Vibration analysis of ship propulsion shafting bearings

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Abstract. The ship power propulsion system is the "heart" of the ship, and the ship propulsion shafting is the core unit of the ship power propulsion system, and it is an indispensable part of the ship's propulsion torque and thrust transmission. The operating status of the propulsion shafting directly affects the operating conditions of the ship, and even the life of the ship. Bearing load is one of the most important manifestations of the operating state of the propulsion shafting. Focusing on changes in the bearing load can better study the operating state of the propulsion shafting. The research on the steady-state load of ship propulsion shafting meets the needs of ship development and has great value for practical engineering applications. This paper takes the ship propulsion shafting-oil film-bearing structure system as the research object. Through the steady-state load mathematical model of ship propulsion shafting bearings, it reveals the coupling relationship among ship propulsion shafting bearing load, oil film force, and journal position, and establishes the ship The steady-state load calculation method of the propulsion shafting bearings solves the basic theoretical problems of modeling and analysis of the steady-state operating state of the ship's propulsion shafting, and provides theoretical support for the safety prediction, management and evaluation of the ship's propulsion shafting operation.

1 The goal and purpose of research

On May 16, 2019, the Ministry of Transport, together with the Central Cyberspace Administration of China, the National Development and Reform Commission, the Ministry of Education, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, and the Ministry of Finance, issued the "Guiding Opinions on the Development of Smart Shipping", marking the future of smart shipping 30 Year development points out the direction. The shipbuilding industry is a modern comprehensive and strategic industry that provides technical equipment for water transportation, marine resource development, and national defense construction. It is an important part of the country's development of high-end equipment manufacturing, and it is the foundation and important support for the country to implement its maritime power strategy. The operation of the shipbuilding industry from January to July 2019 issued by the China Shipbuilding Industry Association shows that my country's shipbuilding industry has made considerable progress, and the three major shipbuilding indicators (shipbuilding completion, new orders and hand-held orders) are second only to In Japan, it is a veritable shipbuilding country. Although my country's shipbuilding industry has achieved rapid development, it is still not a strong shipbuilding country. It is still a long way from Japan and South Korea in terms of quality and efficiency.

The shipping industry is responsible for more than 90% of the world's trade transportation. With the

development of my country's economy and trade, the importance of the shipping industry has become more and more prominent. Ships are the main means of transportation in the shipping industry, and the performance of ships directly affects the development of the shipping industry; as the heart of the ship, its importance is self-evident. The ship's propulsion shafting is an important component of the ship's power propulsion system. Part, so we need to focus on the operating state of the ship's propulsion shafting to ensure that the ship can operate more safely and efficiently. Ship propulsion shafting is not only very important for the normal operation of the ship, but also related to the safety of the ship's personnel and property and marine environmental protection issues. Once the ship's propulsion shaft system fails, it will inevitably lead to a significant increase in the ship's operating and maintenance costs, and the time cost will be greatly lost due to the shafting maintenance.

To sum up, it is of great research significance to carry out research on the operating state of the ship's propulsion shafting, and it is of guiding significance to ship owners, shipyards and ship operators.

2 Status quo at home and abroad

Ship propulsion shafting has always been a hot issue in ship-related professional research. Domestic and foreign classification societies, ship repairing companies, and some ship-related research institutes, universities, etc.

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have carried out a lot of research on this, and formed a series of related issues. Theories, such as: ship propulsion shaft alignment theory, research on the oil film dynamics theory of rotor machinery, research on the operating state of ship propulsion shafting, etc. In order to study the changing laws of the relevant parameters of the ship's propulsion shafting, various universities and research institutes at home and abroad have built a variety of propulsion shafting experimental benches.

3 Analysis of coupled vibration characteristics of propulsion shafting

At present, with the enlargement of propulsion shafting and the increase of ship power, the problem of shafting vibration has become increasingly prominent, and the problems of hull vibration and radiation noise caused by shafting vibration have received more and more attention. Therefore, the research on the dynamic characteristics of the propulsion shaft system is of great significance for both the vibration and noise reduction of ships and the safety performance of civil ships. Shafting vibration can be divided into transverse (rotation), longitudinal and torsional vibration. The main reason for the lateral vibration of the shafting is that the propeller operating in the uneven wake field at the stern has a fluid force that changes periodically according to the blade frequency, and the shafting is produced by the unbalanced centrifugal force of the propeller and the gravity of the eccentric mass of the propeller. The axial vibration of the ship's shafting is mainly caused by two aspects, one is caused by the uneven thrust of the propeller, which accounts for the main part, and the other is caused by the uneven longitudinal thrust of the main engine. Torsional vibration is caused by the swinging of each shaft section when the torque is transmitted from the main engine to the propeller through the propulsion shafting. There is a mutual coupling between the horizontal, longitudinal, and torsional vibrations of the shafting, which has been a hot spot in the research projects related to ship propulsion shafting vibration in recent years.

