

Research on the Alignment Method for Multi-Segment Long Shaft Systems

Peng Tang, Junhua Zhao

School of Mechanical Engineering, Jiangnan University, Wuxi, 214122, China

Abstract

Aiming at the problems of frequent measurement, difficult adjustment and error accumulation in conventional alignment of a ship's multi-segment long shaft system due to many moving parts and dense nodes, this paper proposes an integrated scheme of "tooling constraint-stepwise alignment-laser detection-overall re-inspection" by analyzing technical principles, designing special tooling and optimizing process flow, combined with the onshore experiment scenario. The scheme restricts the movement allowance of self-aligning roller bearings and drum gear couplings through positioning tooling, and achieves high-precision measurement with a laser aligner. Finally, the radial deviation of the shaft system is controlled within $\leq 0.2\text{mm}$ and the axial deflection within $\leq 0.25\text{mm/m}$. Moreover, the shaft system shows excellent precision stability after 4 hours of no-load operation, providing engineering reference for the alignment of similar shaft systems.

Keywords

Multi-segment long shaft system; Drum gear coupling; Self-aligning roller bearing; Laser alignment technology.

1. INTRODUCTION

As the core carrier for power transmission in ships, the alignment precision of the shaft system directly determines the operational stability of the power system, the service life of components, and the navigation safety of the ship [1]. To balance the requirements of small-space installation and high-power transmission, the shaft system of a certain ship adopts a multi-segment long shaft design. It includes 1 gearbox, 3 self-aligning roller bearing housings, 1 load, 4 transmission shafts, and 3 diaphragm couplings, forming 4 key alignment nodes. The structure of the shaft system is shown in Figure 1.

Compared with traditional ship shaft systems, this shaft system integrates components with large movement allowances such as drum gear couplings and self-aligning roller bearings. If the conventional method of "integral shaft connection - sequential alignment" is adopted, problems such as subsequent node adjustments interfering with the previous precision and excessive accumulated errors are likely to occur. Therefore, based on the structural characteristics of this shaft system and the advantages of the onshore experimental scenario, this paper conducts research on the design of special tooling and the stepwise alignment process, aiming to form a high-precision and high-efficiency alignment solution.

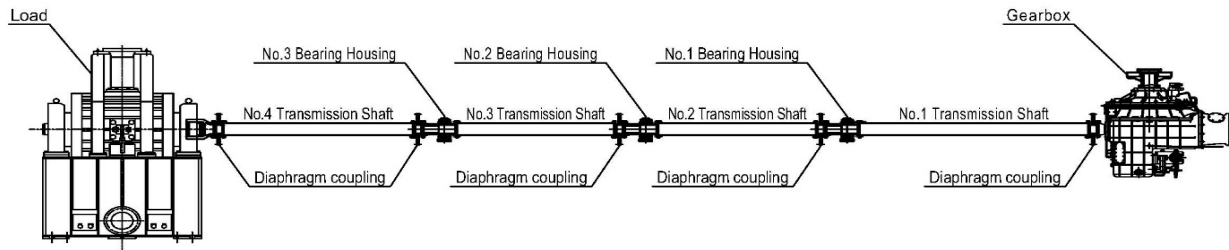


Figure 1. Schematic Diagram of the Transmission Shaft System

2. STRUCTURAL CHARACTERISTICS AND ALIGNMENT DIFFICULTIES OF THE TRANSMISSION DEVICE

2.1. Drum Gear Coupling

The output end of the gearbox is connected to the shaft system using a drum gear coupling, whose structure is shown in Figure 2. This coupling is a rigid-flexible transmission component [2], and its alignment difficulties are as follows:

(1) Large static angular movement: When unloaded, the meshing gap of the tooth surface allows the coupling to deflect freely around the axis, making it difficult to locate the reference position during initial alignment.

(2) Uncontrollable axial clearance: There is a 6mm adjustment allowance along the axial direction. If the axial position is not precisely controlled, it is easy to cause the diaphragm coupling to have an excessive stretching amount.

(3) Narrow installation space: The distance between the coupling and the bearing housing is only 50 - 80mm, which makes it difficult for conventional measuring tools to extend into.

