Simulation Analysis of Installation Process of Long stern Shaft of Large Ship

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Abstract: Due to the large journal and long length, the installation of the stern shaft on the large ship is very difficult. In view of this situation, the numerical method based on three bending moments is used to analyze the number and arrangement position of temporary support during the installation of the stern shaft, to solve the change of the deflection and stress of the stern shaft and the reaction force of temporary support, and to obtain the influence law of the number and arrangement position of temporary support on the deflection and stress of the stern shaft. The calculation results show that when the stern shaft is pushed into the rear end face of the fore stern bearing, the deflection of the front end of the stern shaft is too large to pass the fore stern shaft tube bearing smoothly, so that a new technology of the guide shaft fixing at the front of the stern shaft was adopted, the structure, size and hoisting mode of the guide shaft were optimized, and the smooth installation of the long stern shaft was realized. The research results can provide a theoretical reference for the installation analysis and calculation of stern shaft section of large ships.

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1. Introduction
As an important part of shafting of large ships, the running state and performance of stern part are closely related to the installation process, which has been widely concerned [1]. However, the current research mainly focuses on the vibration state of the installed rear shafting, the shafting alignment [2,3] is limited to the installation of the medium and short stern shaft [4,5], and the research on the installation process method of the long shafting of large ships is relatively insufficient. Under the influence of many factors such as multiple stern bearings, hull deformation and environmental conditions, it is difficult to lift the stern shaft section, especially the long stern shaft directly. In view of this problem, this paper, based on the three-moment method, studies the particularity of the installation process of ship long stern shaft, including adding auxiliary installation device and installation method of guide shaft, determining the number and arrangement of temporary support during installation, and analyzing the deflection of stern shaft and the change of temporary support reaction force. The research results can provide theoretical support for the installation analysis and calculation of stern shaft section of large ships.

2. Basic data and questions raised
The stern shafting system of a large ship mainly includes propeller shaft, stern shaft, intermediate shaft, thrust shaft, coupling, sealing device and other related shafting accessories. The basic data related to the installation of stern shaft are as follows: The stern shaft diameter is Φ770mm, in the before, during and after the copper set of outer diameter of Φ800 mm, Φ810 mm and Φ810 mm, 15 m long; The
stern shaft system three water lubricated stern bearing (from stern to stem of stern: stern shaft bracket bearing, rear stern shaft tube bearing, fore stern shaft tube bearing) of inner diameter of \( \Phi 802 \text{ mm} \), \( \Phi 812 \text{ mm} \) and \( \Phi 812 \text{ mm} \); The stern tube length is 9.8 m. Due to the large shaft diameter and long length of the stern shaft, this technical problem will occur in the installation process: when the stern shaft passes through the stern shaft tube, only the rear stern shaft tube bearing can be used as a support to form the cantilever beam, resulting in the deflection of the front end of the stern shaft exceeding the matching clearance between the shaft and the bearing, making the stern shaft unable to pass through the front stern shaft tube bearing smoothly. Therefore, it is necessary to analyze the variation of the deflection of the stern shaft during the installation of the stern shaft and study the technological measures\(^{1,2}\) to ensure the smooth installation of the stern shaft.

3. Temporary support setting

Temporary support (trolley) shall be installed in the installation process of the stern shaft. The number and arrangement of temporary support will change dynamically with the propulsion of the stern shaft. Therefore, the number and arrangement of temporary support shall be selected to ensure that the deflection, stress and reaction force of the stern shaft (including the stern bearing) are within the allowable range. Figure 1 is a schematic diagram of the number and arrangement of temporary support at a certain time during the installation of the stern shaft.

![Figure 1 Schematic diagram of the shaft installation](image)

3.1 Determination of temporary support quantity

The number of temporary support is closely related to the weight of stern shaft and the allowable counter force of aft stern bearing and temporary support. The minimum value of temporary support is:

\[
a_{\text{min}} = \frac{mg - R'_{\text{max}}}{R_{\text{max}}} \tag{1}
\]

Where:  
- \( m \) — mass of stern shaft,  
- \( g \) — gravitational acceleration,  
- \( R'_{\text{max}} \) — allowable reaction force of rear stern tube bearing,  
- \( R_{\text{max}} \) — temporary support against allowable force.

