Intelligent Welding Technology for Large Deep and Narrow Shaped Box with Robot

Hu Lan, Huajun Zhang, Jun Fu, Libin Gao, and Rui Pan

Abstract Aiming at the difficulty in customizing the production of shaped boxes in large-scale port lifting equipment, a cantilever welding robot comprised of Cartesian and articulation was developed. Based on field bus technology, a fast parameter programming system suitable for robot welding of shaped box developed. Also, the composite sensing method of laser ranging, wire contact seeking and "bow"-shaped oscillating arc tracking is proposed, which overcomes the difficulty of positional accessibility of deep and narrow lattice space, and the long time and single contact of traditional online/offline task programming. Finally, the internal robot intelligent welding of the large-beam box lifting equipment with a length of about 80 m, a height of about 2.4 m and an internal net width of about 0.6 m realized.

Keywords Marine engineering equipment · Intelligent welding · Parametric programming · Laser sensing

1 Introduction

Marine engineering equipment has important national strategic significance in China's marine resource development, new energy construction, logistics, port trade, military and other fields. At present, more than 60% of the world's active port machinery is provided by China, and large port lifting equipment is a product with monopoly advantage of China [1]. Due to the different operating conditions of the marine environment, shipping routes, user terminals, etc., as well as the differences in international standards, national regulations and regional culture, customers' needs for the design, quality and life cycle of port lifting equipment vary greatly, products face many problems such as high degree of customization, small batch size, strict

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delivery deadline control and long manufacturing cycle and long supply chain. As a result, flexible intelligent manufacturing is the highlight. As the core load-bearing component of large port lifting equipment, the box has the characteristics of complex structure, thin and long plate, narrow space, diversified welding positions and strict welding requirements. The manufacturing quality of the box directly affects the safety and use effect of the large port lifting equipment in service. Therefore, the research and development of intelligent welding common key technologies such as robot welding technology, equipment and process sensing suitable for large deep and narrow shaped boxes have important promotion and application value, which can also provide reference and support for the technical development of China's large steel structure manufacturing industry.

2 Box Structure Features

The structure of lifting equipment for large ports is shown in Fig. 1. The main structural components such as front/rear beams, upper/lower beams, columns and connecting beams are all in the form of a box, especially the front/rear beams are most typical, as shown in Fig. 2. The whole box section is pentagonal rather than "mouth" shaped, mainly composed of upper/lower wing plates, straight/inclined webs, baffles, angle steel and T-shaped steel. Since this product is customized, the size of the front/rear beams is 52.5–79.5 m long, 1.2–1.4 m wide, and 1.3–2.4 m high, which belongs to a super-shaped steel structure. The thickness of the box wing plate is between 10 and 28 mm, and the thickness of the straight/inclined web is 8–14 mm, the thickness of the baffles is between 8 and 16 mm, the number of baffles of a single beam is between 28 and 41, and the total length of the weld is more than 600 m. The verticality of the box and the baffles before and after welding should all

