Simulation analysis of modular assembly accuracy of marine power shafting based on 3DCS

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ABSTRACT

Modular shipbuilding can effectively shorten the cycle of construction and improve quality of the product, however stricter requirements of the accuracy control for product have been proposed at the same time. Taking a marine power shafting as an example, the influences of part manufacturing, positioning and matching errors on the axial and radial deviations of the stern and power shaft were studied based on 3DCS. The main factors affecting the assembly accuracy and their contribution were determined. It was found that the sealing device was the most influential factor for the deviation of stern and power shaft. The contribution of sealing device to the radial and axial deviation of stern shaft were 99.45% and 83.12% respectively, and to the radial and axial deviation of power shaft were 98.91% and 74.21% respectively. The research results would provide guidance for accuracy control of marine shafting modular construction.

Keywords: Marine power shafting, modular assembly, accuracy control, simulation analysis

1. INTRODUCTION

In recent years, modular construction technology has been widely used in the field of shipbuilding, which can shorten the production cycle of product, improve efficiency and reduce cost. For instance, the US Virginia nuclear submarine fully adopted the modular design idea, proposed corresponding functional modules for each mission and task, and carried out the combined design of different functional modules at the same time[1-2]. China Donghong Shipbuilding Corporation implemented "modular" technology on the basis of "segmented" shipbuilding, and the shipbuilding cycle was reduced nearly 70 days[3]. Power plant is an important part of ship, and its modular degree is a significant basis for modular shipbuilding. The power plant contains various shafting, such as stern shaft, thrust shaft, power shaft, etc., and each shaft is assembled according to a certain process. The power plant has long installation dimension chain, many installation and docking interfaces, meanwhile some errors are existing, such as manufacturing errors, positioning errors and matching errors, which results in an excess accuracy[4]. Due to the generated large deviation, it is difficult to dock and install with the docking installation equipment, even some abnormal operation problems occur, such as vibrations and noises. Therefore, higher accuracy requirements are required in the ship modular construction.

In the process of shipbuilding, the calculation method of dimension chain is the basis of accuracy distribution and control. The commonly used methods are the worst case method and probability method. Liu[5] introduced the application of worst case and probability method in two-dimensional dimension chain analysis and tolerance distribution, and the adding compensation ring was considered one of the main means to improve accuracy. Zhang[6] used the worst case method and probability method to carry out the calculation accuracy distribution of modular construction of the power plant. The results showed that the accuracy distribution of each docking and installation link were reasonable and feasible, and the setting of relevant adjustment allowance met the construction requirements. Leng[7] studied the accuracy distribution and deviation control of low streamline enclosure construction using the worst case method, and the construction accuracy control measures were described. The worst case method is based on the complete interchangeability of products, which requires high machining accuracy and increases the cost. The probability method considers the statistical distribution law of part tolerance which is closer to reality, but it is only suitable for the linear analysis of two-dimensional dimension chain.

Monte Carlo method could be used to describe the characteristics of things and physical processes realistically through statistical experiments of random variables[8-9]. For example, 3DCS (Three Dimensional Control System) software is a three-dimensional dimensional tolerance simulation software based on Monte Carlo method, which is used in dimensional

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tolerance analysis in automotive, aerospace and other fields widely. Lv[10] simulated and optimized the tolerance allocation scheme of aircraft wing box based on 3DCS. Wang[11] analyzed the dimensional deviation of automobile door assembly based on 3DCS, and determined the optimal assembly scheme. Wang[12] analyzed the tolerance of missile cabin assembly based on 3DCS, and some unreasonable designs were improved. Traditional two-dimensional dimension chain analysis methods have certain limitations when applied to the three-dimensional assembly accuracy analysis of parts, and the assembly process and dimensional deviation changes of parts could not be displayed directly[13]. Therefore, the simulation analysis of modular assembly accuracy of marine power shafting based on 3DCS is of great practical guiding significance.

2. DEFINITION OF MARINE POWER SHAFTING ASSEMBLY PROCESS

2.1 Product description

Marine power shafting is generally composed of sealing device MFZZ, stern bearing WZC, stern shaft WZ, rear shaft HZ, thrust shaft TZ, front shaft QZ, thrust bearing TZC, clutch LHQ, power shaft DZ and platform PT, as shown in Figure 1.