3.2 Determination of temporary support placement

Take \( a_{\text{min}} \) as a whole and assume that the stern shaft has a temporary support. The stern shaft is divided into \( a + 2 \) shaft segments with both ends of the stern shaft and the support (including the rear stern shaft tube bearing) as the nodes. Each shaft segment is assumed to be an equal diameter shaft segment with no cross section change, see figure 2.
As can be seen from figure 2, an Angle equation can be listed for every 3 nodes, and a+1 equation can be listed in total \[^6,7\].

\[
\frac{L_i}{E_i I_i} M_{i+1} + 2 \left( \frac{L_i}{E_i I_i} + \frac{L_{i+1}}{E_{i+1} I_{i+1}} \right) M_i + \frac{L_{i+1}}{E_{i+1} I_{i+1}} M_{i+2} - \frac{6}{L_i} Y_{i-1} + \left( \frac{6}{L_i} + \frac{6}{L_{i+1}} \right) Y_i - \frac{6}{L_{i+1}} Y_{i+1} = - \frac{q_i L_i}{4 E_i I_i} - \frac{q_{i+1} L_{i+1}^3}{4 E_{i+1} I_{i+1}}
\]

(2)

Where: \(M_i\) -- bending moment of node \(i\),
\(L_i\) -- length of axis segment \(i\),
\(Y_i\) -- represents the deflection of node \(i\),
\(E_i\) -- represents the elastic modulus of axis segment \(i\),
\(I_i\) -- represents the moment of inertia of shaft segment \(i\),
\(q_i\) -- represents uniformly distributed load on shaft segment \(i\).

Free ends for stern shaft and zero bending moment. 4 equations can be obtained:

\[
M_i = 0, \quad M_{i+3} = 0
\]

\[
\frac{M_{i+2} - M_{i+3}}{L_{i+2}} + \frac{1}{2} q_{i+2} L_{i+2} = 0
\]

(3)

The actual support has a+1, which is regarded as rigid support, then its deflection value is equal to 0 (i=2, 3, ..., a+1), but since the \(Y_i\) and \(Y_{i+3}\) is unknown, the actual support \(Y_i\) is substituted into equation (2), from which 2a+6 formulas can be obtained. According to different \(L\) values, \(M\) and \(Y\) values can be solved respectively, namely

\[
[M_i, Y_i] = g(L_i), \quad i=1,2,\ldots,a+3
\]

(4)

In the calculation process, the midpoint of temporary support is taken as the supporting point, and the minimum distance \(L_{min}\) exists between the two temporary supports due to the influence of the base length. Set the position of each support point change, that is, the distance increment is \(L_x\), get the distance array.

\[
f = (f_1, f_2, f_3, \ldots, f_n)
\]

\[
f_k = (k_1 L_x, L_{min+k_2 L_x}, 2L_{min+k_3 L_x}, \ldots, k_n L_x)
\]

Where: \(f_k\) -- a set of distances for temporary support,
\(k_n\) -- the maximum number of increases in the distance of supporting points,
\(L_{b}\) -- distance from aft stern end to aft stern tube bearing rear end.

According to the different values of \(k_1, k_2, k_3, \ldots, k_m\), \(f\) can be obtained. By substituting \(f_k\) into equation (4), different \(M\) and \(Y\) values can be obtained. The supporting reaction force of each temporary support can be calculated, and the allowable value of each parameter can be determined.

The flow chart of temporary support determination is shown in figure 3.
Through simulation calculation, it is possible to obtain multiple sets of \( f_k \) that meet the requirements, as well as the corresponding \( M, Y \) and \( R \), and a group of optimal data can be selected as a reference for formulating the technical procedures for stern shaft installation \cite{8}. If the required \( f_k \) value cannot be obtained, the number of temporary support (i.e., \( a+1 \)) can be increased and repeated calculation can be carried out according to the calculation flow chart in figure 3 until the required data is obtained.

