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Comprehensive optimization for the alignment quality and whirling vibration damping of a motor drive shafting

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ABSTRACT

The alignment quality optimization and vibration damping of ship shafting is one of the key issues in ship research field. The quality of shafting alignment affects the vibration characteristics of a shafting and the safety, reliability of a ship in operation directly. A motor drive propulsion shafting was researched in this paper, which focuses on the linear alignment and load coefficient calculation. Based on these calculation results, the alignment quality was optimized and the whirling vibration characteristic under different alignment conditions was calculated. In order to optimize the shafting alignment quality and vibration characteristics simultaneously by adjusting the vertical position of each bearing, optimization weight coefficient was present, which provided a new idea for comprehensive optimization of vibration damping and shafting alignment.

1. Introduction

The vibration characteristics and alignment states of a marine propulsion shafting will affect the safety and reliable operation of a ship seriously, and it is one of the key issues in marine engineering research fields. The main function of shafting is transferring power from main engine and driving propeller rotation for ships, and at the same time transmitting the thrust and tension produced by propeller to the hull through the thrust bearing (G. Chen et al., 2001). However, the shafting bears a variety of loads that influence each other, and its alignment quality affects the bearing load of each bearing directly. A poor shafting alignment state will result in excessive load on the individual bearing and abnormal wear, which will affect the safety, reliable and stable operation of a ship seriously and increase abnormal vibration and noise as well. Many scholars and related research institutions have done much research on the ship shafting alignment optimization, vibration damping and noise reduction.

As to shafting alignment optimization, many research works focus on the alignment methods including linear alignment, allowable bearing load alignment, reasonable alignment, dynamic alignment, etc. H. Wei et al. studied the problem of multi-points support on the stern bearing by transfer matrix method (H. Wei, H. Wang, 2001); R. Zhou et al. researched the three moment method and finite element method in shafting alignment calculation (Zhang et al., 2003); Several methods of static alignment calculation for ship shafting were compared and analyzed by H. Chen, and how the shaft sections' machining errors, hull deformation, flange sag etc. effect on the quality of shafting alignment were analyzed as well.

About the theoretical study of shafting whirling vibration, Z. Chen et al. researched the whirling vibration phenomenon of ship propulsion shafting, in which, the vibration characteristics of shafting was analyzed in details and the calculation algorithm was studied (Z. Chen et al., 1984). Y Hori et al. also studied on the relevant influence factors to the whirling vibration of ship shafting (Y Hori et al., 1978; Al-Bedoor B O, 2001). Meirovith L et al. studied the basic theory of ship shafting whirling vibration (Meirovith L et al., 2001). Brown M. A. et al. applied the multi-elastic method and the dynamics model to calculate the whirling vibration characteristics of rotor shafting (Brown M A et al., 1997). For experimental research on the whirling vibration of shafting, the experimental research is not only beneficial to verify the accuracy of the theoretical model, but also helpful to modify the model and promote the development of the theory of ship shafting whirling vibration. The work of shafting's FEM modified by the modal parameters and experimental data of a propulsion shafting experimental platform was carried out by Liu et al., and the modified FEM of shafting can describe the whirling vibration characteristics of the shafting better (Z. liu et al., 1991). Li et al. applied the hammering method to test the free vibration of a hovercraft scale platform, which was used to verify the accuracy of

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theoretical calculation (N. Li, 2007).

The research works about the influence of shafting alignment optimization on its whirling vibration characteristics. Cao carried out a research on shafting two-way (horizontal and vertical displacement of each bearing) optimization alignment, a chapter of his master's thesis was devoted to researching the effect of axial displacement of intermediate bearings on whirling vibration characteristics of the shafting, and this factor considered in the progress of shafting two-way optimization alignment (X. Cao, 2008). Liu et al. applied the transfer matrix method to achieve the target of two-way optimization for shafting alignment, in which the load on the rear stern bearing is minimized (X. Liu et al., 2016). Zhang et al. studied the calculation model of the influence of shafting curve alignment and the misalignment of coupling on its whirling vibration respectively, and the accuracy of the theoretical models was verified by experiments (X Zhang et al., 2016).

As for vibration and noise control of shafting's whirling vibration, the methods such as frequency modulation, vibration source control and vibration isolation were suggested usually. Logr.zverv et al. proposed a stiffness calculation method of built-in ball bearing model by establishing the finite element model of a bearing, and studied on how the influence of bearing stiffness on the shafting's whirling vibration (Logr.zverv et al., 2010). However, the stiffness value difference between the horizontal and vertical of each bearing was neglected in this study, which could result in some differences between the calculated results and the actual values. X. Lin et al. researched a whirling vibration calculation method of improved Fourier series which is suitable for a shafting with elastic supporting, variable axis neck and multi span, and studied the relationship between the bearing supporting and the whirling vibration characteristics (X. Lin, 2016). In Addition, Zhu et al. considered many factors, e.g. gyroscopic effect, external shock loading, positions of intermediate bearings, bearing support stiffness, the effective contact length on the aft stern bearing, the vertical displacement of shafting center line caused by hull deformation (J. Zhu, 2012). According to literatures review, few scholars have studied the method of optimizing shafting alignment states and vibration damping by the method of adjusting the position of each bearing while in the process of shafting alignment design, especially in the case of a short shafting alignment in which the linear alignment method was generally used.

