered propeller efficiency is determined.

Interaction between Propeller and Main Engine

The following conditions must be met for the hull, propeller, and main engine to interact effectively:
1. The torque applied by the engine to the end of the tail shaft must match the torque required to turn the propeller.
2. The propeller's revolution count must match the engine's rpm (with a gear adjustment for medium and high-speed engines).

Taking into account the thrust deduction, the propeller's thrust must match the ship's resistance at a specific speed.

A thrust power is delivered by the propeller;

$$P_T = T \times V_A \qquad (11)$$

Where;
T = Thrust
V_A = Advance velocity

Equation (11) will be used to determine the vessel's overall resistance; in this instance, the propeller's thrust is taken from the ship's machinery data.

The ship is propelled by a machinery plant which delivers a total power P_D to the propellers. The propulsive efficiency is defined by;

$$\eta_p = \frac{P_E}{P_D} \qquad (12)$$

Where;

$P_D = k_p.P_P$

Where k_p is number of propellers and P_P is power delivered to one propeller.

This delivered power must be greater than thrust power, owing to the unavoidable losses on the propeller itself. The open water propeller efficiency relates the thrust power P_T to the propeller power P_D.

$$\eta_0 = \frac{P_T}{P_D} = \frac{1}{2\pi} \text{ x } \frac{TV_A}{Qn_p} = \frac{K_T}{K_Q} \text{ x } \frac{J}{2\pi} \qquad (13)$$

The total propulsion efficiency is usually computed neglecting the shaft moment of inertia and is given by

$$\eta_P = \eta_H \text{ x } \eta_0 \text{ x } \eta_R \text{ x } \eta_M \qquad (14)$$

Where m is the mechanical efficiency that represent losses in gear and bearings, O is the open water efficiency, R is the relative rotative efficiency dependent on the distribution of the wake velocity and H is the hull efficiency.

Propeller Characteristics

The selection of a suitable propeller is crucial for optimizing ship propulsion efficiency. The propeller's characteristics directly influence the ship's speed, engine operating point, and fuel consumption. The propeller must be matched to the vessel's engine and stern hull form to ensure optimal performance throughout the ship's life.

The choice between fixed pitch propellers (FPP) and controllable pitch propellers (CPP) depends on the vessel's operational requirements. For this study, a CPP is chosen due to its ability to adjust the blade pitch, optimizing thrust production across various load conditions. The propeller's efficiency (η) is a key factor in fuel consumption reduction, and it can be calculated using the following equation:

$$\eta = \frac{J}{Froude\ Number} \qquad (15)$$

Where;

J (Advance Coefficient) is given as;

$$J = \frac{V}{n \times D} \qquad (16)$$

- V = Ship speed (m/s)
- n = Rotational speed of propeller (rev/s)
- D= Propeller diameter (m)

The Froude Number (F_r) is calculated as:

$$F_r = \frac{V}{g \times L} \qquad (17)$$

Where:

- V = Ship speed (m/s)
- g = Acceleration due to gravity (9.81 m/s²)
- L = Waterline length of the ship (m)

The thrust coefficient;

$$K_T = \frac{T}{Pxn^2 x\ d^4} \qquad (18)$$

III. RESULTS AND DISCUSSION

From the results presented in Figure 3 and 4, it is obvious that the nuclear power plant will be grossly underutilized at the cruise speed. Hence, this power plant should rarely be used during cruise. The resistance and power graph are shown below. Such wide variation in propulsion loads justifies the naval ship configuration. Nonetheless, the matching procedure outlined in this work is valid for all marine vessels with screw propeller.