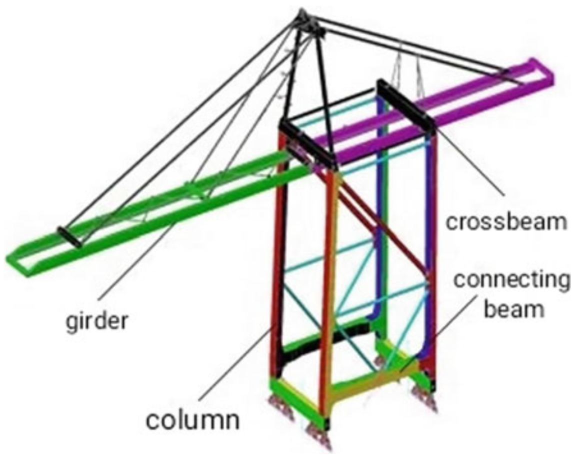


Fig. 1 Structure of lifting equipment for large ports

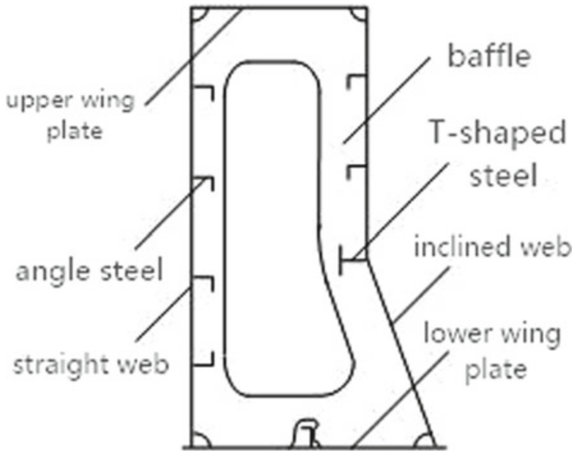


Fig. 2 Structure of boom and girder

be controlled within 3 mm. The straightness at the root position of the web and wing should be controlled within 2 mm/2 m, the (single pass) welding leg size should be 5–8 mm and the deviation on both sides should be controlled within 1 mm. It can be seen that the manufacture of the box structure has the features of large scale, thin plate, many baffles, narrow space, fillet welds and high requirements. It is necessary to develop a special welding robot system suitable for super-large deep and narrow shaped box manufacturing.

3 Automated Robot Welding System for Deep and Narrow Shaped Box

To realize the automatic welding of welds between internal baffles and webs, baffles and wing plates, webs and wing plates, wing plates and angle steel of large-scale port lifting equipment boxes, it is necessary to break through the difficulties of robot position accessibility and posture compliance in super-scale and narrow space, and to develop a compound robot with right angle + articulated cantilever (as shown in Fig. 3). The system is equipped with a total of 10 axes, the robot body has six axes and the external four axes. The working range of the small short-arm robot is about 700 mm, it can flexibly adjust the posture in the space with a clear width of 500–600 mm inside the box. At the same time, in order to make the robot working range cover the maximum size of the beam, the robot adopts external axis linkage in the *X*- and *Z*-directions to ensure continuous and efficient welding process, and through the rotation and translation mechanism driven by external servo to achieve workstation assembly and welding cross-operation. The *X*-axis travel of the cantilever transfer mechanism is 160.0 m, the *Y*-axis travel is 1.5 m, the *Z*-axis travel is 2.0 m, and

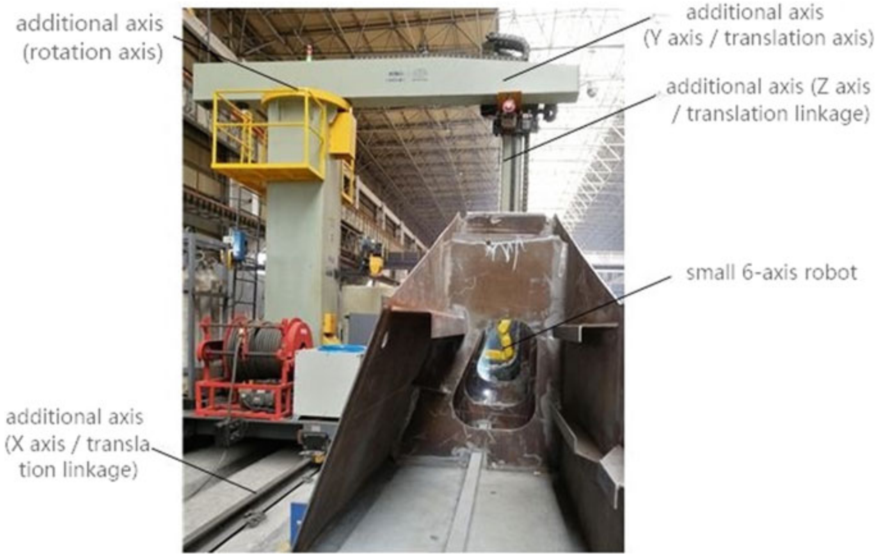


Fig. 3 Cantilever welding robot used for ultra-narrow shaped box

the rotation angle around the *Z*-axis is 180°. The motion control architecture of the entire system is shown in Fig. 4.

4 Fast Parameter Programming System Suitable for Robot Welding of Shaped Box

Lifting equipment for large port is a customized product. Its beam structure has many specifications, long welds and narrow space. So the teaching workload will be large if the traditional online/offline programming method is used, and the programmer needs to confirm the key points on the robot path one by one, and the potential safety risk is also great. How to realize the rapid intelligent programming for robot welding of such special-shaped box is another bottleneck faced by large-scale steel manufacturing industry [2–5]. According to the characteristics of our products' structure, a software system for batch transmission of structural feature parameters and automatic generation of task programs based on field bus technology was developed. During the actual operation, the programmer only needs to enter the box structure parameters such as beam size (length/width/height), the number of baffles and the spacing of the baffles, baffle feature parameters such as baffles width, height, thickness, angle and welding process parameters such as welding sequence, welding position, welding material type and welding foot size on the upper computer man–machine interface (as shown in Fig. 5). The host computer will set the above parameters to the PLC data register in a pointer way through the local area network, and then, the PLC will

