Research on Development and Key Technologies of Intelligent Bed-jig System for Ship Sectional Construction

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Abstract. Nowadays, the existing bed-jig is difficult to meet the requirements of modern ship intelligent manufacturing. This is mainly due to the following three problems: one is the redundancy of location arrangement, the other is the difficulty of moving, and the third is the discontinuity of height adjustment. For the segmental construction of ships, this paper puts forward the research and development of intelligent bed-jig system. Breakthroughs have been made in key technologies, including dynamic placement of jig and dynamic adjustment of support height. It also realizes the intelligent decision-making of process data in ship sectional construction. In general, it provides a technical basis for intelligent manufacturing of ship segments.

1. Introduction

The bed-jig is a shape membrane and workbench, which is used to make the hull surface segment and the surface three-dimensional segment. Its function is to ensure the accuracy of the ship's segment construction [1]. This needs to be accomplished in two parts: one is to support the segment to ensure the accuracy of the shape size; the other is to reduce the deformation of the segment. From the original formwork type to sleeve pillar type, flexible type and numerical control type [2], the automation level has been improved. But there are still problems. They include low level of intelligence, discontinuous adjustment of placement height, low positioning accuracy and lack of process data detection. Because of their existence, the existing jig can not meet the needs of modern shipbuilding mode. This has seriously hindered the development of the intellectualization level in the process of ship sectional construction.

In order to meet the needs of modern shipbuilding, relevant researchers at home and abroad have studied the existing bed-jig. Among them, BS Jang et al [3] proposed a method of ship sectional modeling. BWT Quinton et al. [4] introduced an analysis method of ship and marine jig under moving load. For the finite element analysis of the moving load on hull structure, the basis is provided through real-time monitoring of the positioning and load of the moving jigs. In order to provide reference for structural design and safety assessment of ship's jig, S E Lee et al [5] studied the ultimate strength of the jig through nonlinear finite element analysis. J Cao et al. [6] proposed an experimental and analytical method for a hybrid hull model. In order to realize unrestricted positioning of movable frame, V Rubino et al [7] proposed a test method of Y-type frame under distributed load and local load.

In terms of bed-jig arrangement, the research is divided into the following five parts: In order to provide theoretical basis for placement of bed-jig, Wu G.Y [8] proposed a fast algorithm to reverse the control
vertex of cubic B-spline curve. In order to realize the layout design, installation and allocation of the bed-jig, Xu Peicai et al. [9] calculated the inner longitudinal wall of the bed-jig through the surface module and curved module of Tribon system. In order to allocate the placement of each segment, Xu Xing et al. [10] put forward a layout about the placement of the ship segment construction. In order to optimize the elastic support of the ship’s jig support structure under impact load, Ji Yong Jin et al. [11] proposed a layout method. Wang Xiaolong [12] proposed an intelligent bed-jig, which consists of support/induction system, transmission system, control system and interactive system. In the aspect of bed-jig body design, the research is divided into the following two parts: on the one hand, Li P.Y et al [13] invented an adjustable bed-jig and a method for automatically adjusting the support height. Firstly, the bed-jig unit is fixed on the ground or platform; Secondly, the traction device is moved on the guide rail; finally, the height of each bed-jig is adjusted by the height adjusting device in turn. On the other hand, Chen L. et al. [14] invented a movable marine bed-jig including its control system and control method. Thus the stacking yard of the marine bed-jig is reduced. And the utilization rate of shipyard site is improved. However, the control system module only puts forward the idea and lacks the relevant application.

In the aspect of construction process data acquisition, the study consists of the following four parts: Song J.J et al [15] proposed a flexible manufacturing technology. It was based on segmented numerical control of ship's curved surface. Through post-assembly calibration and anti-deformation compensation technology, the accuracy and quality of surface forming can be guaranteed. It can effectively reduce the assembly difficulty of irregular components and improve the assembly efficiency and quality. Gu Y.F et al. [16] put forward the development of intelligent flexible system under 4.0 mode of shipbuilding industry. With the help of three-dimensional data simulation technology, automatic measurement and screw height adjustment can be realized. Kim T W et al. [17] introduced a design and manufacturing process of marine bed-jig parts. The solution optimized the assembly and welding process of the bed-jig through software data integration. Qin H R [18] and others have studied a ship intelligent painting production line. It realizes the integration of hull sectional painting data. Then it carries out dynamic analysis and prediction by real-time monitoring.

