Numerical and Experimental Evaluation of Natural Frequencies of a Marine Propeller

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Abstract - A propeller is a mechanical element in which blades convert rotational motion into thrust to move the marine vehicle through a transmission system. In the present study, modal analysis was performed to determine the natural frequencies of aft and forward marine propellers using ANSYS Workbench. A comparison was made between the data obtained from the numerical and experimental methods. The aft and forward propellers were tested for extracting natural frequencies using the FRF method. The propeller was attached to a stand in free-free constraint condition. The modal testing was performed using an impact hammer and accelerometer on the propeller to validate the results of the FEA method. The natural frequencies of aft and forward propellers were compared for both methods and a good correlation was found.

Key Words: propeller, modal analysis, vibration, natural frequency, validation.

1. INTRODUCTION

A propeller is a mechanical element in which blades convert rotational motion into thrust to move the marine vehicle through a transmission system. The aerofoil-shaped blade creates a pressure difference between its forward and backward surface, which pushes water or air behind the blade. Marine propellers usually consist of three, four, or five blades. Newton's third law and Bernoulli's principle are the principles based on which marine vehicles propel. According to Bernoulli's principle, "a decrease in pressure or a decrease in the fluid's potential energy is accompanied by an increase in the speed of a fluid" [1]. As a result, the speed of fluid and pressure are inversely related. Thus, the fluid has high pressure near the blade center and low pressure towards the tip. Fluid flows as a result of this pressure difference. "To every action, there is always equal and opposite reaction; or the mutual actions of two bodies upon each other are always equal and directed to contrary parts", states Newton's third law of motion [1]. Vibration is an important phenomenon that needs to be well addressed in the design, development, and maintenance of machines. The causes of machinery vibrations are plenty; they may arise due to the characteristics of the machinery itself, or from an external source. Whatever the source of vibration, the effects of vibration are very disturbing in operating a machine and result in low efficiency. When an elastic system free from external forces is disturbed from its equilibrium it vibrates under the influence of inherent forces and is said to be the state of free vibration [2].

2. LITERATURE SURVEY

The natural frequencies and the mode shapes are important parameters in the design of a structure for dynamic loading condition (C. Navya et al., 2018). Boundary conditions were applied for Eigen frequency analysis, where the root of the propeller is fixed and tip is free. The results for the first six natural frequencies for aluminium were determined (Jyothi Joshi et al., 2021). Solid model of propeller was imported into HYPERMESH 10.0 and tetrahedron mesh was generated for the same. Static analysis and modal analysis of aluminium propeller was carried out (P. Narasaiah and S. S. Basaarkod). The FEM method was used to perform modal analysis on three-bladed propeller. Mode shapes, which are defined as the propeller's deflection at a particular natural frequency were used to represent the results of free vibration analysis of the propeller in air. A flexible string was used to hold the propeller in free-free constraint condition. The brass propeller was hit with a modal impact hammer, and the responses were recorded (Seckin Uslu et al., 2021).

3. MODELING OF AFT AND FORWARD PROPELLER

CAD model of the aft and forward propeller was developed in UG NX CAD software as shown in Figure 1 and Figure 2 respectively.

Figure 1 Aft propeller

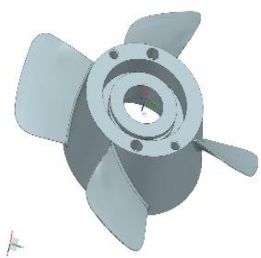


Figure 2 Forward propeller

4. OBJECTIVE

The main of this work is to ascertain the natural frequencies of aft and forward propellers through experimental method and correlate the same with numerical method for design validation and quantifying the deviations.

5. FINITE ELEMENT ANALYSIS OF PROPELLER

5.1 MATERIAL PROPERTIES

Aluminium Alloy 2014 was considered to perform the modal analysis. Aluminium Alloy 2014 is widely used in the aerospace and defence sector in the manufacture of high strength components.

Density – 2800 kg/m^3
Young's Modulus – 73 GPa
Poisson's ratio – 0.33

5.2 MODAL ANALYSIS

The modal analysis is conducted, without considering the forces acting on the propellers, hence, a no boundary condition is applied. Modal analysis is performed for aft and forward propeller by importing CAD model into ANSYS Workbench 2020 R1. The aft and forward propellers were meshed with tetrahedral elements. Six natural frequencies were extracted for both aft and forward propeller from the modal analysis and its corresponding mode shapes. Figure 3 shows the mode shapes and the natural frequencies of aft and forward propeller.