Fig. 4 System architecture of the cantilever welding robot comprised of Cartesian and articulation

send each baffle parameter to the robot controller through the CC-Link communication protocol. After receiving the data, the robot automatically changes the welding program position variable in the internal program library, and the welding expert table is automatically generated by referring to the welding expert library for the welding program to directly call. Through this fast parameter programming system (system architecture is shown in Fig. 6), corresponding program module can be selected according to different product specifications, and the programming time can be shortened to less than 1 h, which solves the problem of long programming time when traditionally welding special-shaped box structures by robots.

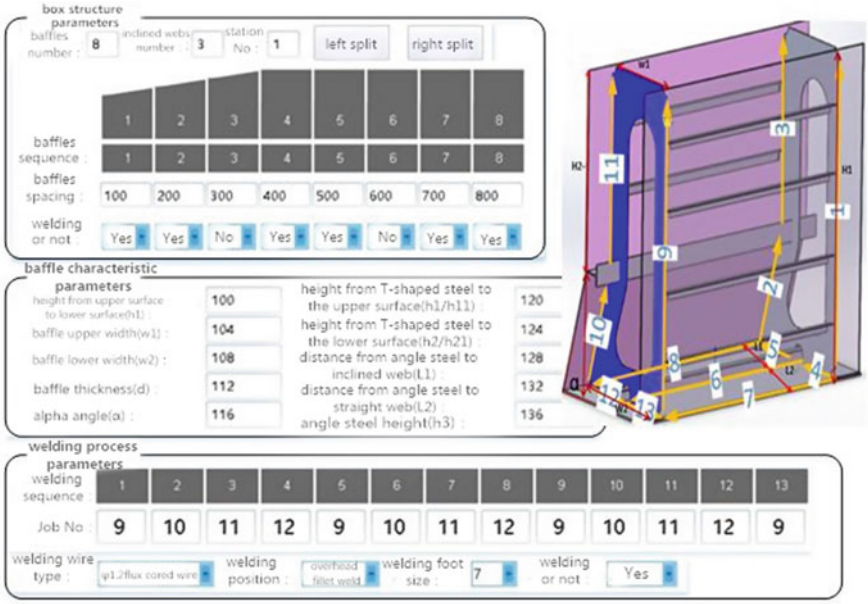


Fig. 5 Parametric programming interface for shaped box welding with robot

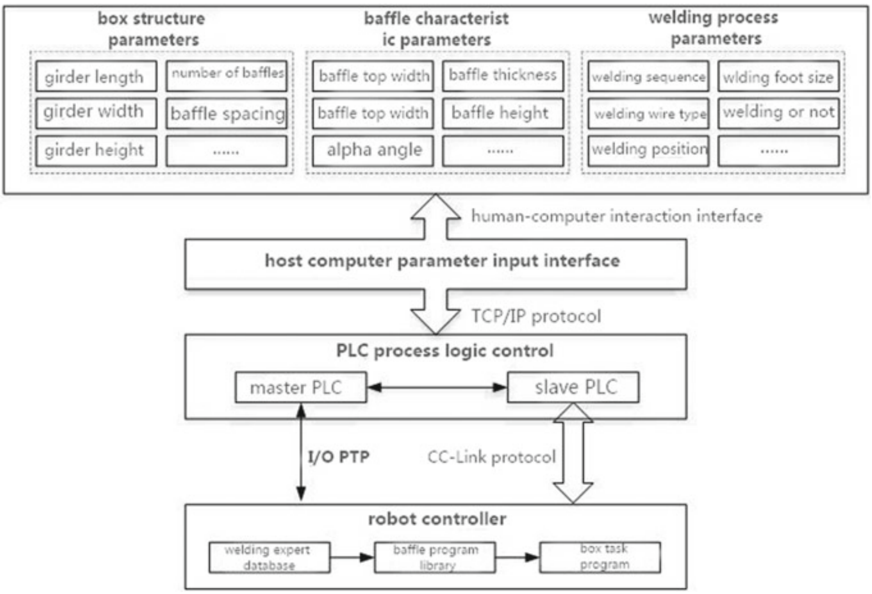


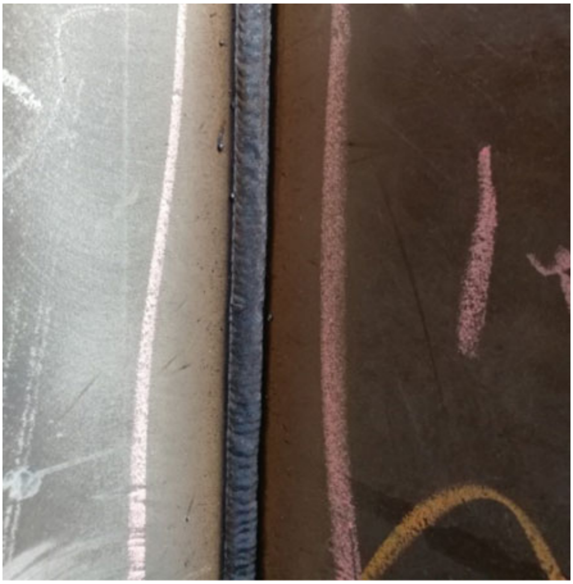
Fig. 6 Data flow of parametric programming for shaped box welding with robot

5 Robot Welding Process and Intelligent Sensor Control Technology of Large Box

In addition to solving the convenience of operating equipment and fast task programming, the automatic welding process and process adaptive control of the special-shaped box of lifting equipment for large port are the third problem faced by the equipment manufacturing industry. It is not difficult to see from Fig. 2 that the baffle plate and the wing plate are T-joint transverse fillet welding (2F), the baffle plate and the web/inclined web are T-joint vertical fillet welding (65°–90°, 3F). Compared with the 2F position, welding process of the T-joint 3F position is more difficult, and the factors such as processing, assembly errors and welding thermal deformation caused by the thin and long plate of the large box require robot welding to have self-locating and tracking functions, which needs to take into account the adaptability of the process to the working conditions and the ability of the equipment to perceive and correct the working conditions. Contact seeking + arc tracking is the traditional mainstream method basically used to solve this problem. Due to the large number of welds in the box (350–550 welds), if we only rely on the contact of the welding wire or the nozzle of the welding gun to find the starting point of the weld, it is not only time-consuming and inefficient, but also the gun is prone to crash during the positioning process [6–15]; at the same time, the process parameters of the vertical fillet welding are small (welding current 120–140 A), the traditional zigzag vector swings are harmful to the stable acquisition of welding current in arc tracking which will lead to the occurrence of welding deviation, and the