The above literature has studied the technology of bed-jig, but the existing technology cannot realize the following three functions. The first is the dynamic layout of the frame, the second is the dynamic adjustment of the support height, and the third is the effective collection and application of construction data. Therefore, aiming at the above problems, the research on development and key technologies of intelligent bed-jig system for ship sectional construction are presented.

2. Development Scheme of Intelligent Bed-jig System

According to the research and development, the main layout mode of the existing bed-jig is "welding-cutting-welding". This mode has the problems of unsustainable adjustment of support height and difficult movement. Therefore, it is not only time-consuming and laborious, but also has seriously hindered the development of modern shipbuilding mode.

In this paper, an intelligent bed-jig system oriented to ship segmental construction is developed. Thereinto, the intelligent bed-jig is the carrier of the system. And the design process of it is shown in Fig. 1. It includes three parts: one is the self-adaptive contact mechanism, which realizes the surface contact between the activating collateral head and the segmented outer plate; the other is the intelligent moving system of the bed-jig, which realizes the movement and positioning in the track; and the third is the stepless adjusting transmission mechanism, which can continuously adjust the support height of the bed-jig.
As shown in Fig. 2, the adaptive contact mechanism consists of two parts: One is the support device, including a ball head and a supporting activating collaterals head, which can realize the surface contact between the jig and the ship's segmented outer panel; the other is the data acquisition module, which is mainly composed of pressure sensors for the analysis and decision-making of the control system. In order to adapt to the outer plate, the universal activating collaterals head is composed of a screw with a ball head and a supporting structure.
Intelligent bed-jig moving system consists of moving chassis and track. The moving chassis is composed of four parts. One is the support mechanism, which is used to carry the intelligent bed-jig or lift the intelligent tire frame off the track; the other is the mobile mechanism, which is set under the support mechanism and moves along the track longitudinally; the last are the control system and positioning system, which are set above the support mechanism to precisely locate the coordinates of the placement.

Stepless regulating transmission mechanism is divided into the following two functions: Firstly, in order to realize the continuous adjustment of the support height, the stepper motor is used to output the power, and then the worm and screw are used to transfer the power; secondly, for realizing stepless adjustment of the bed-jig in the process of ascending or descending, the power is transmitted to the lead screw through synchronous belt and worm gear mechanism driven by stepping motor.

3. Key Technologies of Intelligent Bed-jig System

3.1 Dynamic placement technology of intelligent bed-jig based on multi-objective constraints

The existing bed-jig has the following two problems: the accuracy of point location and height positioning is poor, and it takes a long time to correct repeatedly. Therefore, it is difficult to improve the accuracy and efficiency of hull segmentation construction. Thus, a dynamic placement technology based on multi-objective constraints is designed, which can determine the spatial coordinates of the bed-jig quickly. Finally, the layout problem "construction-cutting-construction" was solved.

In this paper, the surface density is defined as the projection from ship segments to plane. And the distribution of mass in the projection plane is shown in Fig. 3.

The algorithm is divided into two parts: 1) Firstly, the sectional surface density model of ship is calculated by using the BOM table of the sectional components. Then the segmented centroid is solved. Finally, under the constraints of track and maximum support load, the optimal coordinates of the bed-jig are determined. 2) In the first step, discrete data points are obtained by scanning the segmented outer plate. In the second step, the surface model of the ship segmented outer plate is created by data fitting method. In the third step, the contact point coordinates of the bed-jig and the outer plate are determined under the constraints of the point coordinates and the spatial inclination angle. In the last step, coordinate conversion method is used to calculate the support height of each bed-jig.

![Dynamic Arrangement Algorithmic Flow](image)

**Figure 3. Dynamic Layout Algorithmic Flow**
3.2 Height Dynamic Adjustment Technology Based on Measured Data

In the process of ship sectional construction, according to the shape of the segments, dynamically adjusting the bed-jig height is impossible. In order to solve this problem, this paper designs a dynamic adjusting method of the bracing height based on the measured data. This method is divided into the following three steps. Firstly, the Internet of Things (IOT) is constructed to obtain measured data. Secondly, based on the historical database and the anti-deformation rule database, the measured data are compared and analyzed. Then the deformation trend of the segmented outer plate can be predicted. And the compensation of the bracing height of the bed-jig can be calculated. Finally, the control system is used to realize the linkage adjustment of each bed-jig, so as to complete the adaptive compensation of the support height.