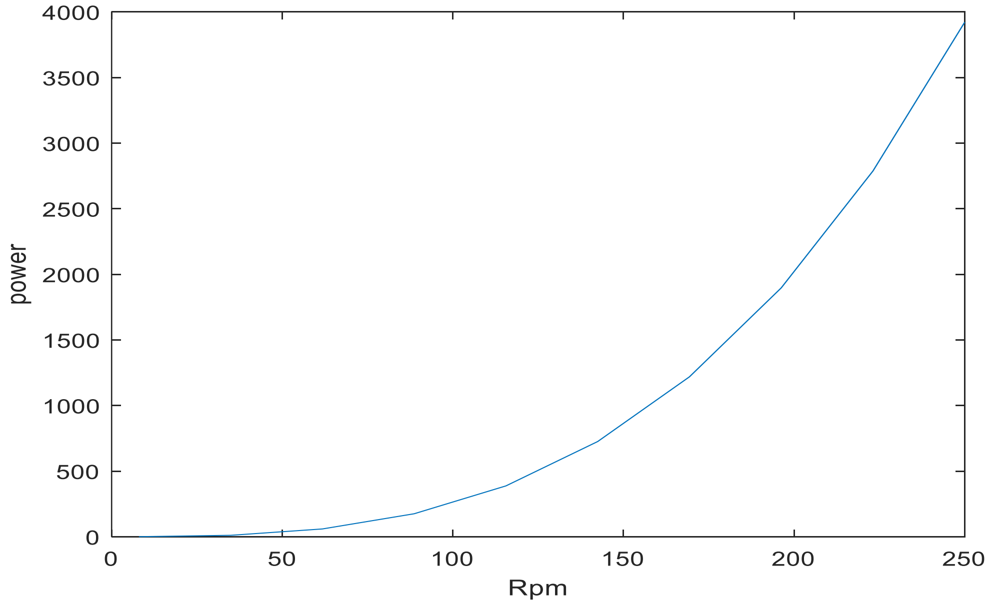


Fig. 3: Power against Speed

The graph illustrated above in figure 3 shows a corresponding relationship between effective power of the ship and the ship speed. It can ascertain that an increase in the ship speed also causes an increase in the effective power of the ship. Maximum effective power is obtained when the ship is running at a speed of 250knots.

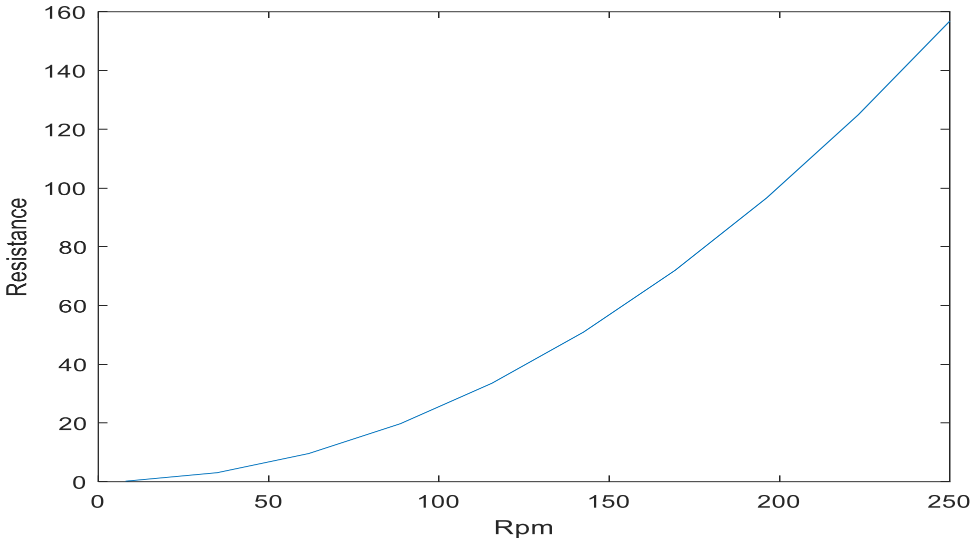


Fig. 4: Resistance against Speed

The graph in figure 4 gives the proportional relationship between the ship resistance and the ship speed. As the resistance increases the ship speed also increases. These two major parameters are used to determine the effective power of the ship.

