

Distortion of Shafting Bearings' Loads in Hot Condition Based on Marine Shaft Alignment Theory

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Abstract. The bearings' loads of marine shafting are the key aspect to evaluate the operating situation of the whole propulsion system. By using the basic theory and mathematical model of marine shafting alignment, the linear relations between the shafting bearings' positions and the bearings' loads are established and the marine shafting bearings' loads in hot condition is calculated and analysed. Then the "distortion" problem of the shafting bearings' loads in hot condition is put forward and discussed by the nominal load bearing. Finally, one important idea of the field on the marine shafting bearings' loads calculation is put forward considering the effects of bearing oil film dynamic response.

1. Introduction

Bearing load calculation of marine shafting is usually used in a static condition or shafting working state as hot condition. The thermal deformation effect of ship's main engine, gearbox and other equipment is compounded to the corresponding bearing deflection value, and the theoretical value of the bearings loads is got through ship shafting alignment calculation, thus to complete the evaluation of shafting bearings' loads. Since YELLOWLEY G. raised ship shafting alignment concept in 1954 [1], the ship shafting alignment theory has undergone more than 60 years and three several representative theories, such as the straight line alignment, the reasonable alignment [2] and the dynamic alignment [3, 4], and three main calculation methods: transfer matrix method [5, 6], three-moment method [7, 8] and finite element method [9~11] have been formed. However, there are still some problems for ship shafting bearings' loads in hot load condition and calculation theories for bearing load in working state. Aiming at solving the problems, some calculation principles are analyzed and compared, and the ideas and methods are put forward.

2. Mathematical model

Generally, ship shafting bearings' loads can be obtained after ship shafting alignment calculation, so the mathematical model is unified in the mathematical model of ship shafting alignment. The three-moment method is adopted, and one unit of the model structure is as shown in figure 1.



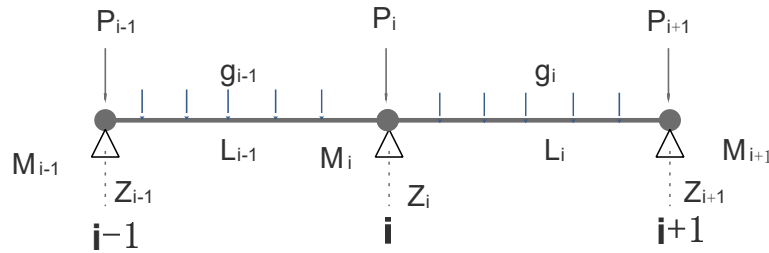


Figure 1. Diagrammatic Sketch of Three-Moment Method

Supposed both ends of the ship shafting is belong to a free end, ship shafting alignment calculation mathematical model can be arranged as equation (1), in which bearing position influence is directly reflected in the equation: $Z_i = C_i$. And under the static condition, the bearing position are known. Then each section's bending moment and the deflection can be obtained after solving the system of equations. Finally, the theoretical value of each bearing load can be got by equation (2).

$$\left\{ \begin{array}{l} \frac{L_{i-1}}{E_{i-1}I_{i-1}} M_{i-1} + 2 \left(\frac{L_{i-1}}{E_{i-1}I_{i-1}} + \frac{L_i}{E_i I_i} \right) M_i + \frac{L_i}{E_i I_i} M_{i+1} \\ - \frac{6}{L_{i-1}} Z_{i-1} + 6 \left(\frac{1}{L_{i-1}} + \frac{1}{L_i} \right) Z_i \\ - \frac{6}{L_i} Z_{i+1} = - \frac{1}{4} \left(\frac{q_{i-1} L_{i-1}^3}{E_{i-1} I_{i-1}} + \frac{q_i L_i^3}{E_i I_i} \right) \\ M_1 = 0 \\ M_n = 0 \\ \frac{M_1 - M_0}{L_0} + \frac{1}{2} q_0 L_0 + P_0 = 0 \\ \frac{M_{i-1} - M_i}{L_{i-1}} + \frac{M_{i+1} - M_i}{L_i} + \\ \frac{1}{2} (q_{i-1} L_{i-1} + q_i L_i) + P_i = 0 \\ \frac{M_{n-2} - M_{n-1}}{L_{n-2}} + \frac{1}{2} q_{n-2} L_{n-2} + P_{n-1} = 0 \\ Z_i = C_i \quad (i \in (1, n-2), \text{bearing}) \end{array} \right. \quad (i = 2, 3, \dots, n-1) \quad (1)$$

$$R_i = \frac{M_{i-1}}{L_i} - \left(\frac{1}{L_i} + \frac{1}{L_{i+1}} \right) M_i + \frac{M_{i+1}}{L_{i+1}} + \frac{q_i L_i}{2} + \frac{q_{i+1} L_{i+1}}{2} + P_i \quad (2)$$

In Equation (1) and Equation (2), M is bending moment, L is axial length, E is section flexural strength, I is cross section moment of inertia, Z for section vertical position, q for uniform mass, i for serial number of a shaft element, P for the concentrate quality or force in the cross section, R for bearing load or reaction, the subscript "0" is the left end position of shafting, the subscript " $n-1$ " is the right end.