As shown in Fig.4, firstly, according to the measured data collected, the data management layer sets the range, including pressure value and pressure warning value. Secondly, the data management layer makes an early warning judgment on the collected pressure data. After not exceeding the early warning value, the range of comparison is made. If the collected pressure value is less than the safe range, the data management layer sends the rising signal to the PLC, and the PLC drives the stepper motor to control the rise of the intelligent bed-jig; if the pressure value is larger than the safe range, the data management layer sends the falling signal to the PLC, and the PLC drives the stepper motor to control the fall of the intelligent bed-jig. Finally, the adjusted data are stored in the database.

![Height Dynamic Adjustment Process](image)

**Figure 4. Height Dynamic Adjustment Process**

4. Key Parts Checking

In the process of ship's segmental construction, the key parts of the bed-jig need to be checked because it will bear large external loads. There are three parts to be checked: activating collaterals head, screw
and chassis bolt. The first is that the activating collaterals head and the screw bear the weight of the ship segments. Secondly, the screw and the worm wheel are connected and driven through the thread pair, and the thread of the matching part has self-locking phenomenon. Thirdly, because the ship has a certain radian, the bed-jig support will bear the lateral force, and the reverse torque generated is borne by the chassis bolt that connects the strut to the track. Therefore, they need to be checked to ensure their stability in the process of work.

Presupposition: The weight of the ship's segmented outer plate is 10t, the intelligent bed-jig system is supported by three tracks and six bed-jigs, and the rated load of a single bed-jig is 3T. After calculation, the bearing capacity of each jig in the vertical direction is 2-3t.

4.1 Pressure Strength Checking

(1) According to the material mechanics, the checking formula of the pressure on the activating collaterals head rod is as follows:

\[ [\sigma] = \frac{F}{A} \tag{1} \]

In Formula 3-1, F is the pressure acting on the member, A is the cross-section area, and [\sigma] is the allowable stress of the material.

The material of the activating collaterals head bar is 45 steel, and the compressive strength [b] of 45 steel is 590 MPa and the yield limit [s] is 310 MPa. The calculation results show that [\sigma] = 155 MPa.

By calculation, F \leq 31.2KN. The ultimate pressure of the activating collaterals rod can be calculated to be 31.2 KN. The rated working load-carrying capacity of the given bed-jig is 3000N, so the strength meets the requirements.

(2) Similarly, the cross-sectional area A of the screw is known to be 3848 mm2. Calculated by formula 3-1, F \leq 596.4KN.

The ultimate pressure on the screw is 596.4KN, and the maximum critical pressure for the whole bed-jig system to maintain stability is 846.2KN, so it meets the requirements.

(3) The bolt will be subjected to axial force Fa due to the existence of overturning moment.

\[ \sigma_{ca} = 4x1.3F_a/\pi d^2 \leq [\sigma] \tag{2} \]

In the formula, F2 is the total axial force of the screw bolt F2 = F0 + Fa [Cv / (Cb + Cm)], F0 is residual preload. Cv/(Cb + Cm) is the relative stiffness coefficient. [\sigma] is the allowable stress.

F2 = 1.1F0, S = 2.5, then [\sigma] = 128Mpa

Then F2 = 1.1F0 \leq [\sigma] \pi d^2 / (4x1.3) = 25.06KN, F0 \leq 22.78KN

From formula F0 = M/4L1 = F10*H/4L1, F10 \leq 4F2L / H = 3.49KN

The maximum lateral force that the chassis bolt can bear is 3.49KN.

Based on the above checking calculation, the following parameters are obtained:

(1) The limit pressure that the movable collar can bear is 31.2KN;
(2) The ultimate pressure that the screw can bear is 596.4KN.
(3) The maximum lateral force that the chassis bolt can bear is 3.49KN.

And they can meet the requirements.

4.2 Virtual Validation Analysis

The stress-strain analysis model of the activating collaterals head, screw and chassis bolt is obtained by ANSYS analysis.

(1) Assuming that the activating collaterals head is offset by 20 degrees and the bearing capacity is 3000N, the maximum deformation is 1.31mm, and the maximum strain is at the junction of the activating collaterals head rod and the sensor.

(2) Loading 30000N pressure on the top of the screw, the maximum deformation is 0.041mm, and the maximum stress is 37.8KN, which meets the application requirements.

(3) Assuming that the contact between the bolt and the bottom surface is bonded, the nut and the bottom surface of the track are bonded, and the rough between the bottom and the track. The theoretical calculation shows that the pretension limit is 18.224KN, the maximum transverse force on the chassis is 3490N, and the maximum deformation is 0.103mm. The stress at the beginning of the thread is the largest, which conforms to the actual situation.