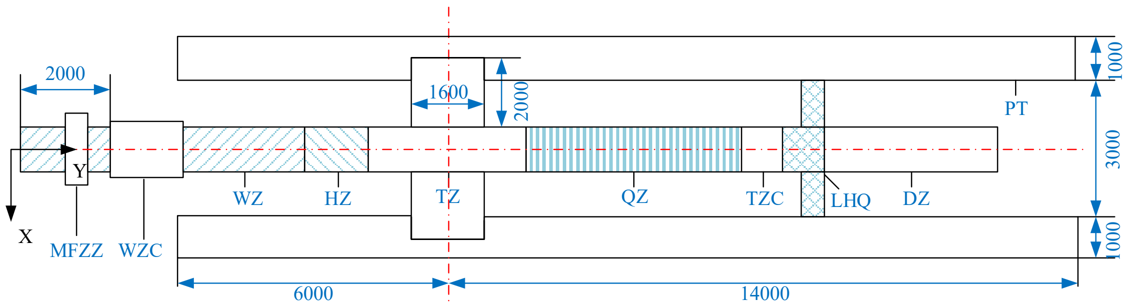

Figure 1. Schematic diagram of marine power shafting.

Among them, the Y axis coincides with the center line of the marine power shafting, and the center of the left end face of the stern shaft WZ is the origin of the coordinates. The specific dimensions of each part are listed in Table 1.

Table 1. The related dimensions of marine power shafting.

Parts	Length (mm)	Outer diameter (mm)	Inner diameter (mm)
WZ	6335	1000	0
WZC	1800	1250	1020
HZ	1420	1000	0
TZ	3500	1000	0
QZ	4800	1000	0
TZC	1530	1000	0
LHQ	950	1000	0
DZ	3840	1000	0
MFZZ	500	1600	1100

2.2 Deviation determination

Each shaft has a centering offset of 0.1 mm relative to the previous adjacent mounting part, and an alignment deflection of 0.15 mm/m. At the same time, the parts have manufacturing errors, which are determined by the upper and lower deviation. The upper deviation is $es = d_{max} - d$, and the lower deviation is $ei = d_{min} - d$. Among them, the axial manufacturing errors of TZ, QZ, DZ, TZC, LHQ, HZ and WZ, as well as the axial and radial installation deviations of MFZZ are listed in Table 2.

Table 2. Deviation values of shafting.

Parts	Reference value (mm)	Upper deviation (mm)	Lower deviation (mm)
The axial manufacturing deviation of TZ	0	0	-1
The axial manufacturing deviation of QZ	0	+1.5	0
The axial manufacturing deviation of DZ	0	0	-0.5
The axial manufacturing deviation of TZC	0	0	-0.5
The axial manufacturing deviation of LHQ	0	+0.8	-0.8
The axial manufacturing deviation of HZ	0	+0.5	-0.5
The axial manufacturing deviation of WZ	0	+1.5	0
The axial installation deviation of MFZZ	0	+2	-2
The radial installation deviation of MFZZ	0	+1	-1

The paper mainly analyzed the influence of the manufacturing deviation and installation error of each shaft on the axial and radial deviation of the rear end face of WZ, and the axial and radial deviation of the front face of DZ.

2.3 Assembly process flow

The assembly process of marine power shafting is shown in Figure 2. According to the base point of the stern of the slipway structure, the sealing device MFZZ is installed. On the platform PT, the thrust shaft TZ is located and installed in the rectangular area according to the bolt hole position. According to the position of the thrust shaft TZ, the rear shaft HZ, stern shaft WZ and stern bearing WZC are installed successively on the end face of the thrust shaft TZ close to the sealing device MFZZ. According to the position of the thrust shaft TZ, the shaft QZ, bearing TZC, clutch LHQ and power shaft DZ are installed in sequence on the end face of the thrust shaft TZ away from the sealing device MFZZ. Finally, the platform PT is installed according to the position of the sealing device MFZZ.

3. MODEL ANALYSIS

As shown in Figure 3, the 3DCS software provides a method to predict the assembly variation, which was caused by part tolerance and assembly process; the software also could trace the influencing factors and analyses the contribution rate of each influencing factor. The simulation process has five major parts: building geometric model, defining feature points, setting the tolerance of part, assembly, setting measurement and running calculation.

