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Modal and Response Spectrum Analysis of Propulsion Shafting of Unmanned Ship Based on ANSYS Workbench

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Abstract: The propulsion shaft system is one of the main parts of the ship's power plant, and its working performance and stability directly affect the safety of the ship, and is also closely related to the life force and strength of the ship. In the environment of rapid development of science and technology, the working performance of the ship propulsion shaft system is becoming more and more demanding, and its components are becoming more and more complex. Therefore, the dynamic response characteristics of the shaft system need to be analyzed to meet the smooth working of the shaft system on the one hand, and to ensure the stability and impact resistance of the ship on the other hand. This paper is based on the traditional ship propulsion shaft system, the propulsion shaft system with universal coupling to modify, design a special transmission mechanism with adjustable tilt angle, firstly, use SOLIDWORKS to establish the propulsion shaft system model, and then import ANSYS for modal simulation analysis, get the first 100 order non-zero modal mass of the tiltable propulsion shaft system, and then simulate the acceleration of the tiltable propulsion shaft system under the action of impact The results show that the dynamic characteristics of the propulsion shaft system are complex and the modal vibration patterns are diverse during the ship navigation, and the tiltable propulsion shaft system can operate safely under the excitation of impact load.

1. Introduction

Ship propulsion shafting is an important part of ship power plant, its performance directly affects the reliability of ship, is also an important index of ship vitality. With the rapid development of science and technology, the superior working performance of ship propulsion shafting is required, and its structure become even more sophisticated.

Therefore, it is necessary to analyze the dynamic characteristics of shafting to meet the working performance requirements of shafting, and at the same time, to ensure that the ship has good vitality and reliability. In this paper, based on the ship propulsion shafting system, a propulsion shafting with a certain tilt angle is adopted to design a new transmission mechanism [1]. Many scholars have also done a lot of research on propulsion shafting and response spectrum analysis. For example, Wang Huan [2] used the torsional vibration model of low-speed diesel engine to study the time-domain vibration of ship shafting, but they have not considered that abnormal vibration of propulsion shafting would occur when the ship was impacted. By analyzing the seismic response spectrum of a certain signal tower, He Zhigang [3] obtained the maximum modal cloud picture and the maximum deformation, but the total order obtained in modal analysis was slightly insufficient. Chengcheng Hong [4] and Benjamin D [5] completed the impact response spectrum analysis of cross-sectional plate beams, but the external environmental effects on cross-sectional plate beams were not fully considered..

2. Establish the Shafting Model

Marine propulsion shafting adopts electric propulsion system, which consists of prime mover generator, power transmission system, motor propeller and control equipment. Because of the hull structure, the unmanned ship has unique motor host can't decorate a cylindrical dive under water body, and placed in the water in the hull structure. The propeller shaft and thrust axis cannot be installed in the water body, so there is a height difference the center line of the motor and the center line of the propeller shaft. In order to meet the special conditions, a reasonable structure is necessary to ensure the safe and reliable of shafting.

The shafting object is established by taking a small unmanned ship as an example. Q235 is selected as material its density is 7850 Kg/m3. The motor speed is 350 r/min. The frequency of the excitation force is 5.83HZ, as shown in the Figure1：

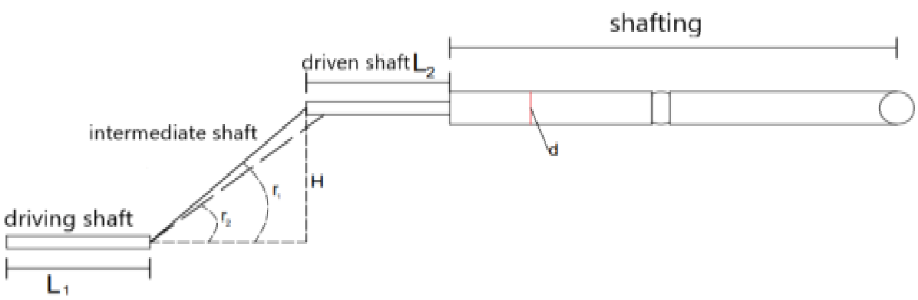

Figure 1: Motor oblique shaft output end.