Set the length of temporary support base as \( L_l \), then the maximum number of temporary support \( a_{\text{max}} \) is

\[
a_{\text{max}} = \frac{L_b}{L_l} \quad (6)
\]

Where: \( L_b \) is the distance between rear end of stern shaft and rear end of stern shaft tube bearing. If there is still no data meeting the requirements when the number of temporary support reaches \( a_{\text{max}} \), the minimum \( Y \) value under this condition can be obtained by comparing the \( Y \) value under different numbers of temporary support, and the number and placement of temporary support represented by the output minimum \( Y \) value can be taken as the best data for this condition.

4. Calculation of installation process of stern shaft

When the stern shaft is installed, the stern shaft is bound to the temporary support (trolley) and moved together. The temporary support is installed in the corresponding groove track by its roller, and the cover plate above the track prevents the temporary support from being lifted when the supporting reaction is negative. The installation of stern shaft is a dynamic process, and the number and placement of temporary support involved is constantly changing. Under the condition of invariable in the temporary support, stern shaft and temporary support can be regarded as a kind of static state, and according to the location of the temporary support change condition is divided into a number of conditions, to get each working conditions is the relative position of stern shaft and temporary support, calculate the stern shaft deflection, stress reaction and temporary support, judge stern shaft can smoothly through the stern shaft tube bearing before.

The ship shafting has a propeller shaft and a stern shaft. When shafting is installed, the stern shaft
is generally installed first, and the propeller shaft and the stern shaft frame bearing are generally installed after the installation of the stern shaft, so that the stern shaft can be ensured to pass through the stern shaft frame without barrier and enter the installation stage of the stern tube. Before this installation stage, the fore and aft stern bearings inside the stern shaft have been installed. However, due to the machining error and coaxiality error of the two bearing holes, as well as the deformation of the stern shaft and the hull, the two bearing axes are not coaxial with the stern shaft, which affects the installation of the stern shaft. Therefore, at the beginning of installation, the optimal temporary support quantity and arrangement position of the stern shaft must be obtained before the installation of the stern shaft. When stern shaft propulsion can't meet the demand of the installation, should again for determining the number and arrangement of temporary support position, at the same time of alternative temporary support means, namely before a temporary support tear down, install the backup temporary support to remove the temporary support behind 0.5 m, in case of stern shaft bracket increases suddenly, cause the stern shaft bending stress and deflection.

In the installation process of the stern shaft, when the front end of the stern shaft is close to the rear end face of the fore stern bearing, the longest cantilever, the largest deflection and the increased temporary support load of the stern shaft are the worst installation conditions. Taking the installation status as an example, the optimal temporary support quantity and position are obtained by simulation calculation, as shown in figure 4.

The number of temporary supports is 3, L1 is 1800 mm, L2 is 2100 mm, L3 is 3500 mm, and L4 is 7700 mm. The deflection of stern shaft front end is minimum in this support plan.

![Diagram](image)

1-rear copper bush, 2-stern shaft, 3-temporary support, 4-rear stern shaft tube bearing, 5-Intermediate copper bush, 6-fore copper bush, 7-stern tube, 8-fore stern shaft tube bearing

Figure 4 Schematic diagram of the installation process of the boring shaft

After calculation, the stress state of temporary support is shown in table 1, and the deflection of stern shaft is shown in figure 5.

| Temporary support position | 1   | 2   | 3   | total |
|----------------------------|-----|-----|-----|-------|
| The reaction force / kN   | 145 | -585| 730 | 290   |

As can be seen from table 2, the reaction force of No.2 temporary support is negative, indicating that temporary support is subject to upward force.