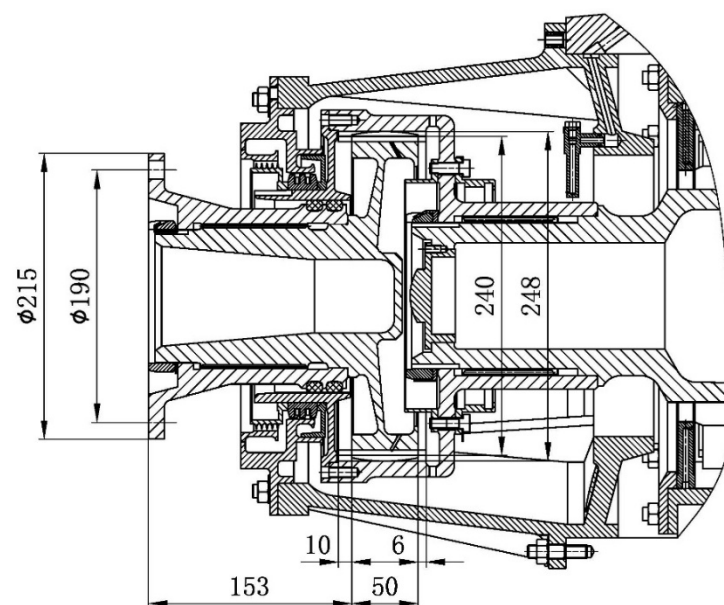


Figure 2. Structural Diagram of the Drum Gear Coupling

2.2. Self-Aligning Roller Bearing Housing

The 3 self-aligning roller bearing housings have the same structure (Figure 3), and the bearing model is 22320CA/W33, which has the characteristics of strong load-carrying capacity and excellent impact resistance [3]. However, its alignment difficulties are mainly reflected in:

(1) Low radial positioning precision: The fit clearance between the inner ring of the bearing and the shaft is H7/js6, and the shaft can have a large radial deviation in the inner ring of the bearing in the static state, affecting the consistency of the centerline.

(2) No reference for angular adjustment: The outer ring of the bearing and the housing hole are in a transition fit, and can deflect around the center of the outer ring when not constrained, leading to the deviation of the centerline of the bearing housing.

(3) Easy deformation of the installation reference: The base frame of the bearing housing adopts a welded structure, and uneven pre-tightening force of the fastening bolts can easily cause deformation of the base frame, affecting the stability of the alignment reference.

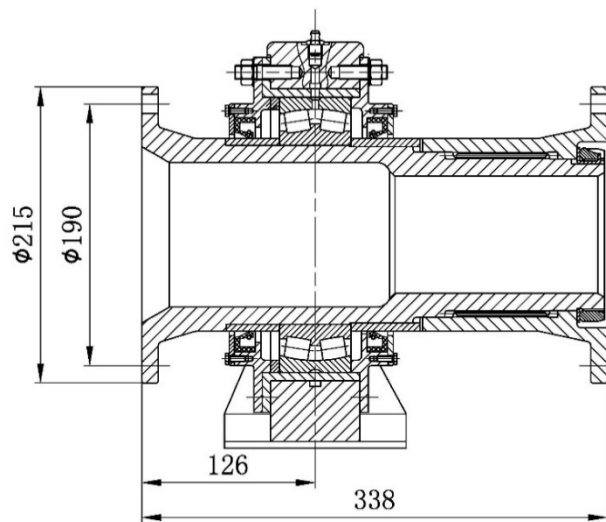


Figure 3. Structural Diagram of the Self-Aligning Roller Bearing Housing

3. SHAFT SYSTEM ALIGNMENT METHOD

3.1. Selection of Centerline Confirmation Method

The first step in shaft system alignment is to determine the reference centerline. Common methods include the wire drawing method, optical lighting method, and laser alignment method. Combined with the onshore experimental scenario of this study, the optical lighting method is selected

3.2. Selection of Alignment Measurement Technology

To meet the requirements of multi-node and high-precision shaft system alignment, the technical characteristics of the double-indicator method and the laser aligner method [4] are compared and analyzed (Table 1). Finally, the laser aligner method is selected, and its advantages are reflected in:

(1) High measurement precision: The radial deviation resolution is 0.001mm, and the angular deviation resolution is 0.001mm/m, which meets the requirements of multi-node accumulated error control.

(2) High operation efficiency: The measurement time for a single node is only 5 - 8min, which is 3 times more efficient than the double-indicator method (20 - 30min/node).

(3) Data visualization: The equipment can display the deviation direction and adjustment amount in real time, avoiding manual calculation errors.