Where, L1 is the length of the driving shaft (mm), L2 is the length of the driven shaft (mm), the solid line represents the initial position of the coupling, the dotted line represents the position of the coupling after the force changes, the starting Angle is r1 (°), the angle of the force changes is r2(°), H is the vertical distance from the driven shaft to the driving shaft (mm), and d is the diameter of the universal coupling (mm).

The shafting shown in Figure 1 has the advantages of superior transmission performance, good technology and good economy. However, due to the existence of high and low difference and great vibration, the structure of oblique shaft transmission is adopted to carry out simulation calculation.

3. Modal Analysis

Modal analysis is the most basic dynamic analysis, but it has very important practical value for every study to help determine the natural frequency and mode of vibration of the structure, so that the structure can avoid resonance phenomenon,through modal analysis of bionic propulsion shafting [6] its natural frequency and mode of vibration are solved, so as to analyze whether resonance exists.

In a general motion system, the general motion equation of dynamics is：

$$[M]\{\ddot{X}\}+[B]\{\dot{X}\}+[K]\{X\}=\{F\} \quad (1)$$

Where, $[M]$ is mass matrix, $[B]$ is damping matrix, $[K]$ is Stiffness Matrix, $\{\ddot{X}\}$ is acceleration vector, $\{\dot{X}\}$ is velocity vector, $\{X\}$ is displacement vector, $\{F\}$ is Load column vector.

Assume free vibration and ignore the damping：

$$[M]\{\ddot{X}\}+[K]\{X\}=\{0\} \quad (2)$$

If the structure vibrates at a certain natural frequency mean： $\{X\}=\{\phi\}\sin(\omega t)$, Substitute into Equation (2), and obtain：

$$([K]-\omega^2[M])\{\varphi\}=\{0\} \quad (3)$$

It can be seen from Equation (3), the $\{\varphi\}=\{0\}$ is one of the solutions, and that all nodes in the structure are at rest. Therefore, in order to obtain the non-zero solution. To meet the $\det([K]-\omega^2[M])=0$, to solve the ω is the natural frequency when the structure vibrates freely. Since the above differential equation cannot be solved, the finite element method is used to solve the eigenvalues.

The Figure 2 is the grid division graph of propulsion shafting：

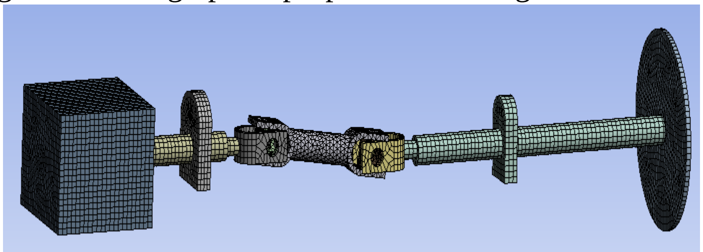

Figure 2: Ship propulsion shafting model diagram.

The Figure 3,4,5 is the cloud diagram of the first six order modal analysis of the propulsion shafting:

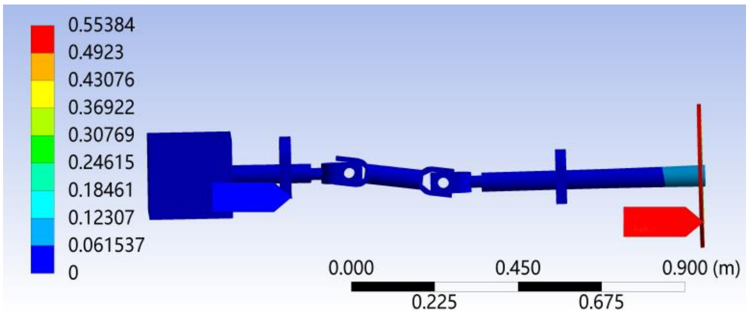

Figure 3: Propulsion shafting second mode shape.