3.1 Geometric model

The accuracy of the simulation results is determined by the accuracy of the three-dimensional geometric model. The constructed shaft models in Section 2 are imported into 3DCS. The assembled models contain the geometric design information and the geometric assembly feature information of the parts.

3.2 Defining feature points

In 3DCS software, Move, Tolerance and Measure are transmitted through the correlation of part feature points, so the feature points of each part should be created firstly. The part TZ and part PT are connected with four equally spaced bolt on both sides. Therefore, feature points are added at the corresponding positions to simulate the connection. Four feature points are created on the circumference of the front and rear end faces, respectively. Number 1-8 are used to name each point in turn. The bolted connection between shafts is simulated by feature point constraints.

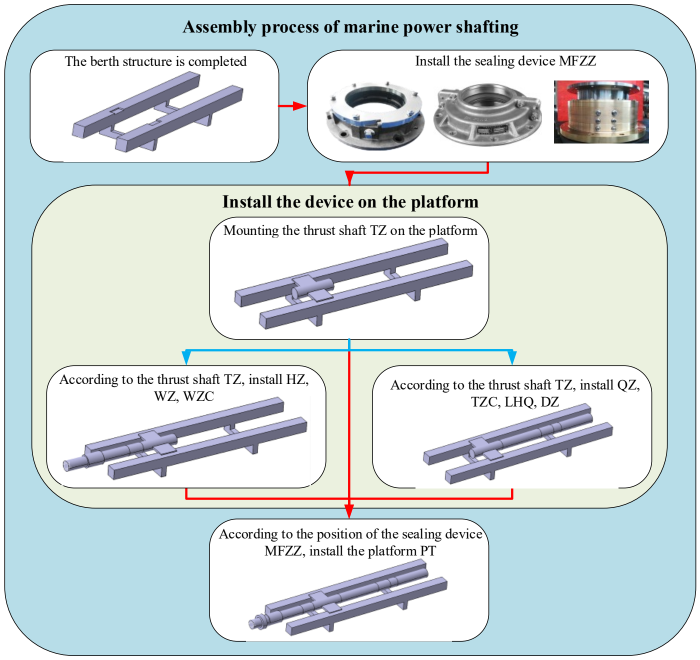

Figure 2. Assembly process of marine power shafting.

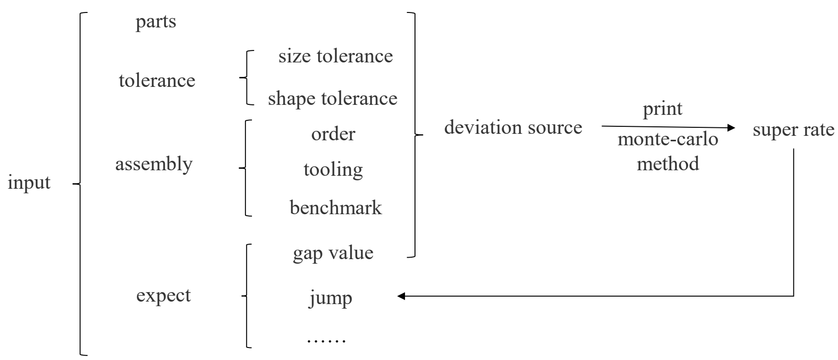

Figure 3. Flow diagram of 3DCS simulation.

3.3 Tolerance setting

Combining the deviation attributes of manufacturing deviation, centering offset and alignment deflection, the Tolerance type of manufacturing deviation is set as Linear Tolerance; the Tolerance type of center bias is set as Arc Tolerance; the Tolerance type of alignment deflection is set as Circular Tolerance, and relevant parameters is set to fully express relevant tolerance information.