Table 1. Comparison of Alignment Measurement Methods

Technical Indicator	Double-Indicator Method	Laser Aligner Method
Radial Deviation Precision	$\pm 0.01\text{mm}$	$\pm 0.001\text{mm}$
Angular Deviation Precision	$\pm 0.01\text{mm/m}$	$\pm 0.001\text{mm/m}$
Single Node Measurement Time	20~30min	5~8min
Applicable Shaft System Length	$\leq 5\text{m}$	$\leq 15\text{m}$
Sensitivity to Environmental Interference	High (easily affected by vibration)	Low (with anti-interference algorithm)

4. DESIGN OF SPECIAL TOOLING AND IMPLEMENTATION OF ALIGNMENT PROCESS

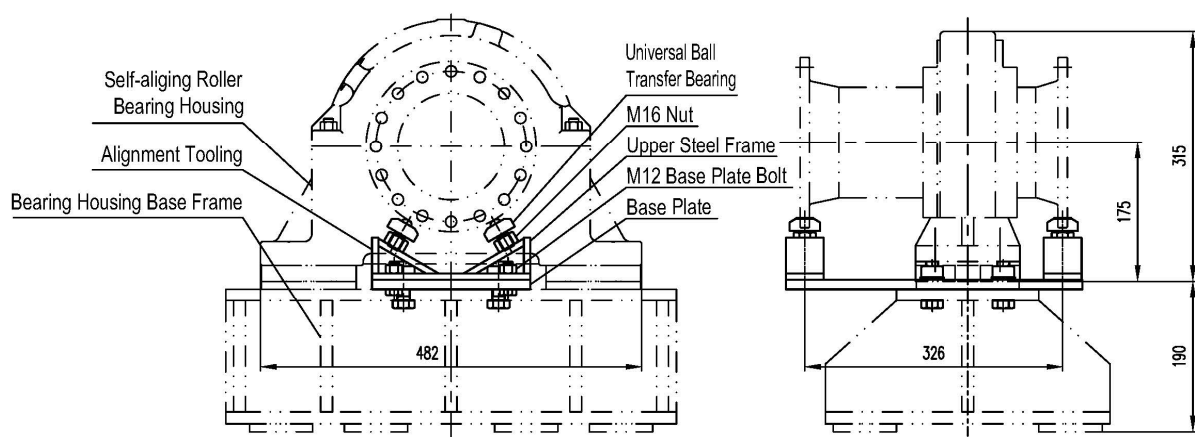
4.1. Positioning Tooling for Self-Aligning Roller Bearing Housing

To restrict the radial and angular movement of the self-aligning roller bearing, a special positioning tooling [5] is used (Figure 4). The tooling consists of the following components:

(1) Bottom base: Processed from Q235 steel plate, it is rigidly connected to the bearing housing base frame through 4 sets of M12 bolts to ensure the positioning precision of the tooling itself.

(2) Middle adjustment mechanism: Contains 4 sets of M16 jacking screws (evenly distributed in the circumferential direction), which can fine-tune the radial position of the bearing housing with an adjustment precision of $\pm 0.02\text{mm}$.

(3) Upper V-shaped positioning frame: Built-in with 4 universal ball bullseye bearings, which are in contact with the outer ring of the bearing to limit the angular deflection of the bearing and avoid damage to the bearing surface at the same time.

**Figure 4.** Schematic Diagram of the Bearing Housing Alignment Tooling

Tooling Usage Process:

(1) Fix the bottom base of the tooling to the base frame of the bearing housing to ensure that the parallelism between the upper surface of the base and the installation plane of the bearing housing is $\leq 0.05\text{mm/m}$.

(2) Rotate the middle jacking screws to push the bearing housing to move radially, and monitor the deviation between the centerline of the inner hole of the bearing housing and the reference line through a dial indicator until the radial deviation is $\leq 0.05\text{mm}$.

(3) Lock the jacking screws and install locknuts, and measure the distance L1 between surface A and surface B of the bearing housing (Figure 5) using a depth micrometer. Ensure that the difference in L1 between the diagonal points is $\leq 0.05\text{mm}$, and the converted deflection angle is $\leq 0.25\text{mm/m}$.