The torsional vibration of the propulsion shaft can excite longitudinal vibration, especially when the natural frequency of torsional vibration is the same or similar to the natural frequency of longitudinal vibration, the longitudinal-torsional coupled vibration is formed by the diesel engine crankshaft and propeller. Wang Yi et al. analyzed the response curves of longitudinal-torsional coupled vibration in combination with the measured longitudinal vibration curves of seven ship propulsion shafts. Zhang Hongtian and others established a calculation model for the longitudinal torsional coupled vibration of the shafting of a large ship. Through calculation and measurement analysis of the shafting of a real ship, the general law of the longitudinal-torsional coupled vibration of the shafting was studied. Qiu Yunming used the mass model to construct the longitudinal torsional coupled vibration model of the ship's propulsion shafting system, and made theoretical calculations for the three situations of torque excitation

force, axial excitation force and two excitation forces simultaneously.

The unbalanced mass of the propulsion shafting components, the unbalanced rotation of the propeller, the excitation of the propeller and the excitation of gear meshing, etc., can all cause the torsion-transverse coupled vibration of the ship's shafting. Zhang Zhenguo considered the coupling effect of torsion-transverse vibration under nonlinear friction excitation, and established the nonlinear dynamic equation of continuous shaft system based on Hamilton principle and finite element method. Qin Wenyuan analyzed the torsional-transverse coupled vibration characteristics of the shafting system under the friction force of the rubber bearing on the stern and its main influencing factors through a simplified model of the propulsion shafting. Zhu Hanhua et al. gave the lubrication equation of the bearing and the coupled motion equation of lubrication and torsional-transverse vibration, and studied the effect of lubricating oil viscosity on coupled vibration through numerical calculation.

The propulsion shaft system is simultaneously subjected to the gravity, unbalanced rotation force, and uneven thrust of the propeller, so longitudinal-transverse (cyclone) coupled vibration will occur. This coupled vibration is particularly obvious when the excitation is large. Research on the longitudinal-transverse coupled vibration of ship propulsion shafting is rare at home and abroad. Aiming at the actual engineering structure of ship propulsion shafting with multiple masses and multiple elastic supports, Yang Zhirong uses the finite element method to establish the finite element dynamics analysis model of the structure through the nonlinear stiffness matrix and the mass matrix of the longitudinally coupled vibrating beam element, and draws conclusions: Longitudinal-transverse coupled vibration has a strong coupling effect, and its dynamic response displacement is larger than that without coupling. Zou Donglin studied the longitudinal-transverse coupled vibration of the propulsion shaft under the excitation of the first-order blade frequency, and used Hamilton's law and Galerkin's method to model and solve it. The effect of support stiffness, propeller mass, damping, and shaft size on the longitudinal and transverse coupled vibration was analyzed influences.

As for the longitudinal-transverse-torsional coupling vibration of the propulsion shaft system, the coupling effect is very complicated and the solution is very difficult, and only a few scholars have involved it in the research. In the last chapter of his doctoral dissertation, Zhou Chunliang used numerical simulation to calculate the dynamic characteristics of the shafting longitudinal-transverse-torsion coupled vibration system under various parameters. Yang Yong used the wave propagation method and the matrix transfer method to simultaneously consider the three-way vibration of the propulsion shaft.

4 Analysis of Propulsion Shafting-Hull Vibration and Transmission Characteristics

Many scholars have done research on the vibration characteristics of the shaft itself or the sound and vibration characteristics of the shell structure, and the relevant theories have gradually improved. These studies on isolated systems did not consider the coupling between the shaft and the shell, and could not explain the interaction between the shaft and the shell structure vibration, so they can only be used as the basis for the coupled vibration research. In the early days, people did not fully understand the vibration and sound radiation caused by the propeller excitation force transmitted to the hull structure through the shafting, and rarely considered the coupling effect of the shafting and hull vibration characteristics, so the research results were few. The importance of studying the vibration characteristics from the perspective of the coupling system lies in the analysis of the structural vibration from the system level, which has important theoretical guiding significance for the optimal design of the acoustic and vibration characteristics of the hull structure.