![Diagram](image)

Figure 5 Tail shaft installation deflection diagram
As can be seen from figure 5, when the stern shaft is close to the rear end face of the front stern shaft tube bearing, the front deflection of the stern shaft reaches 12mm, and the front deflection of the front copper sleeve reaches 8.5mm. The front copper sleeve will touch the tube bearing base of the front stern shaft, and the reaction force of No. 3 temporary support support exceeds the allowable load (385 kN), resulting in the failure to continue the installation of the stern shaft.

5. Guide shaft installation analysis and calculation

In order to solve the problems existing in the installation process of the stern shaft, such as excessive deflection of the stern shaft and excessive temporary support load, the guide shaft and corresponding hoisting measures are proposed to reduce the deflection of the stern shaft and reduce temporary support load, so as to ensure that the stern shaft can safely pass through the tube bearing of the fore stern shaft. The guide shaft is connected with the fore end of the stern shaft. When the guide shaft goes through the stern tube, hoist crane is used to lift the guide shaft and improve the coaxiality between the stern shaft and guide shaft and the two stern tube bearings, so that the stern shaft can pass through the stern tube bearing smoothly.

When the stern shaft with guide shaft is mounted out of the fore stern shaft tube, install the hoist crane at 0.5m from the front end of the guide shaft, and bear a certain load, and move synchronously with the stern shaft. In the next working condition, keep the original hoist crane, install the new hoist crane in a new position, and remove the original hoist crane after adjusting the lifting distance of the hoist crane. There are three calculation conditions after installing the guide shaft of the stern shaft, as shown in figure 6.

![Figure 6  Schematic diagram of the installation condition of the guide shaft](image)

The working condition 1 is that the front end of the stern shaft is 0.1m from the rear end face of the front stern shaft tube bearing. The working condition 2: the front copper sleeve is 0.1m away from the rear end face of the front stern tube bearing, and the guide shaft shall be hoisted 2.4mm at the place where the hoist crane is installed. The working condition 3 is that the medium copper sleeve is 0.1m away from the rear end face of the fore and aft bearing. After calculation, the supporting force status is shown in table 2, and the deflection of stern shaft is shown in figure 7. As can be seen from table 3, the reaction force of each support does not exceed the allowable load.

| Table 2  | Each support branch reaction force (kN) |
|----------|----------------------------------------|
| item     | support 1 | support 2 | support 3 | total |
| The working condition 1 | 63 | -74 | 262 | 72 | 323 |
| The working condition 2 | 61 | -120 | 287 | 95 | 323 |
| The working condition 3 | 59 | -183 | 343 | 104 | 323 |
In the working condition 1, 2 and 3 cases, the guide shaft must lift the corresponding height, respectively, in this height under various conditions through the dangerous section of stern shaft tube bearing before, such as: the stern shaft front in working condition 1, the former copper in the copper set of front in working condition 2 and sets of front end in working condition 3, their deflection are less than 1 mm, stern shaft can be successfully installed.

In the actual installation process, the vertical distance between the outer diameter of the guide shaft passing through the stern tube and the inner surface of the bearing of the fore stern tube can be measured, and the lifting amount of this section center relative to the theoretical center line can be calculated.

With the continuous propulsion of the stern shaft, the length of the stern shaft entering into the stern tube increases accordingly, the height of the hoist lifting stern shaft becomes smaller and smaller, and the temporary support force of the hoist crane and the rightmost end also increases gradually.

6. Conclusions
In this paper, three moment method is adopted to simulate and analyze the number and arrangement of temporary support during the installation of a long stern shaft of a real ship, and the size optimization analysis of the guide shaft is carried out to ensure the smooth installation of the stern shaft. The main conclusions are as follows:

1) based on the three-moment method, the optimal calculation results of the number of temporary support and the arrangement position are given to minimize the deflection of the long stern shaft under the condition of cantilever and ensure the smooth installation of the long stern shaft.

2) the installation method of guiding the large-diameter and long-length stern shaft through the tube bearing of the fore stern shaft by means of the guide shaft is proposed, and the inner diameter, outer diameter and length of the guide shaft are optimized by means of the three-moment method.

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