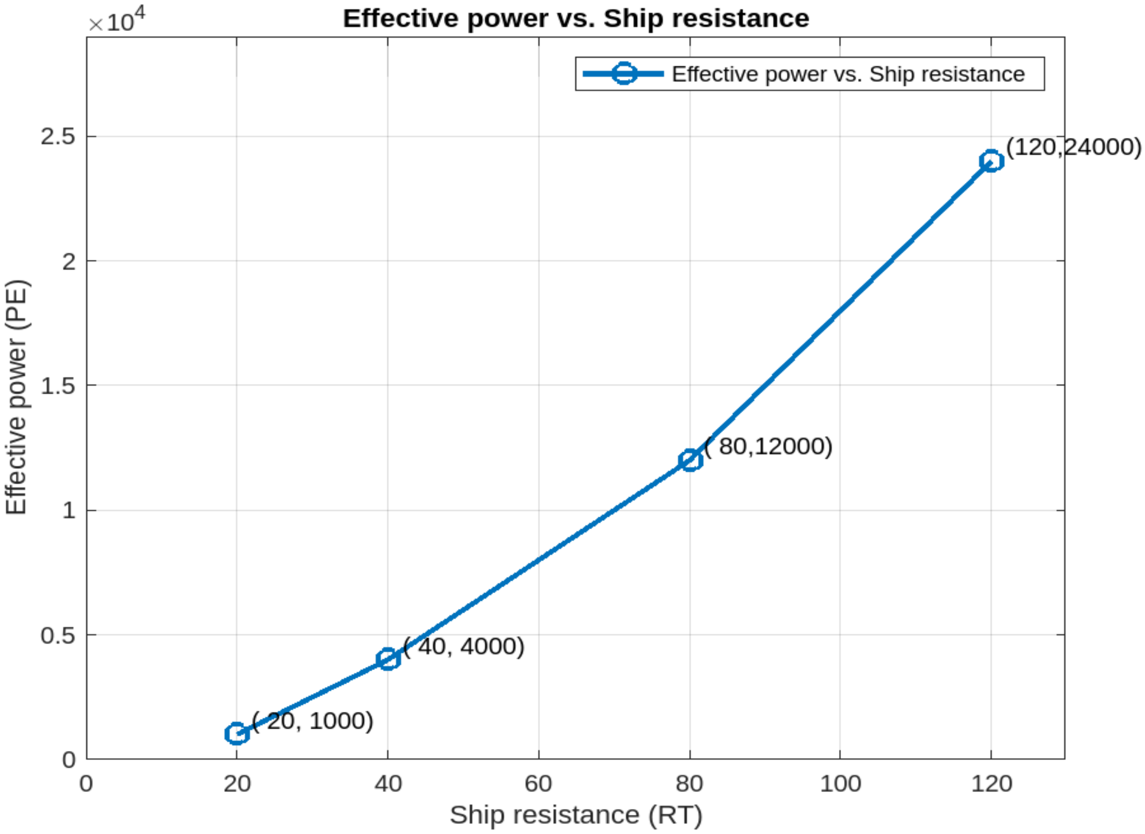


Fig. 5: Relationship between Ship Effective Power and Ship Resistance

The graph of P_E against R_T as illustrated in figure 5 above shows that as the ship resistance increases it causes a corresponding increase in the effective power and vice versa. This shows that a proportional relationship exists between the ship resistance and the effective power. Also we can deduce that an increase in the ship speed will also influence an increase in the effective power.