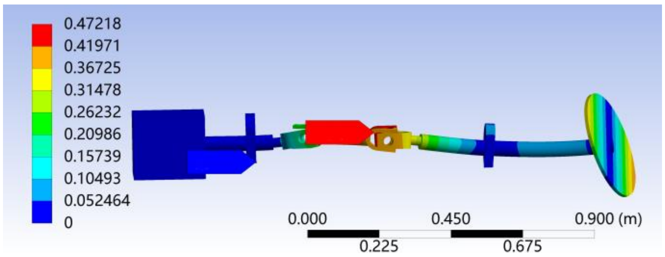

Figure 4: Propulsion shafting fourth mode shape.

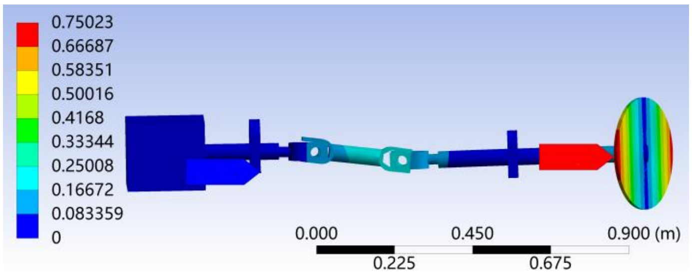

Figure 5: Propulsion shafting sixth mode shape.

Furthermore, the first 100 modes of shafting are calculated, and the modal quality and natural frequency of each mode can be obtained. After the calculation is completed by ANSYS Workbench, the participation factors can be obtained by using solution information. Therefore, this modal analysis calculates the mode of order 100 of shafting for the convenience of modal extraction. The Table 1, 2, 3 shows the modal parameters of the propulsion shafting in the X, Y and Z directions.

Table 1: Modal parameters of propulsion shafting (X direction)

degree	frequency	Modal Mass
1	77.66	0.0422
6	303.1	0.2100E-01
13	739.3	0.1336E-02
…	…	…
99	7928	0.1044E-01

Table 2: Modal parameters of propulsion shafting (Y direction)

degree	frequency	Modal Mass
1	77.66	7.016
6	303.1	0.5049E-01
13	739.3	0.1393E-01
..	…	..
99	7928	0.2352

Table 3: Modal parameters of propulsion shafting (Z direction)

degree	frequency	Modal Mass
1	77.66	0.3176E-02
6	303.1	2.578
13	739.3	0.8530E-02
…	…	…
99	7928	5.74E-03

4. Design of Impact Spectrum

In engineering practice, it is necessary to understand the maximum value of displacement and acceleration of system vibration, that is, the maximum response value of the object under impact load. The relationship of the maximum response value and excitation time and other parameters is called response spectrum. The response spectrum analysis method can be used for seismic analysis of communication tower structure by ANSYS Workbench Response Spectrum [7]. Modal response spectrum analysis mainly includes single-point response spectrum analysis and multi-point response spectrum analysis. The single-point response spectrum is specified on a point set of the model, and the multiple point response spectrum analysis rule is to specify different response spectrum responses at different point sets of the model [8].

According to the natural frequencies and modal masses of shafting obtained from shafting modal analysis in the previous section, the calculation formula of impact spectrum can be obtained as follows：

$$A_0 = 196.2\frac{(17.01+m_0)(5.44+m_0)}{(2.72+m_0)^2} \tag{4}$$

$$V_0 = 1.52\frac{5.44+m_0}{2.72+m_0} \tag{5}$$

$$f_i = \frac{\omega_i}{2\pi} \tag{6}$$

A_0——reference acceleration, m/s^2; V_0——reference speed, m/s; m_0——Modal Mass; f_i——Modal Frequency of i degree; ω_i——Modal circle frequency of i degree; A_a——Design acceleration, m/s^2; V_a——design speed, m/s; ω_a——Modal circle frequency, rad/s.

The design acceleration of impact should adopt the design values for surface ships given by GJB1060.1, that is, Aa and Va 1.0 in vertical direction (Y direction), Aa and Va 0.4 in transverse direction (Z direction) and Aa and Va 0.2 in longitudinal direction (X direction) [9].According to the formula calculated in the above table, the impact spectrum of ship propulsion shafting can be obtained as shown in the Table 4, 5, 6.

