Friction and Impact Load Response of Ship Shafts under Microscope

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Abstract
Transmission stability is one of the important performances of ship propulsion shafting. However, when the impact load acts on the shafting, it will inspire the vibration response of the shafting. Since the propulsion shafting of the ship is supported on the sliding bearing, when the rotation speed is different, the bearing oil film bearing force changes, and the bearing state of the shafting system is changed. Therefore, the vibration response of the shafting system changes with the rotation speed under the impact load. The impact calculation is studied by theoretical calculation and test method. The relationship between the rotation speed of the propulsion shafting of the ship and the vibration characteristics of the shafting is obtained. The vibration of the shaft in the self-excited vibration region of the bearing is the strongest and the most destructive.

Keywords: Ship Propulsion Shafting, Impact Load, Cyclotron Vibration, Vibration Test

1. Introduction
The ship propulsion shafting is an intermediate transmission hub connecting the main engine and the propeller. It transmits the torque of the main engine to the propeller, and transmits the propulsion force generated by the propeller hitting the water flow to the hull to propel the ship. The shaft rotation is stable. To ensure the safe operation of the ship, suppressing or weakening the vibration of the ship's shafting is the key to improving its working stability and improving the transmission performance of the shafting. However, when the ship is sailing in a complex environment, the shafting will be affected by various dynamic factors. For example, changes in bearing support force, external load disturbances, and changes in shafting speed, etc., may arouse the vibration of the shafting. These dynamic factors exhibit different characteristics for the vibration. Shaft vibration to the ship's power the damage of the system is very great, such as vibration caused by ship noise, increased collision and wear of journal and bearing, damage to ship tail seal, generation of cavitation of propeller blades, fatigue of main engine crankshaft, etc.

2. Vibration Equation and Oil Film Bearing Force Calculation
The ship propulsion shafting is a slender shaft with great flexibility. The cyclotron vibration is one of the important vibration modes in its work. There are many calculation methods for the whirling vibration of the ship shafting system, and the element matrix method is a widely used method. In the calculation, a discrete model analysis model of the ship's shafting lumps is established. For any calculation unit, the vibration equation is:

\[
\begin{align*}
mx &= m\omega^2\cos\omega - f_x \\
my &= m\omega^2\sin\omega - f_y + mg
\end{align*}
\]

Where: m is the mass of the calculation unit; e is the mass eccentricity of the calculation unit; f_x, f_y is the bearing oil film bearing force of the calculation unit, when the calculation unit has no bearing support, f_x The values of f_y are 0; x and y are the amplitudes of the centroid of the calculation unit in the horizontal direction and the vertical direction respectively. The bearing of the ship shaft system is generally a radial sliding bearing of limited width, and the lubricating oil film force of the bearing f_x, f_y The Renault lubrication equation is obtained by numerical integral calculation method. The lubrication equation of the bearing is:

\[
\frac{\partial}{\partial R^2} \left[ \frac{h^3}{R} \frac{\partial p}{\partial \varphi} \right] + \frac{\partial}{\partial z} \left[ \frac{h^3}{R} \frac{\partial p}{\partial z} \right] = 6\omega \frac{\partial h}{\partial \varphi} + 12(e\cos\varphi + e\theta\sin\varphi)
\]

Where: \(\omega\) is the rotational speed of the ship's shafting; \(p\) is the oil film pressure of the bearing; \(\eta\) is the viscosity of the lubricating oil; \(R\) is the radius of the journal; \(z\) is the coordinate of the bearing width direction; \(e\) is the journal mass center relative to the bearing center; \(\varphi\) is the angle of rotation of the journal; \(h\) is the film thickness of the bearing lubricant; \(C\) is the gap between the journal and the bearing, and \(\theta\) is the eccentric direction of the center of the journal relative to the center of the bearing. The angle between the y axes in the vertical direction. The numerical integral calculation formula of the oil film bearing force of the bearing is
From the bearing lubrication equation (2), the bearing force \( f_x, f_y \) of the bearing lubricant film is related to the rotational speed \( \omega \) of the shaft system. The supporting force also changes, which leads to the change of the bearing state and vibration response of the shafting, that is, the relationship between the rotational speed of the ship’s shafting and its gyroscopic vibration. In this paper, the numerical calculation and experimental verification method are used to study the shafting under impact [1].