deviation of the welding feet on both sides of the fillet weld will exceed 1 mm. For this reason, a new process of medium-thick plate T-joint robots vertical fillet welding is developed using flux cored wire, and the weld seam is well formed (as shown in Fig. 7); the composite sensing method of laser point distance measurement and welding wire contact positioning is proposed. The laser arc sensor is used to perform the rough positioning of the welding arc starting point (with an accuracy of up to 10 mm), and then, the welding arc contact is used to accurately locate the arc starting point. It can effectively shorten the contact positioning empty stroke. The arc tracking process uses the "bow" shape vector swing technology to stably collect the welding current on both sides of the swing position. The above process technology effectively breaks through technical bottlenecks such as the vertical fillet robot welding, long traditional single-contact sensor positioning time, single-laser sensor interference and rifle gun, and the reliability of the tracking process of vertical fillet welding, and have reduced the online preparation time of the task program after the parameterized programming of the robot welding of the box to less than 15 min, realizing the intelligent robot welding in the internal space of the large deep and narrow shaped box.

Fig. 7 Vertical fillet welding of shaped box T-joint with robot

(a) Robot vertical welding



(b) Forming of vertical welding joint

6 Conclusion

1. Developed a right angle + joint compound cantilever robot, which broke through the problem of robot position accessibility in deep and narrow lattice space of super-large shaped box, and realized the robot welding of the box with a length of about 80 m, a height of about 2.4 m and an internal clear width of about 0.6 m for large port lifting equipment.
2. Based on the field bus technology, a robot welding parameter programming system suitable for special-shaped box structures was developed, broke the problem of long time-consuming of traditional online/offline task programming and realized fast and intelligent programming of robot welding for customized large port lifting equipment box.
3. Developed a robot welding process and intelligent sensor control technology suitable for large boxes and proposed a composite sensing method of laser point distance measurement + wire contact positioning + "bow" swing arc tracking, which effectively breaks through technical bottlenecks such as the vertical fillet robot welding, long traditional single-contact sensor positioning time, single-laser sensor interference and rifle gun, and the reliability of the tracking process of vertical fillet welding, realized the intelligent robot welding for large port lifting equipment box.

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