In the calculation process of the ship shafting alignment, the bearing load influence coefficient matrix C_{eff} is generally used to stand for the influence of the change of bearings' positions to the change of bearings' loads. According to the characteristic of bearing load influence coefficient matrix C_{eff} , the linear relationship between bearings' loads and bearings' positions can be expressed as:

$$R_{new} = C_{eff} \cdot \begin{bmatrix} Z_1 \\ \vdots \\ Z_i \\ \vdots \\ Z_m \end{bmatrix} + R_0 \quad (3)$$

where, $[Z_1 \ \dots \ Z_i \ \dots \ Z_m]^T$ is bearings' positions matrix, R_{new} is bearings' loads matrix after changing bearings' positions, R_0 is the bearings' loads matrix based on shafting bearings' positions in the same datum, i.e. when the bearings' positions are zero. The above method can be name "C-method".

3. Numerical calculation

The main parameters of a 64000DWT bulk carrier: the overall length of the ship is 199.90m, the length between the perpendiculars is 194.5m, the width is 32.26m, the molded depth is 18.50m, the design draft is 11.30m, the deadweight is 63800t, and the design speed is 14.00kn. The basic parameters of ship propulsion system: main engine is MAN B&W 5S60ME-C8.2 with two-stroke and slow-speed, the rated power is 8050kW, and the rated speed is 89.0r/min. The propeller is a fixed pitch propeller with 5 blades, the diameter is 6.70m and clockwise running. The shafting consists of 1 intermediate shaft, 1 propeller shaft, 1 intermediate bearing and 1 stern-tube bearing. The arrangement of the main engine and shafting is shown in figure 1, where the intermediate bearing is close to the propeller shaft, mainly considering the ship adopted single stern-tube bearing form, the position of intermediate bearing and stern-tube bearing has remarkable effect on shafting bearings' load distribution.