Table 4: Impact spectrum of shafting (longitudinal)

degree	frequency	Modal Mass	Acceleration /m/s2
1	77.66	0.0422	294.2594
6	303.1	0.2100E-01	485.7616
13	739.3	0.1336E-02	490.4656
…	…	…	…
99	7928	5.74E-03	488.2768

Table 5: Impact spectrum of shafting (vertical)

degree	frequency	Modal Mass	Acceleration /m/s2
1	77.66	7.016	247.7753
6	303.1	0.5049E-01	957.7418

13	739.3	0.1393E-01	974.8855
…	…	…	…
99	7928	0.2352	879.4976

Table 6: Impact spectrum of shafting (transverse)

degree	frequency	Modal Mass	Acceleration /m/s2
1	77.66	0.3176E-02	1481.758
6	303.1	2.578	1097.82
13	739.3	0.8530E-02	2443.672
…	…	…	…
99	7928	5.74E-03	2447.022

5. Calculation of Impact Spectrum

In this section, the natural frequency and natural mode of vibration of shafting are obtained according to the modal analysis in the previous section, and the acceleration impact spectrum of the impact load in the vertical and transverse directions of the shafting is calculated by the impact spectrum calculation formula required by the GJB1060.1, which provides input impact spectrum for the frequency domain analysis of the impact load [10].The shock spectrum is applied to the base of the propeller shaft system and the lower half of the shaft 1/4, and the simulation can be performed by the SRRS root-mean-square method that is, the maximum response of each mode is added.

SRSS can be expressed as follows:

$$x_i = \sqrt{\sum_a x_{ia}^2} \quad (7)$$

In this formula: x_{ia}—Any modal response; x_i—Represents the modal synthesis response

The displacement and stress response of ship propulsion shafting in impact spectrum in different directions can be obtained by ANSYS. The following Figure 6-11 shows the displacement response cloud of ship propulsion shafting in impact spectrum in X, Y and Z directions

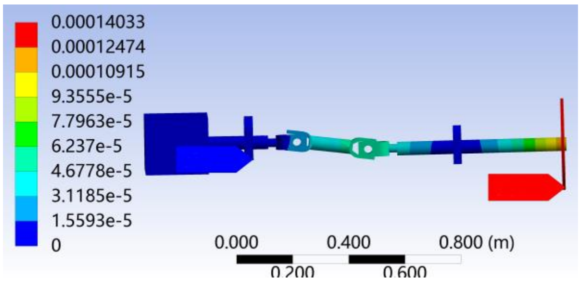

Figure 6: Cloud image of longitudinal X direction displacement response cloud.

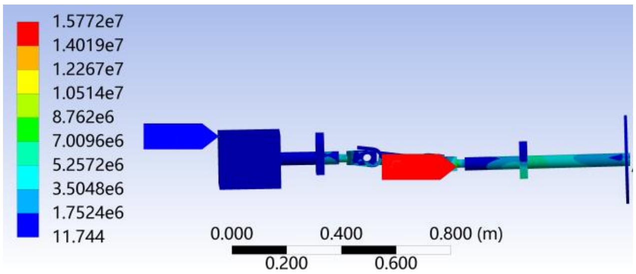

Figure 7: Longitudinal X direction stress response cloud image.

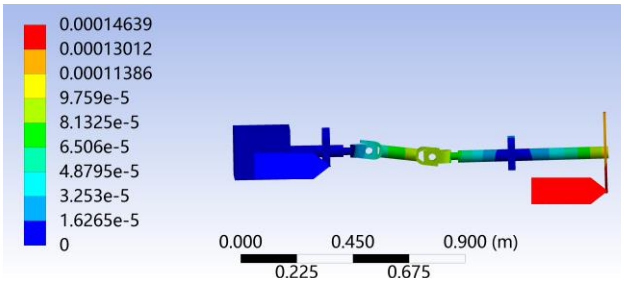

Figure 8: Cloud image of vertical Y direction displacement response cloud.

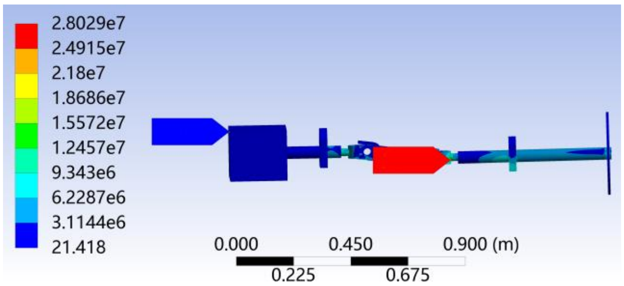

Figure 9: Vertical Y direction stress response cloud image.