The research on the vibration of the shafting-hull coupling system mainly focuses on its longitudinal and transverse vibrations. This is because the shafting and the hull are connected by bearing supports and mainly transmit longitudinal and transverse vibrations, which are reflected in these two directions. Coupling between structures. Due to the complexity of the solution method, the related literatures using analytical or semi-analytic methods to study the vibration characteristics of shafting and hull are relatively rare. Analytical method is the method of converting structural vibration problems into mathematical and physical problems, listing and solving system motion equations, and is the earliest method used to solve structural vibration problems. The analytical method has always been valued by scholars at home and abroad because of its clear concept definition, its ability to separate and combine systems, to decompose and analyze complex problems, and to easily reveal the influencing factors of vibration characteristics. Yang Lihong established the dynamic model of the shafting-shell coupling structure, used the equivalent energy method and the matrix combination method to theoretically derive the vibration analysis solution of the coupled system, and analyzed the vibration response characteristics of the propeller's longitudinal and transverse pulse forces. The solution of the propulsion shaft system is based on the theory of coupled beams with arbitrary elastic boundaries. The lateral and longitudinal vibrations of the multi-axis shaft system are analyzed, but the hull is only simplified into a cylindrical shell for modeling analysis.

The study of vibration transmission can analyze the mechanism of vibration occurrence and transmission path, and has a guiding significance for the control of vibration, so it occupies a certain position in the analysis of structural vibration characteristics. The power flow method is an effective method to analyze vibration

transmission. It takes into account the combined effect of force and speed, takes into account the dynamic force transmitted to the structure and the resulting dynamic response of the structure, and can pass the space vector image of the power flow. Make an intuitive description and determine the propagation characteristics of energy.

5 Modeling of submerged cone-cylinder combined shell

Figure 1 The establishment of the continuous condition of the cone-cylinder composite shell model

The longitudinal-transverse vibration equations of cylindrical and cone shells established by Flügge shell theory. Consider the external fluid immersed in the composite shell, that is, calculate the external normal pressure generated by the fluid load on the shell surface. By establishing the boundary conditions at both ends of the cone-cylinder composite shell and the continuous conditions of the displacement, rotation angle, force and moment at the junction of the cone and cylinder, the vibration equation of the submerged cone-cylinder composite shell is formed simultaneously.

For complex cone-cylinder composite shells, the analytical sub-structure method is adopted, that is, according to the sub-structure types (such as bulkheads, ring ribs, and cylindrical or conical sections separated by them) that make up the cone-cylinder composite shells, they are divided into different substructures. Each substructure is described by the corresponding dynamic partial differential equation. Among them, the circular plate vibration equation is used for the bulkhead and the ring plate vibration equation is used for the ring ribs. The continuous conditions of displacement, rotation angle, force and moment are established at the place where the substructure and the substructure are connected.

Figure 2 Longitudinal-transverse coupled vibration of circular cross-section beam axis

As shown in Figure 2, the axis is located on the XY plane. The initial point A moves to point B after longitudinal-transverse coupled vibration. Considering the coupling direction between the longitudinal and transverse vibrations, the longitudinal-transverse coupled vibration equation of Euler beam is established as the

formula For multi-span beams, the transmission matrix is obtained through the continuous conditions of displacement, rotation angle, force and moment at the support to establish the vibration equation.

6 Conclusion

The submarine shell is simplified into a cylindrical shell and a conical shell, the propulsion shaft system is simplified into a multi-span beam structure, and the bearing support is regarded as a spring damping. Based on the shell vibration theory and the multi-span beam vibration theory, a shaft-submerged cone column combination is established The longitudinal-transverse coupled vibration equations of the shell system form an effective semi-analytical solution method to study the coupling vibration characteristics and transmission laws of the system under the excitation of the propeller and the external excitation of the hull, and analyze the coupling between different vibration forms and between different substructure vibrations It is used to sort and analyze the importance of multiple transmission paths of the vibration power flow, and based on this, a preliminary vibration control method is proposed, which aims to reveal the vibration characteristics and transmission relationship of the submarine's propulsion shafting-hull system and optimize the submarine Design and vibration and noise reduction provide theoretical basis and basic technical support.

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