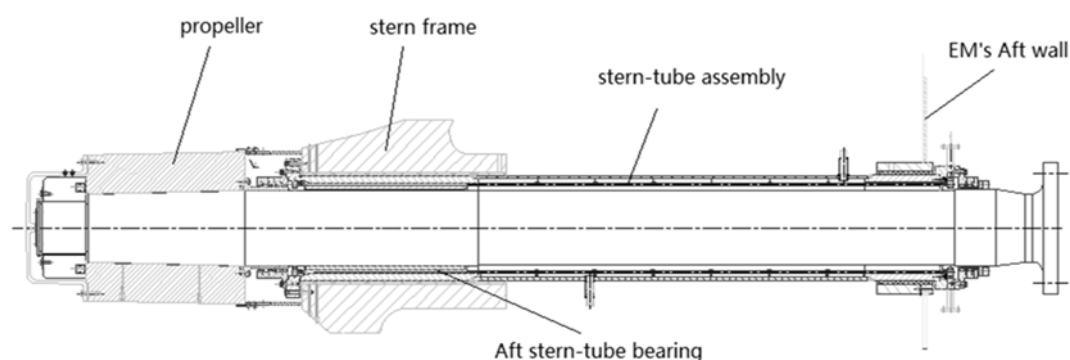


Figure 2. Schematic diagram of shafting with single stern-tube bearing

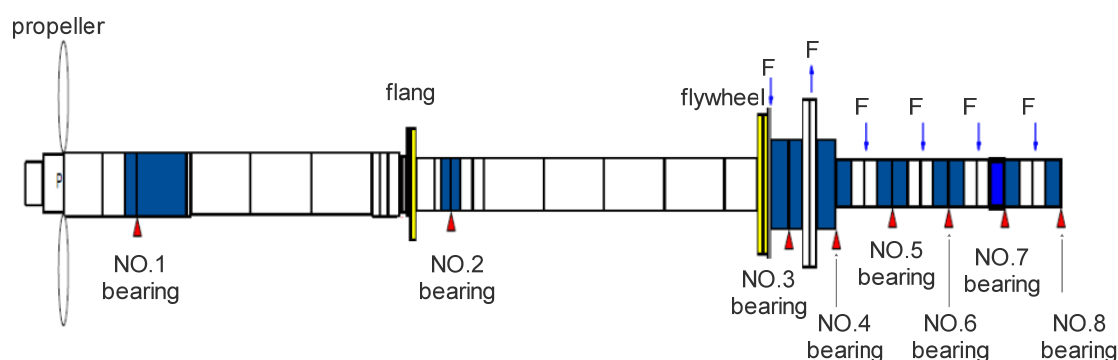


Figure 3. Geometric diagram of the marine shafting alignment

According to the basic methods of shafting alignment calculation, Figure 2 is obtained by simplifying the ship shafting system and the calculated elements' division. Figure 2 shows there are eight bearings in the shafting, one concentrate mass and 6 concentrate force, where No. 1 bearing is the stern-tube

bearing, No. 2 is intermediate bearing, No.3 ~ No.8 is the main bearings of main engine which are installed in the crankcase of the main engine integrally (Figure 3).

4. Marine Shafting Alignment Calculation

According to Equation (1), the deflections and bending moments of ship shafting nodes can be got in MATLAB platform, plug them into equation (2), the bearings loads initial value namely R_0 when each bearing elevation is zero can be got. According to the bearing load influence coefficient definition, in turn the bearing elevation would be improved by 1 mm, the difference in value between R_0 and bearings' loads is shown in Table 1, which shows the influence coefficient of shafting bearings' loads, which has the characteristics of symmetric matrix and shows the linear relations between ship shafting bearings' loads and bearings' deflections.

Table1. Effective coefficient of the shafting bearings' loads (ken/mm)

SN	1	2	3	4	5	6	7	8
1	4.229	-10.58	25.426	-20.955	2.388	-0.637	0.159	-0.027
2	-10.584	0.032	-114.60	102.126	-11.641	3.104	-0.776	0.129
3	25.426	-114.61	1209.77	-1817.5	883.377	-235.57	58.892	-9.815
4	-20.955	102.126	-1817.5	3469.83	-2547.8	1028.51	-257.13	42.854
5	2.389	-11.641	883.378	-2547.8	3264.70	-2354.3	915.854	-152.6
6	-0.637	3.104	-235.57	1028.51	-2354.3	3071.54	-2077.0	564.36
7	0.159	-0.776	58.892	-257.13	915.854	-2077.0	2155.68	-795.66
8	-0.027	0.129	-9.815	42.854	-152.6	564.36	-795.66	350.8

Equation (3) shows that under known numbers C_{eff} and R_0 , the bearings' loads can be directly calculated through the shafting bearings' deflections, so it is easy to get the theoretical value of the shafting bearings' loads in the cold and hot states, which are shown in Table 2.

Table 2. The bearings' loads of marine shafting

Items \ SN		1	2	3	4	5	6	7	8
Zero-con	Z/mm	0	0	0	0	0	0	0	0
	R0 /ken/mm	289.8	14.8	280.7	-108.0	20.6	149.0	203.1	57.2
Cool-con	Z/mm	0	-1.7	-4.62	-4.62	-4.62	-4.62	-4.62	-
	Arc/ ken/mm	278.4	60.1	63.5	93.4	183.4	155.1	201.6	57.5
Hot-con	Z/mm	0	-1.7	-4.34	-4.34	-4.34	-4.34	-4.34	-
	Rh/ ken/mm	280.2	54.0	88.4	70.7	186.0	154.4	201.7	57.5

As shown in Table 2, only taking the thermal deformation of bearings, gear box and main engine into consideration and taking the ship shafting bearings' thermal loads as the evaluation criterion for shafting bearings' loads of working state, therefore the shafting bearings' loads change under different working conditions cannot be reflected. If taking the applicability of the calculation results in hot condition, and the consistency of bearings' positions change under different speed conditions and hot conditions into consideration, then the basic theory of oil film dynamics is needed for the preliminary calculation and analysis of each bearing position under hot conditions.

By MATLAB programming, the curve of the shafting bearings' position under different speed and the same bearings' loads, is got and shown in Figure 4, which shows: 1) the change rate and range of bearings' elevation values is different, namely suppose that the ship shafting bearings' loads remain constant and the shafting journals move up with rotation speed increasing, there is big difference between different journals' positions, especially the No. 1 bearing's journal has the biggest change

according to the corresponding curve; 2) due to the bearings' journal deflections are different, according to the basic theory of ship shafting system alignment, will inevitably lead to the bearings' loads change, and it is a thus contradiction to the assumption that the bearings' loads remain the same. The main reason is that the bearing oil film dynamic response is not considered in the process of the traditional theory of shafting alignment calculation.