2.1. Numerical Calculation and Test of the Influence of Ship Shafting Friction Shock Load

Using the above vibration calculation analysis model and bearing oil film force calculation theory as the theoretical calculation basis, the vibration characteristics of a real ship's transmission shafting are numerically calculated. The actual parameters of the actual ship are: shaft length 7538 mm, shaft diameter 420 Mm, the diameter of the journal is 450 mm, the width of the rear bearing is 1210 mm, the width of the front bearing is 890 mm, the mass of the propeller is 1127.5 kg, the bearing clearance is 1.20 mm, and the viscosity of the lubricating oil is 0.055Pa•s. In the calculation, the viscosity of the bearing oil is 0.055Pa•s and the mass eccentricity of the journal unit is 0.0015mm. Under the condition that the parameters are kept unchanged, only the value of the rotation speed of the shaft is changed, and the effect is on the shaft. The impact load amplitude is 500 N, and the action time length is 0.1 s. The vibration response of the shaft is calculated by the dynamic numerical integration method.

It can be seen from the calculation results that when the impact load is the same and the shaft speed is different, the rotation speed of the shaft system has a significant influence on the vibration response caused by the impact load. As the shaft rotation speed increases, the bearing oil film force is supported. The change of dynamic characteristics, the initial amplitude of the shafting cyclotron vibration caused by the impact of the shafting is larger. However, the length of the vibration duration is related to the swirling speed. From the long to short attenuation change process, this indicates that in the frequency region of the self-excited vibration of the bearing, the impact vibration shock is maintained for a long time, and the self-excited eddy of the bearing oil film is excited. However, the non-self-excited vibration of the bearing in the region, the impact of the impact load is quickly attenuated, and the dynamic characteristics of the bearing oil film are not obvious. That is, the impact of the impact on the shafting in the self-excited vibration zone of the shafting is greater, but in the non-self-excited vibration zone. The impact of the impact on the shafting is small [2].

2.2. Analysis of the Frictional Impact Test of the Ship Shafting

It consists of variable frequency motor, analog crankshaft, intermediate shaft, propeller shaft, intermediate bearing, propeller shaft front and rear bearing, analog propeller and data acquisition and control parts. In the test, impact load The impact force generated by the free fall of the weight is generated in the vertical direction of the simulated propeller, so that the height of the weight falling each time is the same, and the impact load and the action time generated when the hammer hits the shaft are the same.

while maintaining the impact on the propeller shaft, the inverter is used to control and change the rotational speed of the propeller shaft. The impact test of the shaft is carried out at min. The corresponding bending vibration response curves under different speed conditions are tested by vibration measuring instrument. The amplitude-time response curve of the test is shown in Fig. 1. In Fig. 1 a) – d), in the same under the impact load, when the rotation speed of the shaft system is different, the oscillation amplitude of the shafting and the vibration response time have different variation characteristics.

With the increase of the rotation speed, the vibration speed of the shock load is accelerated faster. The slower, slower to faster, vibration maintenance time is also different. This shows that when the speed of the shaft changes, the oil film lubrication characteristics of the bearing change, the oil film stiffness of the bearing and the oil film damping change, thus showing the sliding bearing support. The oil film dynamically changes its support stiffness and variable damping characteristics, which is different from the fixed elastic damping bearing that, is not affected by the speed. Therefore, when the speed is in the self-excited vibration region of the sliding bearing The impact time is long, the amplitude attenuation is slow, and when the speed changes are not in the self-excited vibration region of the bearing, the impact response decays fast, and the farther the shaft speed is from the region, the faster the shock response amplitude decays. It is also consistent with the theoretical calculation results [3].

\[
\begin{align*}
  f_x &= \int_{-\beta_1}^{\beta_2} \int_{-\beta_2}^{\beta_1} (-PR\sin\varphi) d\varphi dz \\
  f_y &= \int_{-\beta_1}^{\beta_2} \int_{-\beta_2}^{\beta_1} (-PR\cos\varphi) d\varphi dz \quad (3)
\end{align*}
\]