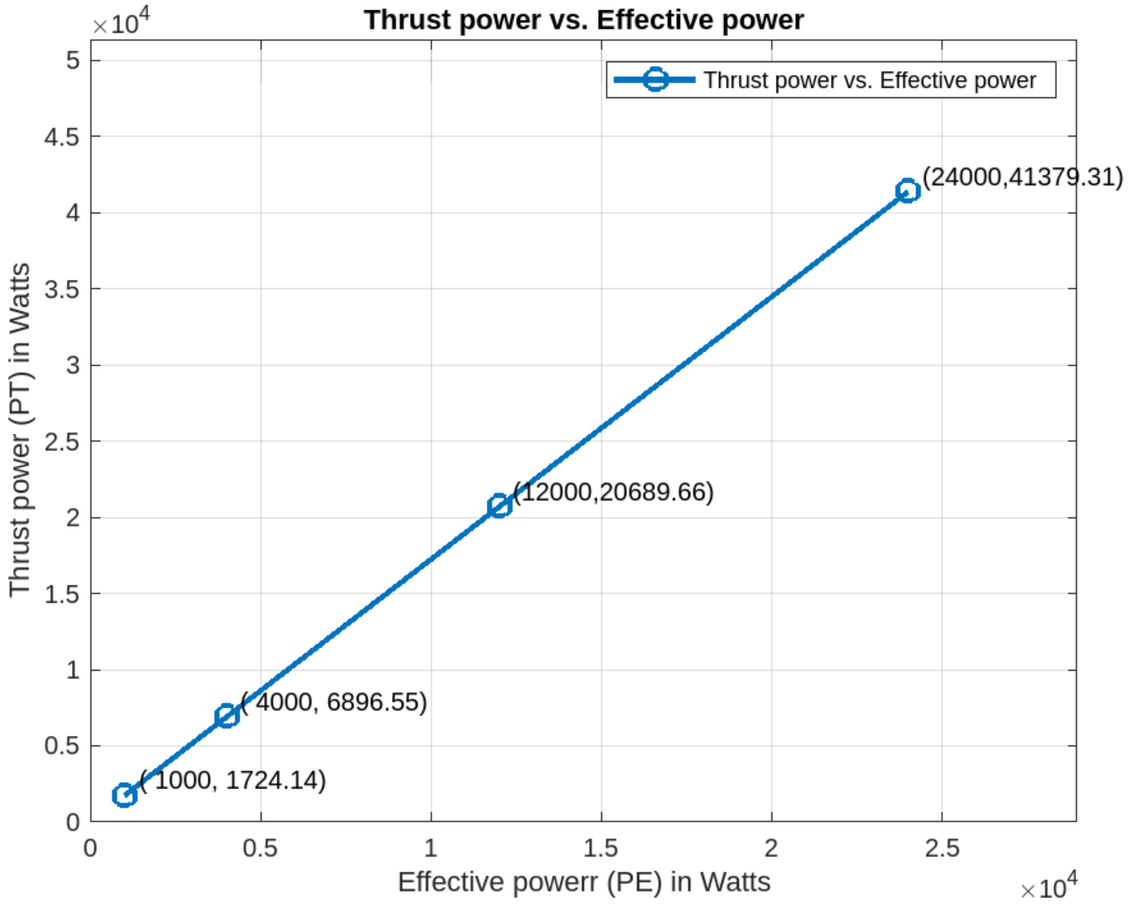


Fig. 6: Relationship between Ship Thrust Power and Effective Power

From the calculations carried above it can be observed that as the effective power increases as the Thrust Power also increases. A graph of P_T against P_E as in figure 6 above depicts a proportional relationship.

Figure 6 above suggests that there is a proportional relationship between the thrust power and the effective power.

Also, from the result of the calculation of frequency shows that vibration effect is higher in solid propulsion shaft when compared with the hollow propulsion shaft. With the same shaft diameter of 0.78 meters and length of 3 meters, solid propulsion shaft has a frequency of 407.02 Hz while the hollow shaft has a frequency of 248 Hertz. The amplitudes of vibration are in phase relative to the frequency. Misalignment, which happens when the shaft lengths of two directly mating pieces meet at an angle, produces high amplitudes with a phase angle of 180° or π rad. Additionally, at a phase angle of 0°, connections like coupling angles, thrust blocks, and engine connection flanges generate reaction forces that support vibration throughout the shaft and the complete propulsion system.

$$\% \text{ increase} = (407.02 - 248)/407.02$$
$$= 0.3906 \text{ or } 39.06\%$$

This implies that the solid propulsion shaft contributed about 39.06% increase in frequency as compared to the hollow propulsion shaft.