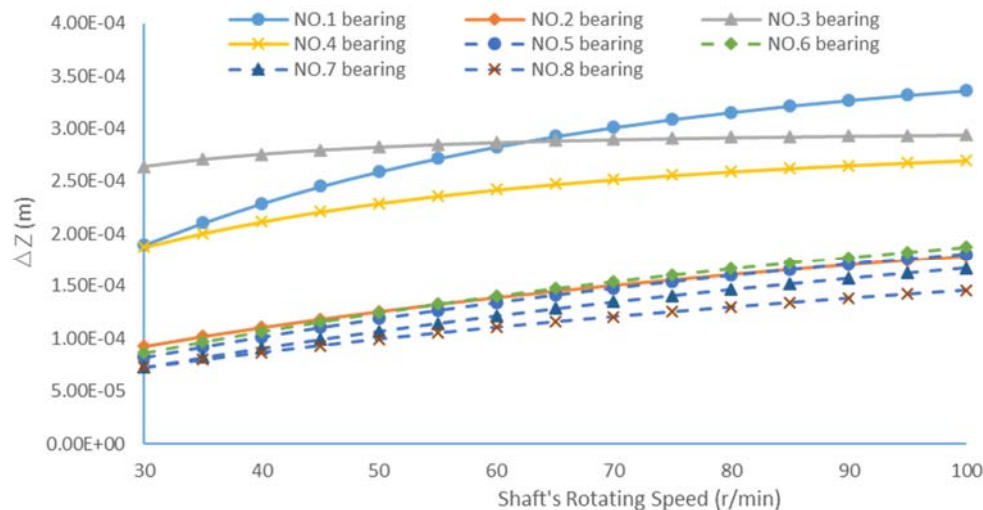


Figure 4. Shaft journals' deflections of marine shafting (constant bearings' loads)

5. Oil film dynamic response

Consider the bearing oil film dynamic response as one-way feedback, i.e. simply compound journals' deflections to shafting bearings' deflections, the bearings' "nominal loads" are obtained by "C-method" under different rotation speed working conditions. The "nominal loads" is based on the journals' deflections when ship shafting bearing load remain constant in hot condition, plug it into Equation (3) to get the corresponding bearings' loads. The "nominal loads" change rule according to the speed change is shown in Figure 5, where the fore and aft bearings' loads changes little, while the other four bearings' loads change is significant, particularly No. 5 bearing load changes from positive value to negative, i.e. the bearing supports empty, which is against with the actual engineering phenomenon.

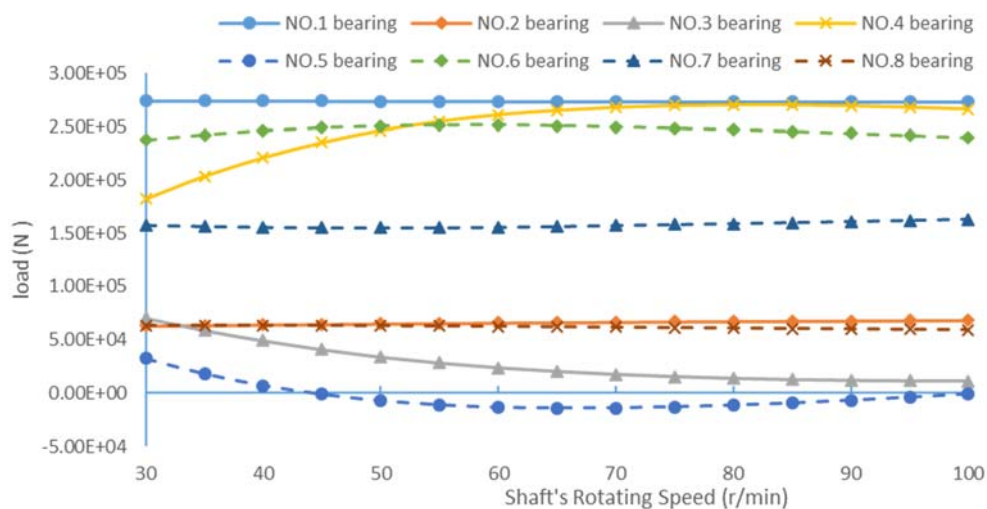


Figure 5. Nominal loads of marine shafting bearings

6. Conclusion

There is a certain difference between the thermal bearings' loads and the actual bearings' loads, which shows the "distortion" of bearings' loads calculation. The nominal loads of marine shafting bearings can represent the "distortion" of bearings' thermal loads to a certain extent. The bearings' loads of marine shafting are affected by the dynamic response of bearing oil film during the actual working process, and which will result in the redistribution of marine shafting bearings' loads.

Acknowledgments

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