The centering offset refers to the translation of the whole part along the radial direction, so only feature points 5-8 of parts are selected and the deviation is applied for them, where Rand#1 is the numerical value, and it is set to follow the right-skewed distribution along the diameter according to the actual situation. The setting of axial manufacturing deviation is similar to the centering offset. Linear Tolerance simulation requires only one parameter, so Rand#1 is the deviation, which is set to normal distribution, and the Range and Offset are set to correspond to the upper deviation value and lower deviation value, respectively. Arc Tolerance is used to set the deflection angle and deviation value for each shaft component. The deflection of the end point (points 5-8) of each shaft component relative to its starting point (point 0) is added when selecting the feature point. However, this Tolerance type can only represent the deflection on one-sided, so it is necessary to add the deviation in both X direction and Z direction. Rand#1 is the amplification factor, which is set to constant 1. Rand #2 is the deflection angle, which is set as normal distribution along the circumference.

3.4 Move and measure

Six-Plane Move is an assembly method of the most powerful and widely used in 3DCS. It has no direction requirements for six planes except that all degrees of freedom must be constrained. In this paper, the Move types between HZ and TZ, WZ and HZ, QZ and TZ, TZC and QZ, LHQ and TZC, DZC and LHQ are set to Six-Plane Move. Two-Point Move is mainly used to control the assembly of six degrees of freedom of parts by two points. The Move type between MFZZ and other parts is set as Two-Points, and each part is connected end to end.

The 3DCS provides several measurement methods such as point distance, line angle, surface angle, circle diameter, circle interference and combined measurement, and Nominal Point among them is the most common in point measurement. Since the measured positions are the axial or radial deviation of a part, the command Point Distance is used to add Measure information.

4. RESULTS AND DISCUSSION

The constructed model in Section 3 was run 20000 times within the given tolerance range by Monte Carlo method, and the simulation results were described as follows. Figure 4 showed the simulation analysis result of radial deviation of the power shaft. The probability of upward and downward out of tolerances were 1.09% and 1.03%, and the total probability of overproof was 2.12%. Simulation results between -2.00 mm and 2.00 mm were account for 97.88%. Sensitivity analysis of the deviation sources indicated that the dominant influence on the measurement results was the part MFZZ, and the contribution rate are as high as 76.12%.

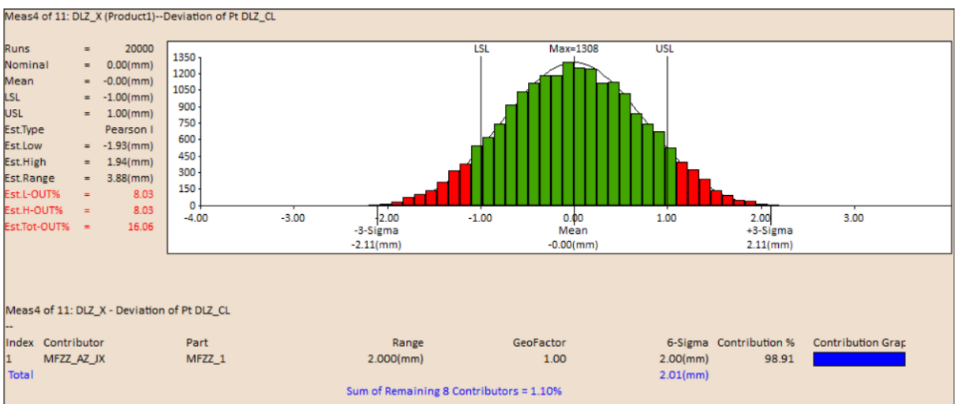

Figure 4. The simulation analysis result of radial deviation of the power shaft.

The simulation result of axial deviation of the power shaft was shown in Figure 5. The simulation values between -2.00 mm and 2.00 mm were accounts for 99% of the total results. The upward probability of out of tolerance was 0.51% and the downward one is 0.50%. Through the contribution analysis of the component ring of the measuring point, the main deviation sources were: MFZZ, LHQ, and QZ. Among them, the part MFZZ contributed the most, which was 74.21%.