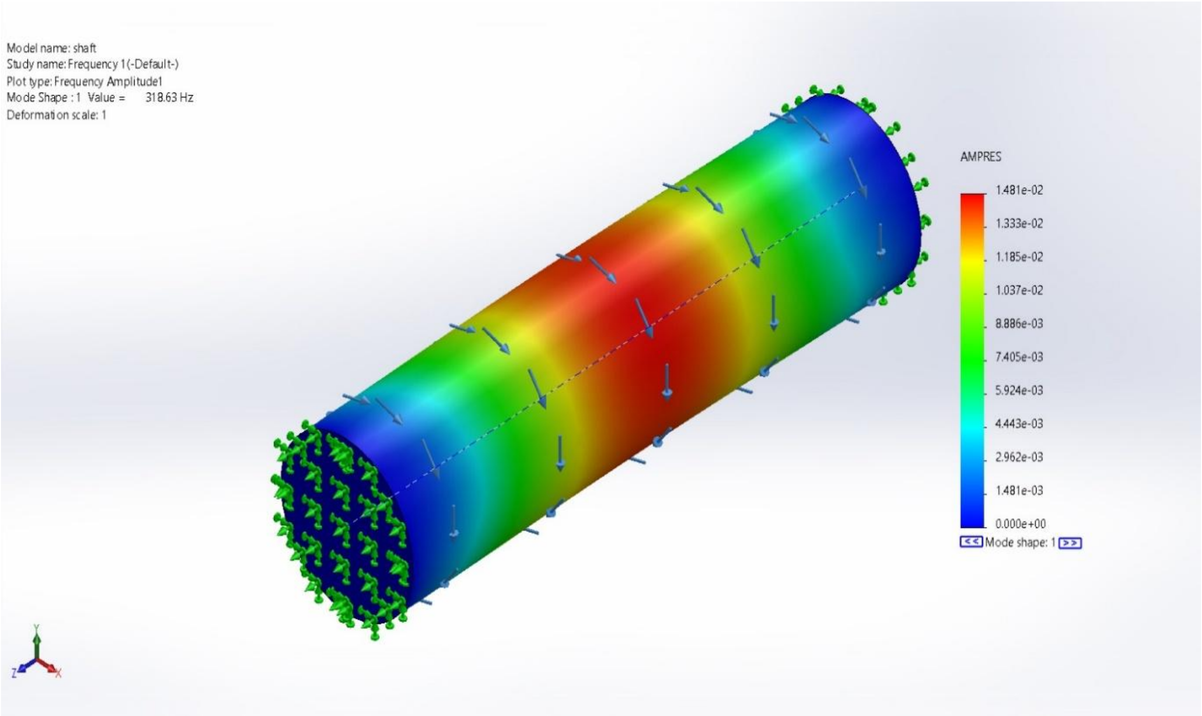


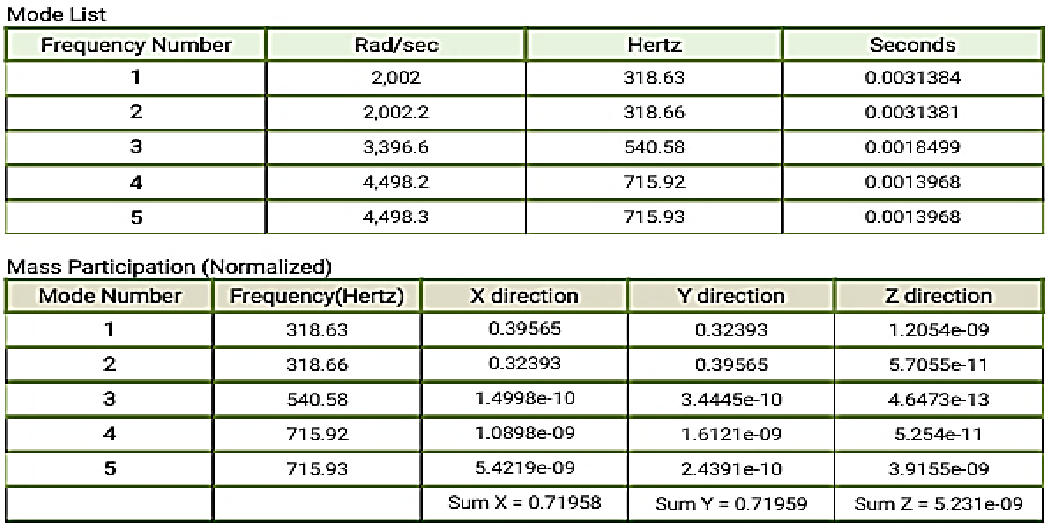
Fig. 7 Amplitude - Frequency response of shaft