6. EXPERIMENTAL ANALYSIS OF PROPELLER

The experimental modal analysis involves the measurement of frequency response function (FRF). These FRFs can be processed to estimate the modal parameters namely natural frequencies, mode shapes and damping factor. The experimental setup consists of a CSI Machinery Health Analyzer 2140, B & K Accelerometer Type 4514 001 and Modally Tuned Impact Hammer CSI A034701.

The aft and forward propeller is tested for extracting natural frequency using the modal testing method. The propeller was attached to a stand in free-free constraint condition. An accelerometer was used to measure the output of the system. Before impacting the hammer onto a specified point on one of the blades, the propeller was kept at rest. The hammer test (Figure 4) excites all frequencies simultaneously with an equal amount of energy. The output response of the propeller vibration was measured using an accelerometer attached to the propeller. Figure 5 and Figure 6 shows the natural frequency spectrum for aft and forward propeller respectively.

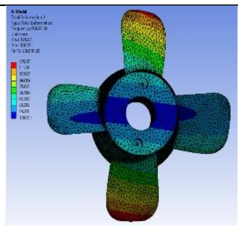
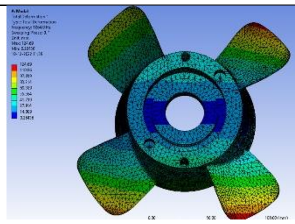
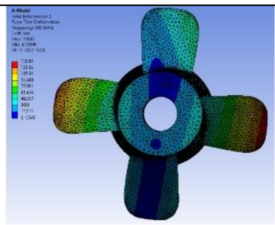
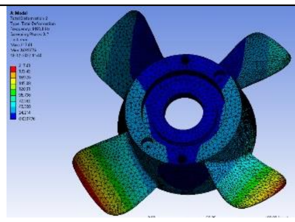
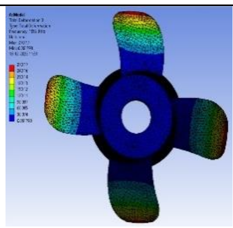
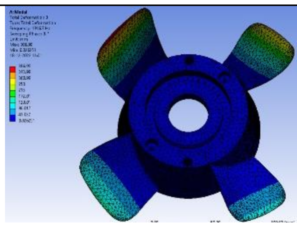
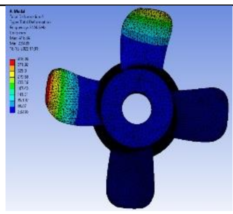
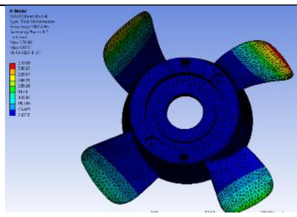
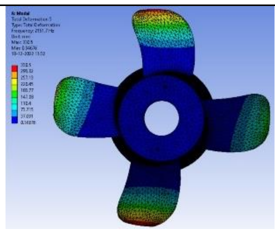
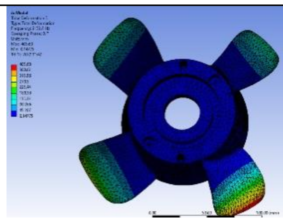
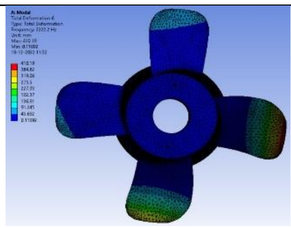
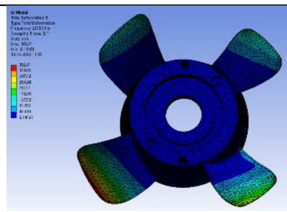
MODE	Mode shapes and natural frequency (Hz) in air of aft propeller	Mode shapes and natural frequency (Hz) in air of forward propeller
1	 826.22 Hz	 1064.8 Hz
2	 940.36 Hz	 1493.1 Hz
3	 952.9 Hz	 1916.7 Hz
4	 2124.6 Hz	 2061.4 Hz
5	 2151.7 Hz	 2132.4 Hz
6	 2222.2 Hz	 2213.5 Hz

Figure 3 Mode shapes and natural frequencies of aft and forward propeller in air.