3. Influence of Bearing Friction Change Caused by Hull Deformation on Vibration

3.1. Different Effects under Different Draft Conditions

In recent years, with the development of large-scale ships, due to the softer hull, the hull will produce different degrees of large deformation under different draft conditions, which will cause changes in the relative position of the bearing housing. As the power of the main engine increases, the stiffness of the shafting becomes larger. Especially for the tail-type ships, the short and thick shaft system makes the shaft stiffness larger, and the slight change of the vertical position of the bearing base will be the shafting system. Lateral vibrations have a large impact. Therefore, studying the influence of ship hull deformation on the lateral vibration of the shafting under different working conditions is of great significance for ensuring the normal operation of the ship's propulsion shafting and ensuring the safety of the ship. Previous studies by domestic and foreign scholars on the vibration of the shafting system are mostly based on the parallel relationship between the shaft and the bearing centerline, and are carried out on a horizontal straight line, regardless of the influence of the hull deformation, which is inconsistent with the actual working conditions of the shafting. As shown in the figure 1, the rear bearing is the reference, and the relative displacement of each bearing can be obtained. When shown in Figure 1, the displacement of the bearing caused by the deformation of the hull still ensures that the centerline of the shafting is in a straight line and can be processed on a horizontal line according to the centerline of the shafting:

![Figure 1. Corresponding to the impact load caused by the friction of the ship's shafting](image)

When shown in Figure 1, the bearing displacement caused by the deformation of the hull causes the centerline of the shafting to bend, and the conventional calculation method will no longer be applicable. In this chapter, a tail-type bulk carrier is studied, and the influence of the displacement of the bearing on the lateral vibration of the shaft under the deformation of the hull is explored. The purpose is to improve the vibration response of the shafting when the ship is running [4].

3.2. Shaft Friction Impact and Hull Structure Finite Element Analysis

Structural strength analysis is one of the key aspects of ship strength analysis. Compared with the simplified formula derived from the simple beam theory, the structural finite element analysis can more accurately simulate and reflect the ship's structural form, as well as its characteristics and details, and can match the wave external load outside the model, which embodies limited The feasibility and superiority of meta-theory in solving practical engineering problems. Ship strength analysis has made great breakthroughs with the development and application of finite element theory. At present, finite element method has become the most commonly used method for engineers to analyse ship structural strength. This paper mainly uses commercial finite element software to process and analyze the hull structure, and the impact of the shafting friction on the impact load is also serious, as shown in Figure 2 below:

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At present, finite element method has become the most commonly used method for engineers to analyze ship structural strength. Usually, the following two application methods are used: one is to write a specific one. The finite element program, the other is the commercial analysis software developed by the finite element software company. This paper mainly uses commercial finite element software to process and analyze the hull structure, and the impact of the shafting friction on the impact load is also serious, as shown in Figure 2 below:

![Figure 2. Adverse effects of shafting vibration on ship bearings](image)

From the influence of Fig. 2, it can be found that the finite element modeling level of the ship, that is, the sequence of hull modeling, uses a reasonable procedure to scientifically and effectively establish the whole ship model. However, there is no order in the modeling process. The hull structure is composed of beams and plates. In order to ensure accuracy during calculation, the established finite element model needs to reflect the actual structure of the hull as much as possible, but it does not mean that the higher the complexity of the model, the higher the calculation accuracy. When the model is too complicated, the calculation workload is large, the original data is cumbersome, and the possibility of errors will increase accordingly. Finally, the calculation result will not improve the accuracy, but will increase the calculation error [6].

In the process of establishing the finite element model of the ship, the structure and type of the model to be considered and concerned are usually different according to the actual requirements and the purpose of the analysis. That is to say, in order to meet the analysis purpose of the engineering and technical personnel, different Finite element model model. However, in general, the finite element model of the hull structure is established by the following five levels:

1. Whole ship analysis model

When it is necessary to consider the structural strength, stress distribution and deformation of the hull from a holistic perspective, it is common to establish a whole ship analysis model. At this time, the stress distribution and deformation requirements of the ship are not very strict, so the mesh can be relatively coarsely divided, and only the part that needs specific research can be refined.

2. Cabin analysis model

In the analysis of the deformation and stress response of the main components of the ship's raft area; it is usually used to establish a cabin analysis model. At this time, the local deformation and stress response of the cabin section are strictly required, and the grid needs to be refined according to actual requirements.