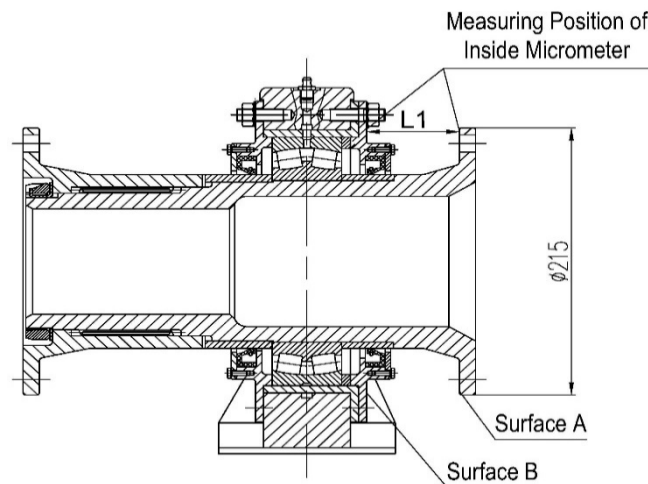


Figure 5. Schematic Diagram of Bearing Housing Alignment Measurement

4.2. Axial and Angular Positioning of the Drum Gear Coupling

The drum gear coupling needs to complete the pre-adjustment of the axial position and angular deviation, and the specific operations are as follows:

4.2.1 Axial Adjustment

According to the structural parameters in Figure 2, the axial adjustment amount of the drum gear coupling is 6mm. To ensure that it is in the axial central position (to avoid excessive stretching of the diaphragm coupling), the operation steps are as follows:

(1) Clean the surfaces of the inner gear ring and outer gear sleeve of the coupling, and apply a small amount of lubricating grease (model: L-AN46) to reduce sliding resistance.

(2) Use a copper rod to push the coupling inward, and at the same time slowly rotate the shaft (rotating speed: 5r/min) until the coupling reaches the axial thrust point (sudden change in hand feeling resistance).

(3) Pull out the coupling in the reverse direction by approximately 3mm, and measure the distance L2 between the end face of the coupling and the bearing housing (Figure 6) using an internal micrometer (precision: 0.001mm). Select 4 points evenly along the circumference, and require the deviation of L2 to be $\leq 0.03\text{mm}$ to ensure accurate axial position.

4.2.2 Angular Adjustment

With reference to the precision requirements of the self-aligning roller bearing, the deflection angle of the drum gear coupling should be $\leq 0.25\text{mm/m}$. Due to the narrow installation space of the coupling, the method of extending with a dummy shaft is adopted (Figure 7), and the specific process is as follows:

(1) One end of the dummy shaft is connected to the outer gear sleeve of the coupling through a taper fit with no clearance.

(2) The other end of the dummy shaft is supported by the positioning tooling of the self-aligning roller bearing housing to ensure that the parallelism between the centerline of the dummy shaft and the reference line is $\leq 0.02\text{mm/m}$.

(3) Use a laser aligner to detect the angular deviation of the dummy shaft, and adjust the height of the bullseye bearing of the tooling until the deflection angle is $\leq 0.25\text{mm/m}$; at the same time, measure the distance L2 between surface A and surface B of the coupling (Figure 6), and require the difference in L2 between the diagonal points to be $\leq 0.05\text{mm}$ to verify the angular precision.