Figure 4 Experimental Modal Analysis

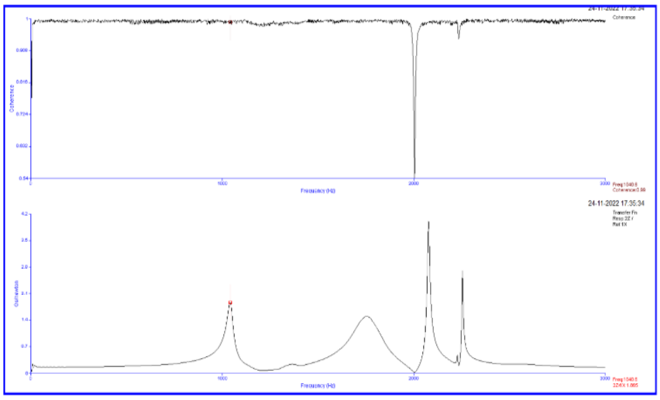


Figure 5 Natural frequency spectrum extracted for the aft propeller

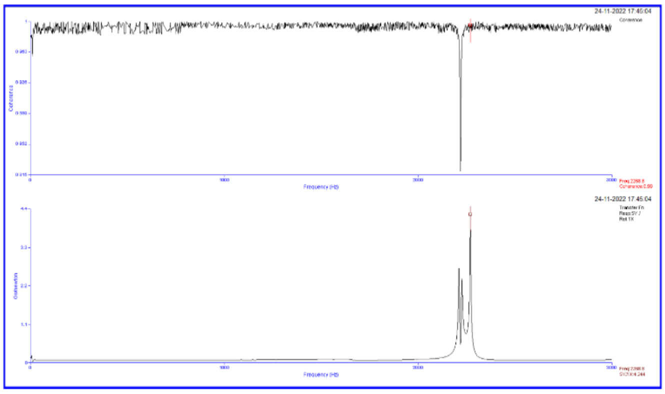


Figure 6 Natural frequency spectrum extracted for the forward propeller

7. RESULTS AND DISCUSSION

The FEA results were validated with the obtained experimental results and compared for correlation.

7.1 FEA RESULT

Modal analysis is performed for aft and forward propellers to extract six natural frequencies of these propellers. The six natural frequencies of the aft propeller from the numerical method are in the range of 826.22 Hz to 2222.2 Hz. Figure 7 shows the six natural frequencies obtained for the aft propeller. Similarly, the six natural frequencies of forward propeller from numerical method are in the range 1064.8 Hz to 2213.5 Hz. Figure 8 shows the six natural frequencies obtained for forward propeller.

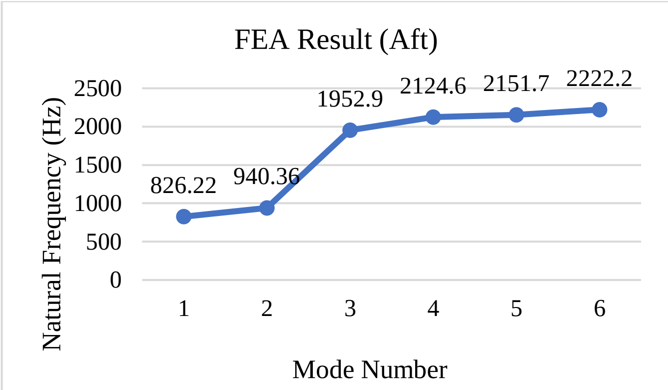


Figure 7 FEA Result of Aft Propeller

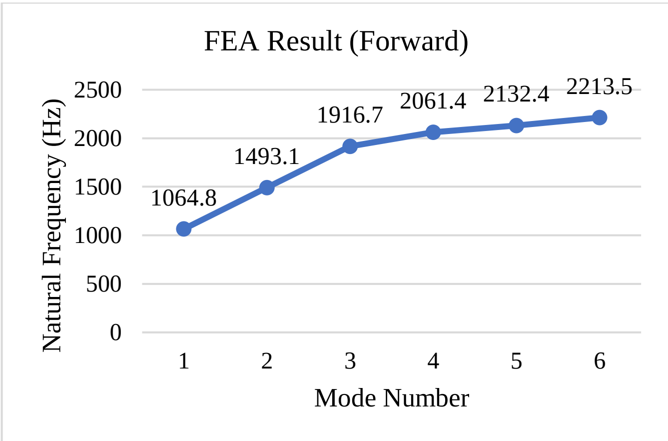


Figure 8 FEA Result of Forward Propeller

7.2 EXPERIMENTAL RESULTS

The experiment is performed for aft and forward propellers to extract six natural frequencies of these propellers. The six natural frequencies of aft propeller from experimental method are in the range 1038.8 Hz to 2253.8 Hz. Figure 9 shows the six natural frequencies obtained for aft propeller. Similarly, the six natural frequencies of forward propeller from experimental method are in the range 1215.0 Hz to 2850.0 Hz. Figure 10 shows the six natural frequencies obtained for forward propeller.