A motor drive shafting was studied in this paper, and its load effect coefficients were obtained on the basis of the linear alignment calculation results. Considering the load on the rear stern bearing is minimal as the optimizing target to get its reasonable alignment state, and within the displacement (−10–10) mm for each bearing, the vertical displacement of three bearings were adjusted to obtain a high alignment quality for the shafting. The whirling vibration characteristics of this shafting under different alignment states were calculated. Then, according to the relevant experts' opinions, the weight coefficients of the alignment quality and whirling vibration characteristics were established to seek for a suitable displacement of each bearing to improve shafting alignment quality and reduce whirling vibration responses.

2. Brief introduction of the motor drive shafting

The sketch of the motor drive shafting arrangement is shown in Fig. 1.

The motor drive shafting system mainly consists of a propeller, a stern shaft, an intermediate shaft, two stern bearings and a thrust bearing, a high elastic coupling, and a motor etc. Wherein, the stern shaft is supported by the front bearing and rear one; the thrust shaft is supported by a thrust bearing; the stern shaft is connected with the intermediate shaft by a coupling flange. The intermediate shaft is connected with the thrust shaft by a flange. The rear stern bearing of the motor drive shafting is lubricated by water, while the front stern bearing and the thrust one are lubricated by oil.

In this paper, the lubrication characteristics of each bearing have been considered separately. For convenience, they are generally referred to as oil film lubrication, but the different properties of the lubricating fluid are treated differently in calculation.

3. Calculation and optimization for shafting alignment

Considering the complicated force acting on the shafting system, before alignment calculation, the physical model of the shafting should be simplified by making some reasonable assumptions.

The simplified model of shafting alignment is shown in Fig. 2. Taking the apex of propeller hub as the coordinate origin, the X axis is the axial direction, pointing to the bow is positive; the Y axis is the vertical direction, the gravity direction is negative; the Z axis is the horizontal direction, and vertical surface outward is positive. Each bearing is replaced by a vertical direction spring and a horizontal direction spring respectively. The other ends of springs are fixed on the ground, their free lengths are 0.6m and their stiffness values are provided by the manufacturer. Because of the influence of the edge load of propeller, the action point of the springs used to simulate the rear stern bearing is located at 1/3 length of the rear stern bearing, while the other two bearings are located at the middle position of the corresponding bearing, and the ends are fixed on the ground. Besides, an axial spring is added to the right end face of the thrust bearing to simulate the effect of the thrust bearing on the axial thrust, but the other end is fixed on the ground. The free length is 1.2m and value of stiffness is provided by the manufacturer (C. Xiong, 2017).

3.1. FEM of the motor drive shafting

The FEM of the motor drive shafting established by the Beam188 element according to its relative parameters is simplified on the basis of relative literatures (Z. Feng et al., 2008, H. Zhang et al., 2005 and G. You

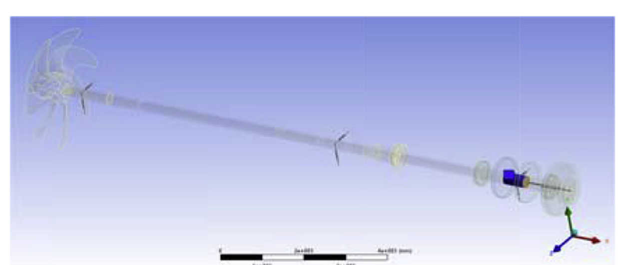

Fig. 2. Simplified calculation model of the shafting alignment.

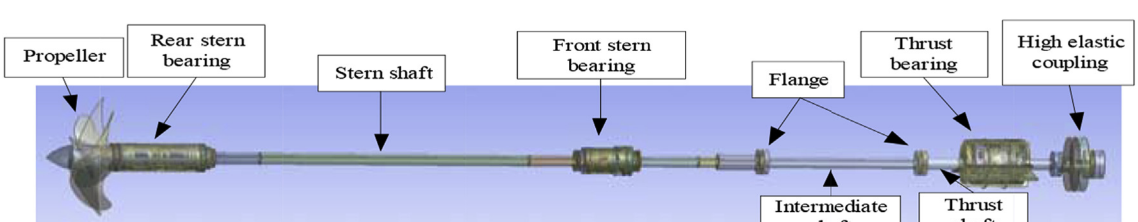

Fig. 1. Sketch of the motor drive shafting arrangement.