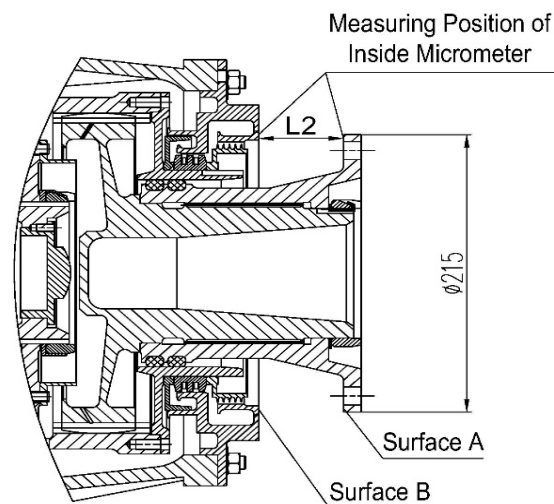


Figure 6. Schematic Diagram of Drum Gear Coupling Alignment Measurement

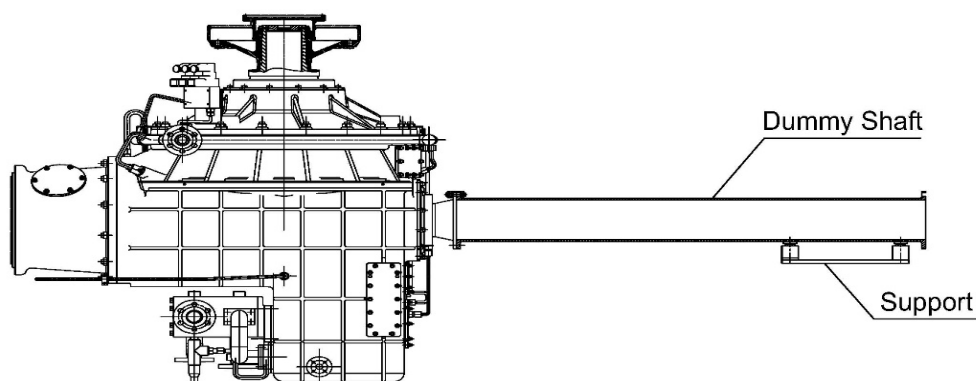


Figure 7. Schematic Diagram of Dummy Shaft Installation for Gear Coupling

4.3. Alignment Process and Precision Control

A stepwise alignment process of "independent node adjustment - overall connection calibration" is adopted, and the operations are performed sequentially for the 4 alignment nodes. The specific process is as follows:

(1) Pre-adjustment stage: Complete the tooling positioning of the bearing housing and gearbox according to the processes in Sections 3.1 and 3.2, ensuring that the reference deviation of each component is $\leq 0.25\text{mm/m}$.

(2) Alignment of Node 1 (Gearbox - No.1 Bearing Housing):

Install the transmitter and receiver of the laser aligner on the output end of the gearbox and the flange of the No.1 bearing housing;

Rotate the shaft system by 360°, collect the deviation data of 3 cross-sections (0°, 120°, 240°), adjust the jacking screws of the base frame of the No.1 bearing housing to make the radial deviation and axial deflection meet the required values, and at the same time measure the distance between the two transmission devices using an internal micrometer to ensure the diaphragm stretching amount is 0.1 - 0.5mm.

(3) Alignment of Node 2 (No.1 Bearing Housing - No.2 Bearing Housing):

Remove the laser device at the gearbox end and install it on the flange of the No.2 bearing housing;

Rotate the shaft system by 360°, collect the deviation data of 3 cross-sections (0°, 120°, 240°), adjust the jacking screws of the base frame of the No.2 bearing housing to make the radial deviation and axial deflection meet the required values, and at the same time measure the distance between the two bearing housings using an internal micrometer to ensure the diaphragm stretching amount is 0.1 - 0.5mm.

(4) Alignment of Node 3 (No.2 Bearing Housing - No.3 Bearing Housing):

The process is the same as that of Node 2 alignment.

(5) Alignment of Node 4 (No.3 Bearing Housing - Load):

Install the transmitter and receiver of the laser aligner on the flange of the No.3 bearing housing and the load flange;

Rotate the shaft system by 360°, collect the deviation data of 3 cross-sections (0°, 120°, 240°), adjust the jacking screws of the load base frame to make the radial deviation and axial deflection meet the required values, and at the same time measure the distance between the two transmission devices using an internal micrometer. Since there are 2 diaphragm couplings installed in the middle, the total diaphragm stretching amount should be ensured to be 0.2 - 1.0mm.

(6) Overall re-inspection: Install all transmission shafts and diaphragm couplings, and re-inspect the deviations of the 4 nodes using a laser aligner (Table 4).

5. ALIGNMENT DATA AND EFFECT ANALYSIS

5.1. Alignment Data of Key Components

Table 2. Alignment Precision Data of Self-Aligning Roller Bearing Housing

Serial Number	Bearing Housing Name	Distance L1 between Surface A and Surface B (mm)				Deflection Angle (mm/m)
		Point 1	Point 2	Point 3	Point 4	
1	No.1	143.33	143.32	143.33	143.33	0.06
2	No.2	143.38	143.36	143.36	143.37	0.12
3	No.3	143.41	143.42	143.42	143.40	0.12

Table 3. Alignment Precision Data of Drum Gear Coupling

Serial Number	Part	Distance L1 between Surface A and Surface B (mm)				Deflection Angle (mm/m)
		Point 1	Point 2	Point 3	Point 4	
1	Output End of Gearbox	59.77	59.76	59.77	59.77	0.05