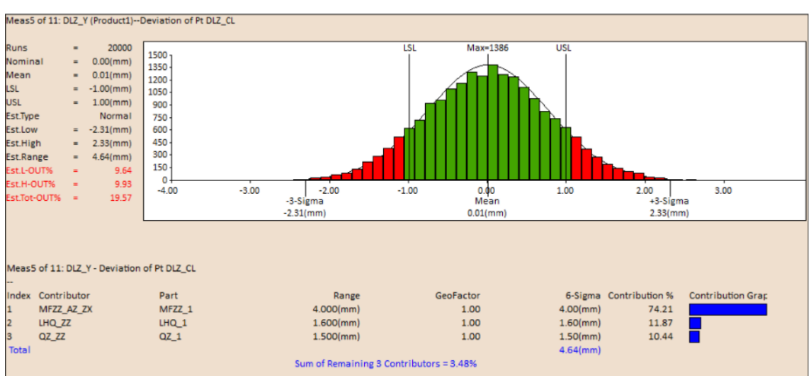

Figure 5. The simulation analysis result of axial deviation of the power shaft.

The analysis result of the radial deviation of the power shaft was shown in Figure 6. The out-of-tolerance probabilities for were 0.01% and 0.01%, respectively. Simulation values between -2.00 mm and 2.00 mm were up to 99.99%. The sensitivity analysis of deviation source showed that part MFZZ had the greatest impact on the measurement results, with a dominant contribution rate of 88.40%.

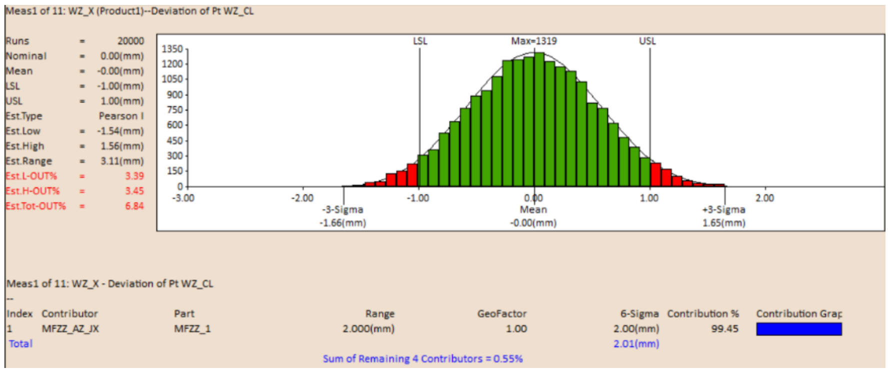

Figure 6. The simulation analysis result of radial deviation of the tail shaft.

The simulation analysis result of axial deviation of the tails shaft was shown in Figure 7. The out-of-tolerance probabilities were 2.16% and 0.03%, respectively. The results of the simulation between -2.00 mm and 2.00 mm were account for 97.81%. Sensitivity analysis of the deviation sources indicated that part MFZZ dominated the impact on measurement results, and the contribution rate were 82.05%.

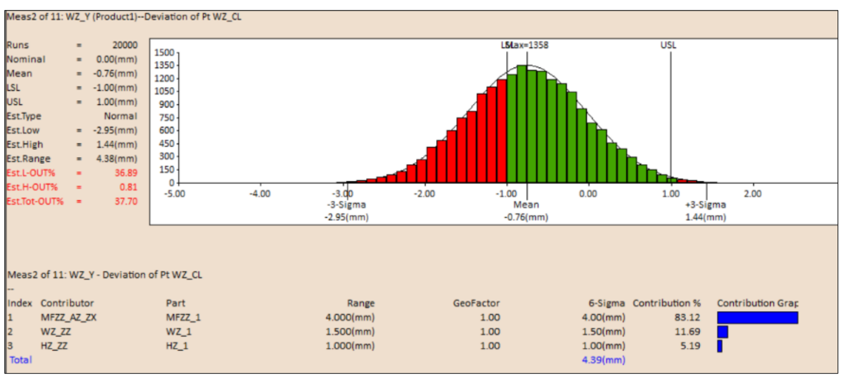

Figure 7. The simulation analysis result of axial deviation of the tails shaft.

5. CONCLUSION

In this paper, the advantages and disadvantages between the calculation methods based on two-dimensional dimension chain and Monte Carlo simulation method were analyzed, and the importance of the simulation analysis of marine shafting modular assembly accuracy based on 3DCS was presented. The assembly process of marine power shafting was taken as an example, and the 3DCS software was used to analyze the influence of shaft manufacturing error and installation error on the assembly accuracy. Meanwhile, the important factors affecting the target accuracy and the probability exceeding were determined, which provided guidance for the accuracy control of shipbuilding.

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