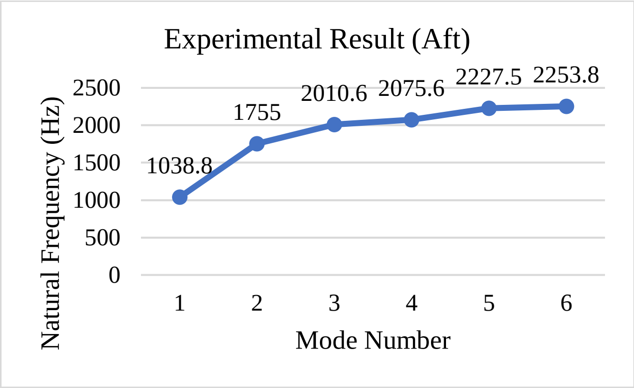


Figure 9 Experimental Result of Aft Propeller

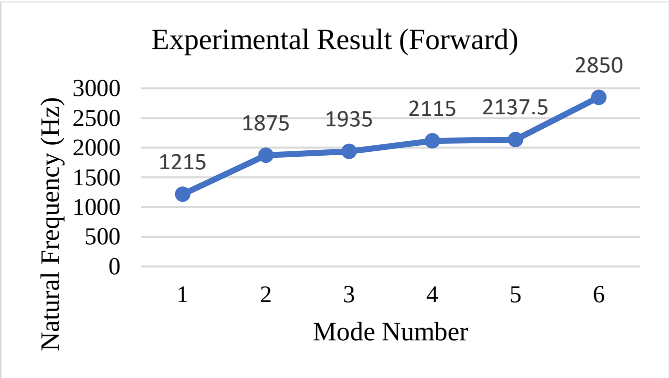


Figure 10 Experimental Result of Forward Propeller

7.3 COMPARISON OF EXPERIMENTAL AND FEA RESULTS

The values obtained in testing are very close to FEA results. Shown in Figure 11 and Figure 12 are the natural frequency values obtained from the experimental modal testing and the FEA plotted against the modes. It can be noticed that the natural frequency values obtained from the experiment and FEA are very close, thus validating the results obtained. The overall percentage error between the experimental and numerical methods is found to be 12.03% for forward propeller and 9.79% for aft propeller.

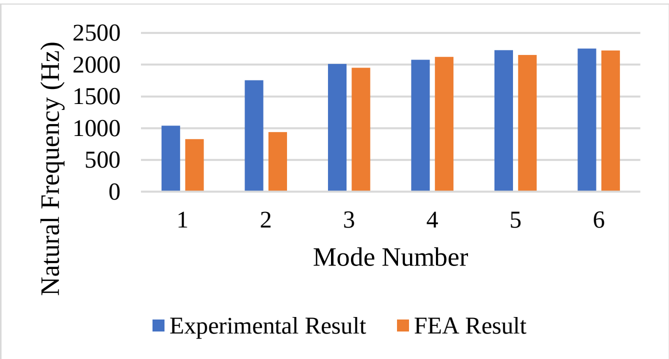


Figure 11 Comparison of experimental and FEA results of aft propeller

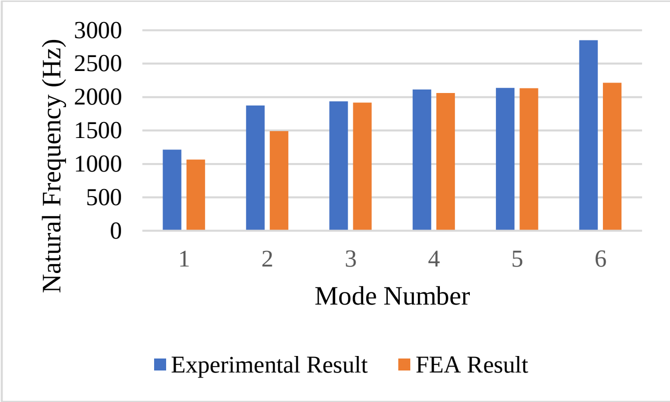


Figure 12 Comparison of experimental and FEA results of forward propeller

8. CONCLUSIONS

Modal analysis was performed to find the natural frequencies of aft and forward propellers. The natural frequencies were first extracted by conducting modal analysis using the finite element method in ANSYS Workbench software. The modal testing was performed using an impact hammer and accelerometer on the propeller to validate the results of the FEA method. The natural frequencies of aft and forward propellers were compared for both methods and a good correlation was found.

The natural frequencies found through modal analysis and experimental method are close enough with a deviation of approximately 9.79% for the forward propeller and 12.03% for the aft propeller. Considering the complexity of the part and the infeasibility of measurements along mutually perpendicular directions, the results are acceptable. Therefore, the analysis results are validated with experimental results and the approach shall be extended for a similarly complex part.

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