3. Frame and beam model

This model was chosen for the analysis of ship frames and beam systems. For example, the transverse bulkhead, the slab frame and the double-layer slab system are analyzed. At this time, in order to accurately reflect and describe the stress gradient of the key parts, the finite element mesh is accurately divided.

4. Local structural model

When analyzing the local structure of a rib that is subjected to relatively large deformation, a local structural model is generally selected [7].

5. Local finite element model

On the basis of the analysis of the whole ship, in order to obtain the stress distribution and stress level of key parts or main components more accurately, a local finite element model is used.

In summary, at the time of modeling, the structural model is selected based on the actual structural arrangement of the hull and the type of response to be considered. The change in the stiffness of the hull in the area determines the response within that length, at which point the finite element model established must include at least all of the areas within the range considered.

3.3. Finite Element Modeling Principle of Hull Based on Ship Shaft Friction Impact

The previous section discusses the finite element modeling hierarchy. The general principles of modeling using finite element methods are described below. Before proceeding with modeling, it is necessary to have a
correct understanding and analysis of the load transfer, bearing mode and corresponding deformation characteristics of the ship structure, and construct the overall structure as shown in Figure 3:

![Figure 3. Ship shafting friction impact load affects Cartesian coordinate system](image)

Through the coordinate system of Fig. 3, the structural elements such as beam element, rod element, plate element and membrane element are properly combined, the longitudinal bones and other components are reasonably simplified, and the grid lines are correctly divided, so that the actual ship model is simplified and the calculation is guaranteed. The results are true, credible and effective. The finite element model of the ship structure is usually established by following the following principles:

If the cross section of the hull is symmetrical about the longitudinal plane, it is only necessary to model half of the ship's structure. Otherwise, the entire ship structure must be modeled.

- Reasonably model the main structural components of the ship, such as side ribs, longitudinal, deck beams, support plates, bottom girders, and longitudinal girders.
- Reasonably divide the finite element mesh according to the accuracy requirements and objectives of the calculation. To divide the mesh too finely will greatly increase the workload in the modeling and calculation process; on the contrary, if the mesh is too coarsely divided, the calculation results cannot fully express the stress and deformation of the structural parts of the ship, resulting in unsatisfactory results[8].
- When expressing the total longitudinal and local bending of the hull structure, it is appropriate to select the coarse mesh model and meet the calculation accuracy requirements.
- Whether the selection of the unit is reasonable will directly affect the accuracy of the calculation results. The following four types of units are usually used to establish the hull model: membrane unit, plate element, beam unit and rod unit.
- Try to use the four-node unit type to establish the hull finite element model and reduce the use of triangular elements. In addition to the use of triangular elements in some places, quadrilateral elements are used elsewhere.
- In the actual modelling process, in order to avoid false deformation and stress, it is necessary to prevent the distortion of the shape of the unit.
- In the modelling process of the hull structure, only the static dimensions of each component are considered, and the corrosion allowance is not considered. However, in some countries' classification societies, it is pointed out that corrosion allowances need to be considered.

Due to the complexity of the hull structure, it is necessary to simplify the simulation as long as it does not adversely affect the results [9-15]. When doing a whole ship analysis, most of the simplified methods of combining several minor components are used. The combined components must be located at the geometric center of the relevant components, and the simplified components should maintain the same stiffness as the original components. Some minor components that have no effect on the calculation results may be considered, such as small open-cell structures and stiffeners that prevent buckling. However, larger openings must be included in the model.

4. Conclusions

Under the impact load, the cyclotron vibration response of the ship propulsion shaft system is affected by the rotation speed of the shaft system. The vibration response of the impact load is maintained for different time. As the rotation speed increases, the amplitude decay time is as fast as Slow, then slow to fast. This shows that in the self-excited vibration frequency region of the bearing, the impact time is long and the amplitude decays slowly. In the non-self-excited vibration frequency region, the shock response decays fast, and the shaft speed deviates from the frequency [16-23]. The farther the area is, the faster the impact response amplitude is
attenuated. Therefore, adjusting the working speed of the shafting under the impact load can avoid the damage of the shafting by the impact.

References