However, the result derived from the numerical value of 318.63Hz differs with the manual computation of the natural frequency of 407.02Hz. For the propulsion shaft system's lifetime and seamless operation, as well as the screw's comfort. A hollow propulsion shaft is recommended and it is advisable to avoid the speed range of 318.63Hz to 407.02Hz.

% error = (407. 02 - 318.63)/407.02

= 0.2172or 21.72%

Table 1: Frequency-Displacement Response of Shaft



Mode List

Frequency Number	Rad/sec	Hertz	Seconds
1	2,002	318.63	0.0031384
2	2,002.2	318.66	0.0031381
3	3,396.6	540.58	0.0018499
4	4,498.2	715.92	0.0013968
5	4,498.3	715.93	0.0013968

Mass Participation (Normalized)

Mode Number	Frequency(Hertz)	X direction	Y direction	Z direction
1	318.63	0.39565	0.32393	1.2054e-09
2	318.66	0.32393	0.39565	5.7055e-11
3	540.58	1.4998e-10	3.4445e-10	4.6473e-13
4	715.92	1.0898e-09	1.6121e-09	5.254e-11
5	715.93	5.4219e-09	2.4391e-10	3.9155e-09
		Sum X = 0.71958	Sum Y = 0.71959	Sum Z = 5.231e-09

Table 1 displays the shaft's response to sinusoidal loads of 384.72 Nm and 202 Nm as well as exposure to a frequency range of 318.63 ≤ fn ≤ 715.93. At 540.58 Hz, the displacement quickly decreases to $1.4998 \times 10^{-10} m$ before rising to $5.4219 \times 10^{-9} m$. Due to severe vibration, these displacement variations may result in a poor alignment of the shaft's length.

In terms of vibration analysis, the strength and vibrational characteristics of the propeller blade are evaluated as discussed below. With the aid of SolidWork analysis model the various propeller blades are analysed to obtained the distribution of stresses to the propulsion shaft.