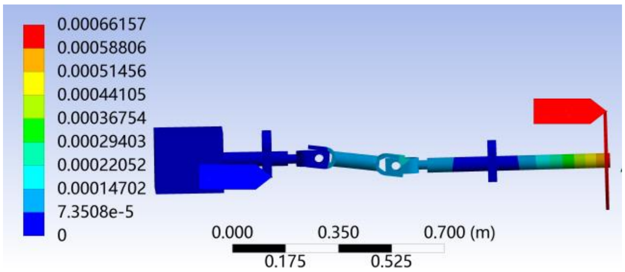

Figure 10: Cloud image of transverse Z direction displacement response.

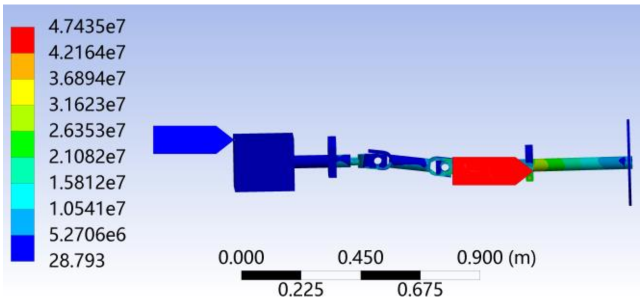

Figure 11: Transverse Z direction stress response cloud image.

It can be seen from the Figure 6, 7, 8, 9, 10, 11 that the maximum displacement occurs at the propeller and the maximum stress is mainly concentrated at the coupling when applying the three impact spectrum calculation to the ship propulsion shafting. The maximum displacement at the propeller is caused by transverse impact, with a size of 0.66mm, and the maximum stress of the coupling is 1.37e7Pa. Different positions are subjected to different stress and displacement sizes. This is because the ship's propulsion shafting has a certain dip angle, and under the action of gravity and fixed support, the mass of the propeller is relatively large and only one end is supported by the bearing base, so the displacement is relatively large when it is impacted. Because the mass of the coupling is relatively small, both ends have the support of the bearing base. Therefore, due to a certain angle, the displacement is relatively but the stress will be relatively large.

From the analysis above, it can be concluded as follows：

(1) The maximum lateral displacement response and stress response of the impact is greater than the longitudinal displacement and vertical displacement of shock response, the model of location and the actual match, the location of the response spectrum in the bearing pedestal and the part of the propeller. Ship sailing on the actual process by shock wave by screw position at impact to the bearing base Because the propulsion shafting is installed vertically in the hull structure and is arranged horizontally, the most important influence on the propulsion shafting is the lateral force.

(2)It can be seen that the maximum impact response displacement of the propulsion shafting occurs at the propeller shaft, which further indicates that the propulsion shafting with a certain inclination angle can operate more safely under impact without dislocation deformation.

(3)Shaft system under the effect of three kinds of impact acceleration spectrum, the different parts of the shaft under shock response is not the same, the maximum displacement of propeller, and the stress of the coupling of the largest. Thus under impact load, the propeller shaft and the shaft are most heavily affected, the crank shaft and intermediate shaft is affected relatively small; The acceleration impact spectrum in different directions has different influences on shafting, and the transverse impact spectrum has the greatest influence on shafting.

6. Conclusion

In this paper, the modal analysis of the propulsion shafting is carried out, and the results show that the low order modes of the propulsion shafting are mainly the deformation of the propeller shaft and the coupling vibration of the universal coupling. The diversity of vibration modes indicates that the dynamic characteristics of the propulsion shafting are complex, and further research is needed. Based on shock response spectrum analysis, the results showed that the stress and displacement of propulsion shafting is different in different directions. The maximal vibration and deformation are located in propeller shaft under the external excitation, that should be pay attention to the protection of the propeller shaft and the shaft in the actual process of navigation.

Acknowledgements

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