5.2. Shaft System Alignment and Re-Inspection Data

Table 4. Shaft System Alignment Precision Data (Initial Alignment)

Serial Number	Alignment Node	Radial Deviation (mm)		Axial Deflection (mm/m)		Diaphragm Stretching Amount (mm)	
		Required Value	Measured Value	Required Value	Measured Value	Required Value	Measured Value
1	Gearbox and No.1 Bearing Housing	≤ 0.2	0.08	≤ 0.25	0.09	0.1~0.5	0.34
2	No.1 and No.2 Bearing Housing	≤ 0.2	0.07	≤ 0.25	0.06	0.1~0.5	0.33
3	No.2 and No.3 Bearing Housing	≤ 0.2	0.08	≤ 0.25	0.14	0.1~0.5	0.27
4	No.3 Bearing Housing and Load	≤ 0.2	0.04	≤ 0.25	0.07	0.2~1.0	0.59

Table 5. Shaft System Alignment Precision Data (Overall Re-inspection)

Serial Number	Alignment Node	Radial Deviation (mm)		Axial Deflection (mm/m)	
		Required Value	Measured Value	Required Value	Measured Value
1	Gearbox and No.1 Bearing Housing	≤ 0.2	0.08	≤ 0.25	0.09
2	No.1 and No.2 Bearing Housing	≤ 0.2	0.07	≤ 0.25	0.06
3	No.2 and No.3 Bearing Housing	≤ 0.2	0.08	≤ 0.25	0.14
4	No.3 Bearing Housing and Load	≤ 0.2	0.04	≤ 0.25	0.07

5.3. Verification of Alignment Effect

1. Precision compliance rate: The re-inspected values of radial deviation and axial deflection of the 4 alignment nodes all meet the design requirements, with a compliance rate of 100%; due to the elastic compensation effect of the diaphragm coupling, the re-inspection precision is better than the initial alignment precision.

2. Efficiency improvement: By adopting the stepwise alignment process, the average alignment time for a single node is 8min. Compared with the conventional overall alignment method (25min/node), the efficiency is improved by 68%.

6. CONCLUSIONS

1. Aiming at the alignment difficulties of the multi-segment long shaft system, the designed positioning tooling for the self-aligning roller bearing housing and the dummy shaft extension tooling for the drum gear coupling can effectively restrict the movement allowance of the components, and control the initial positioning precision within 0.25mm/m.

2. The proposed stepwise alignment process solves the problem of accumulated errors in the conventional overall alignment method through "independent node adjustment - overall connection calibration", enabling the overall alignment precision of the shaft system to meet the requirements of radial deviation $\leq 0.2\text{mm}$ and axial deflection $\leq 0.25\text{mm/m}$.

3. The diaphragm coupling can provide a deviation compensation of 0.05 - 0.10mm during the operation of the shaft system, further optimizing the alignment precision, which verifies the compatibility and reliability of this alignment scheme.

REFERENCES

- [1] XIA, X. S. (2011). Research on alignment installation process and practice of long shaft system for 6500HP AHTS main power unit [in Chinese]. *Ship Standardization Engineer*, 44(2), 33-35. <https://doi.org/10.3969/j.issn.1005-7560.2011.02.005>
- [2] ZENG, W. L., GUO, Z. J., HUANG, S. Y., & others. (2019). Installation and maintenance of drum gear couplings [in Chinese]. *China Metal Bulletin*, (12), 71, 73. <https://doi.org/10.3969/j.issn.1672-1667.2019.12.045>
- [3] WU, G. (2020). Simulation of contact characteristics of double-row self-aligning roller bearings based on ANSYS Workbench [in Chinese]. *Coal Mine Machinery*, 41(6), 191-193. <https://doi.org/10.13436/j.mkjx.202006063>
- [4] HUANG, D. M. (2017). Comparison of several methods for coupling alignment [in Chinese]. *Mechanical and Electrical Information*, (30), 67-68. <https://doi.org/10.3969/j.issn.1671-0797.2017.30.035>
- [5] Wuxi Branch of No. 703 Research Institute of China Shipbuilding Heavy Industry Corporation. (2023). An eccentric alignment adjustment tooling and adjustment method for self-aligning roller bearings: CN202210705736.3 [Patent] [in Chinese]. 2023-05-02.