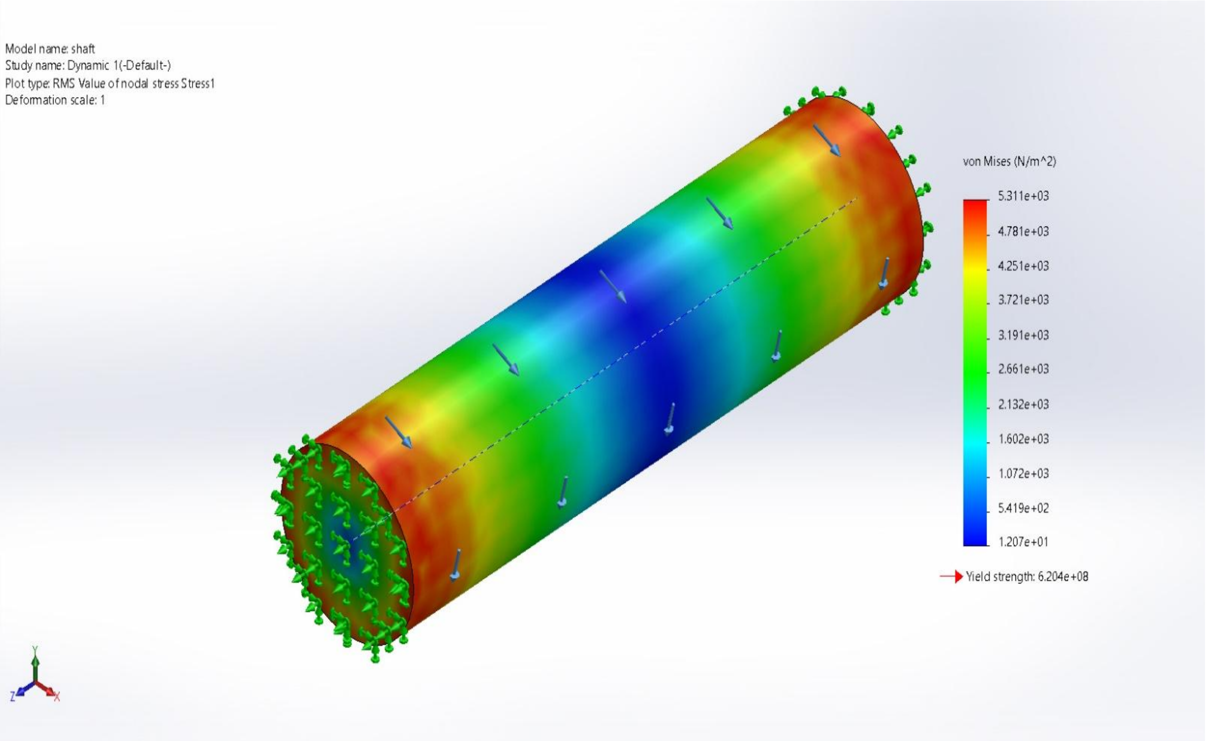


Fig. 8: The stresses on the propulsion shaft system due to vibration

From the results of the analysis from SOLIDWORKS software, it can be seen that the maximum stresses are obtained at the both end of the propulsion shaft while it reduces along the length and its minimum value is around the middle of the shaft.

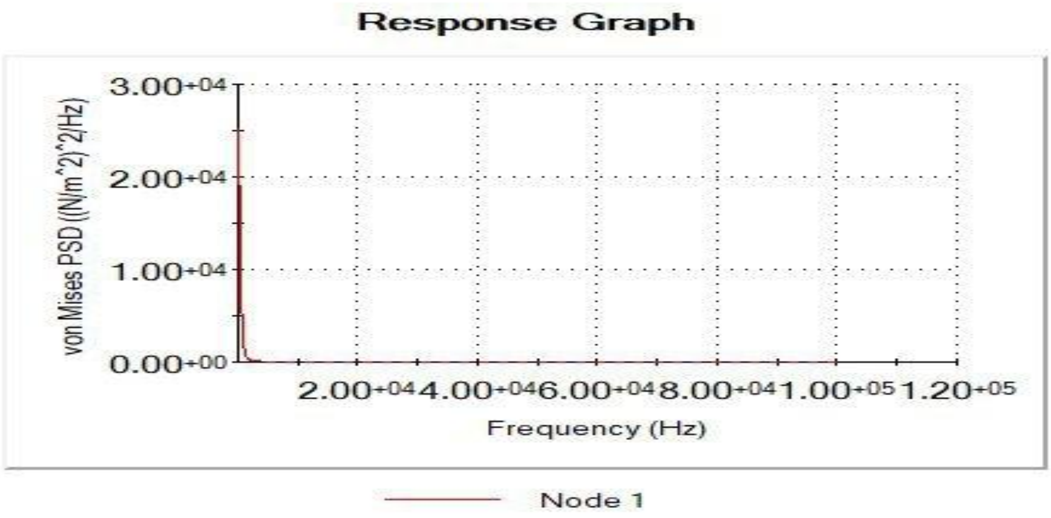


Fig. 9: Response Graph of the propulsion shaft system

However, an increase in the number of propeller blades lead to a corresponding increase in the shear stress values which will result to damage of the blades by causing imbalances in the propeller itself due to uneven weight distribution within the propeller blades which could lead to possible failure of the propeller blade and the entire propulsion system.