In summary, the activating collaterals head, screw and chassis bolt can meet the design requirements. And the stability of the bed-jig system is guaranteed in the process of ship's sectional construction.
5. Conclusion and future works
In this paper, an intelligent bed-jig system for ship sectional construction is developed. And a kind of movable intelligent bed-jig is studied, which has self-adaptive contact mechanism and stepless regulating transmission mechanism. The next step is to optimize the flow chart of dynamic placement algorithm and the structure of intelligent mobile system. At the same time, the function of intelligent bed-jig system will be fully utilized and deeply developed, so that it can also play a role in the process of ship sectional assembly and welding.

6. References
[1] Xu Z K. Shipbuilding Technology [M] Beijing: China Communications Press. 2010.
[2] She J G, Gu Y F. Analysis and Design of Flexible Bed-jig Based on Center Manufacturing Ship [J]. Ship Science and Technology20, 08, 30(1):120-123.
[3] BS Jang, YS Suh, EK Kim, et al. Automatic FE modeler using stiffener-based mesh generation algorithm for ship structural analysis[J]. Marine Structures, 2008, 21(2-3):294-325.
[4] BWT Quinton, CG Daley, RE Gagnon, et al. Guidelines for the nonlinear finite element analysis of hull response to moving loads on ships and offshore structures[J]. Ships and Offshore Structures, 2017, 12 (sup1): S109-S114.
[5] SE Lee, AK Thayamballi, JK Paik.Ultimate strength of steel brackets in ship structures [J].Ocean Engineering, 2015, 101:182-200.
[6] J Cao, JL Grenestedt, WJ Maroun. Testing and analysis of a 6-m steel truss/composite skin hybrid ship hull model[J]. Marine Structures, 2006,19(1):23-32.
[7] V Rubino, V S Deshpande, NA Fleck. The collapse response of sandwich beams with a Y-bed-jig core subjected to distributed and local loading [J]. International Journal of Mechanical Sciences, 2008, 50(2):233-246.
[8] Wu G Y, Wang X H. A Fast Algorithms for Inversely Finding the Control Vertex of Cubic B-Spline Curve [J]. Journal of Hangzhou Dianzi University, 2005, 25(3).
[9] Xu P C, Hong A C. Application of TRIBON System in Calculating Inner Longitudinal Wall Platform [J]. Guangzhou Shipping Science and Technology, 2012, 32 (02):54-58.
[10] Xu X, Gu X B. Bit Layout Plan and System Development for Segmental Construction of Ships [J]. Shipbuilding Technology, 2014(2).
[11] Ji Yong Jin, Kwak Jeong Seok, Lee Hyun Yup, et al. Optimal Arrangement of Resilient Mount installed on Bed-jig Support Structure at Shipboard Equipment under Shock Load[J]. Journal of the Society of Naval Architects of Korea, 2015, 52.
[12] Wang X L. Technology and Development Prospect of Ship Bed-jig [J]. China Water Transport (Second Half of the Month), 2015, 15(03):18-20.
[13] Li P Y. A Method of Automatic Adjustment of Support Height of Shipbuilding Bed-jig and Adjustable Bed-jig: China. CN201810115290.2 [P] 2018-02-06.
[14] Chen L, Meng Q etc. Control System and Control Method of Movable Marine Jig and Marine Jig: China. CN201810712928.0 [P] 2018-07-02.
[15] Song J J,Yu Y,Wang J,Chen Y,Zhao S J. Research on Flexible Manufacturing Technology of Numerically Controlled Jig Based on Surface Section of Ship[J].Ship and Marine Engineering, 2016,32 (02) : 63-68.
[16] Gu Y F, Xie R. Development of Intelligent Flexible Bed-jig System in Shipbuilding Industry 4.0 Mode [J]. Jiangsu Ship, 2016, 33(3):29-31.
[17] TW Kim,SS Lim ,HH Seok,et al.Concurrent engineering solution for the design of ship and offshore bracket parts and fabrication proess[J].International Journal of Naval Architecture and Ocean Engineering,2013,5(3):376-391.
[18] Qin H R,Wang Y,Zhong Q W,Dong H. Research on Intelligent Coating Production Line for Ships [J]. Marine Engineering Equipment and Technology, 2018, 5(04):288-292.