Table 2: Result of the static load on the propulsion system

No.of blades	Stress (N/m^2)
3 blades	5.311 × 10^3
4 blades	6.360 × 10^3
5 blades	1.897 × 10^4

Material Yield Strength= 6.204×10^8

It can be deduced that the stresses increased on increasing the number of blades as shown in table 4.2 above. Maximum stresses of 5.311KN/m^2, 6.360KN/m^2 and 18.97KN/m^2 on the propulsion shaft were obtained for vessel with 3 to 5 propeller blades respectively, which are lesser than the yield stress of the material of 620.4MN/m^2 is suitable to the vessel at constant RPM without causing any damage on the entire propulsion system.

Also, with the shear stresses as shown above at constant RPM. Three (3) blade has a percentage difference of 16.5% with four (4) blade and 28% as against five (5) blade. It was clearly shown that the three (3) blade have lower shear stress value compared to the four (4) and five (5) blades respectively, hence it is recommended to ensure smooth operation.

Given the impact of propeller pitch variation, a sudden shift in pitch causes pressure fluctuations that resemble pulses, which may cause the blade to vibrate and potentially harm the entire propulsion shaft system.

However, on increasing the number of blades, the pressure built up on the surface of the blade increased as a result of increase in the mass of water impelled, causing misalignment of the propeller shaft as a result of wear and tear on the shaft bearings and the result is the possible failure of the propeller over time due to vibration.

The relationship of the pitch radius of the propeller blade at varying percentages is shown in figure below

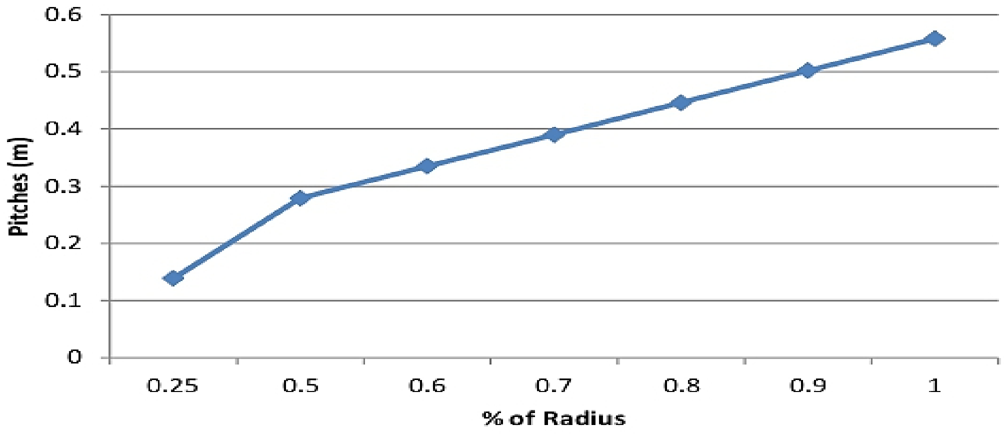


Fig. 10: Graph of Pitches against varying Percentages of radius

The graph clearly demonstrated that the pitch of the blade from the blade hub interception to the tip of the blade gradually increases as the radius varied positively.

IV. CONCLUSION

Using SolidWorks software, a propulsion shaft model was created in accordance with the mathematical analysis's parameters. Additionally, the frequency-displacement response of the propeller shaft was determined using numerical analysis using modal analysis (FEA).

Hence the followings were deduced:

- Solid propulsion shaft contributed about 39.06% increase in frequency as compared to the hollow propulsion shaft. Hence vibration effect is higher in solid propulsion shaft.
- There are about 21.72% error in the manual value of the natural frequency calculated and the value obtained from the numerical analysis, therefore it's advisable to avoid the frequency range of 318.63Hz and 407.02Hz.
- It is also concluded that on increasing the number of propellers blades the vibration is

reduced and the performance of the propulsion system is increased.

- An abrupt change in pitch, changes the pressure resembling pulses which might affect the blade causing it to vibrate, thereby resulting to possible damage of the entire propulsion shaft system.

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