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Design of Structure and Control System for Ultrasonic Welding Industry Robot

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Abstract: *The mechanical structure and control system of ultrasonic welding industrial robot were designed for the problem of low-precision of welding pressure. Firstly, the mechanical structure of the ultrasonic welding module was designed and the workspace of the robot was analyzed. Secondly, an ultrasonic welding industrial robot control system and a human-computer interaction system were designed. Finally, the welding verification experiment was carried out. The results show that the design of ultrasonic welding industry robot is reasonable and can quickly change the welding head. The workspace resembles a spherical shape and has better accessible in space with a radius of r < 1500 mm. The control system and the human-computer interaction system can work properly and reliably, the control precision of welding pressure can reach 1 N, the human-computer interaction system is clear and smooth, the maximum can meet the parameter setting of 30 welding points; The welding point quality of the door plate is better and the strength is higher. With high welding pressure control accuracy and high integration, the device has better suitable for most plastic ultrasonic welding scenarios.*

Keywords: *ultrasonic welding robot, welding pressure control, structure design, control system*

1. Introduction

Plastics are the most widely used lightweight materials. Currently the most used plastic is PP (polypropylene), PVC (PVC), ABS (Acrylonitrile-Butadiene-Styrene copolymer), PA (nylon) and PE (polyethylene). With the development of modern plastic industry, high-performance engineering plastics are also increasingly used in the mechanical manufacturing industry [1]. However, due to the limitations of injection molding process and other factors, some complex shape products cannot be directly injection molded and need to be welded together, while traditional plastic welding is not only inefficient, but also the binder has some toxicity [2]. Therefore, plastic ultrasonic welding with high efficiency, high quality, environmental protection, energy saving and other advantages stand out [3]. In the ultrasonic welding process, the ultrasonic generator produces ultrasonic waves and transmits ultrasonic waves to the transducer, the piezoelectric ceramic in the transducer converts the high frequency electrical signal into high frequency mechanical vibration [4]. The high frequency mechanical vibration is amplified by the ultrasonic amplitude modulator, the amplitude of the high frequency mechanical vibration is amplified, and transferred to the welding head, the final high frequency vibration wave is transferred from the welding head to the surface of two objects to be welded, while the press provides pressure perpendicular to the workpiece. Under the action of pressure and high frequency vibration, the surface of the two objects rub with each other to form a molecule fusion, and finally achieve welding of the workpiece. Plastic ultrasonic welding is a bonding method that focuses energy on the surface of the workpiece by ultrasonic vibration, allowing the contact surface molecules to quickly fuse under thermodynamic coupling [5]. Compared with traditional fixing methods, ultrasonic welding has the advantages of short welding time, high welding strength, no intermediate medium, friendly environment, easy automation, and is widely used in the same material or different materials [6]. Ultrasonic welding has been used in automotive interior, home appliances, toys, instrumentation and other industries of shell welding [7,8]. Although plastic ultrasonic welding has obvious advantages, in practical applications, manual operation is often used, which can easily lead to low production efficiency and poor production quality [9]. In recent years, many scholars have studied high efficiency and easy integration of ultrasonic welding equipment, using an integrated method of ultrasonic welding equipment and industrial robots, improving productivity and welding quality, and making it easy to integrate with other line equipment. However, existing research results often use cylinders or mechanical arm joints to provide welding pressure, resulting in poor pressure control accuracy and low welding quality [10,11]. Therefore, in order to solve the problem of poor precision of welding pressure control of ultrasonic welding industrial robot, the structure and control system of ultrasonic welding industrial robot are designed by means of servo motor, push rod mechanism, weighing sensor, PLC and other devices.

2. Ultrasonic Welding Industrial Robot Structural Design

2.1 Structural Design of Robotic Ultrasonic Welding Module

The robot ultrasonic welding module designed in this paper is mainly composed of robot connection plate, servo motor, spiral actuator mechanism, pusher, stabilizer bar, pressure sensors, quick-change disk, bracket, transducer, ultrasonic amplitude modulator, welding head and other components, the three-dimensional model shown in Figure 1. In order to reduce the overall weight of the ultrasonic welding module, the connecting parts of the module are made of high-strength aluminum alloy, such as the robot connecting plate, stabilizer bar, bracket, quick-change disk and so on. The overall weight of the module is 12 kg, and it can be mounted on the end of most industrial robots. The robot connection plate can connect the ultrasonic welding module to the end of the industrial robot. The servo motor is a Delta servo motor (ECM-B3M-C20602RS1). The rotation of the servo motor spindle drives the rotation of the spiral pusher mechanism, thus realizing the reciprocating linear motion of the pusher. The movement of the pusher drives the welding head to realize reciprocating movement, and the maximum stroke of the movement is 100 mm. During the movement, the welding pressure applied to the workpiece is measured by a pressure sensor (0 - 30 kg, accuracy 0.01 kg). The ultrasonic transducer uses a frequency of 20 kHz and a power of 1500 W. In the production process, the shape of the welded workpiece is varied, which requires the ultrasonic welding module to be able to quickly change the welding head in order to adapt to the welding needs of different workpieces. For this reason, this paper uses the quick-change disk to design a robot ultrasonic welding module that can quickly replace the welding head. Quick-change disk consists of two parts, one part is fixedly connected with the pressure sensors, and the other part is fixedly connected with the bracket. The quick-change disk has a built-in micro-cylinder, which can realize the separation and combination of the two parts of the quick-change disk under the action of air pressure, so as to realize the separation and combination of the ultrasonic welding head and ultrasonic welding module.

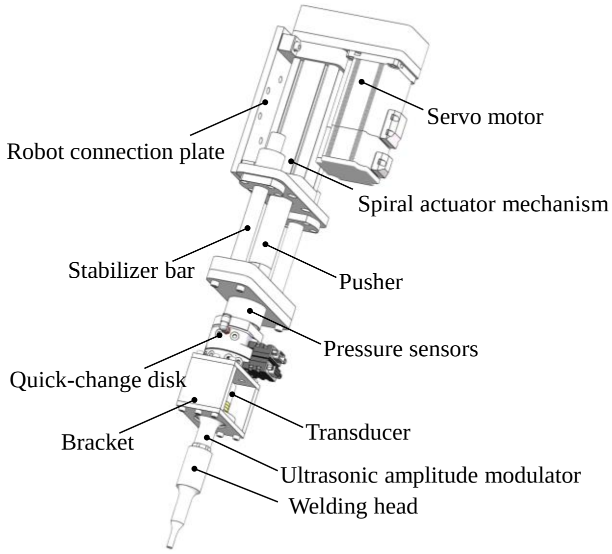

Figure 1: Three-dimensional model of ultrasonic welding module

2.2 Ultrasonic Welding Industrial Robot Workspace Analysis

Workspace analysis of robots can analyze the range of workspace at the end of the robot, which plays an important role in analyzing the adaptability of industrial robots. In this paper, a CRP industrial robot (CRP-RH18-20-W) is used, which has a load of 20 kg and a maximum arm span of 1730 mm. The robot

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ultrasonic welding module designed in this paper is installed on the end flange of the 6-axis industrial robot, and the ultrasonic welding industrial robot model is shown in Figure 2. When the welding head of the ultrasonic welding module is fully extended, the distance between the center point of the welding head and the center point of the 6th axis flange of the industrial robot is 45 mm and 530 mm, respectively.

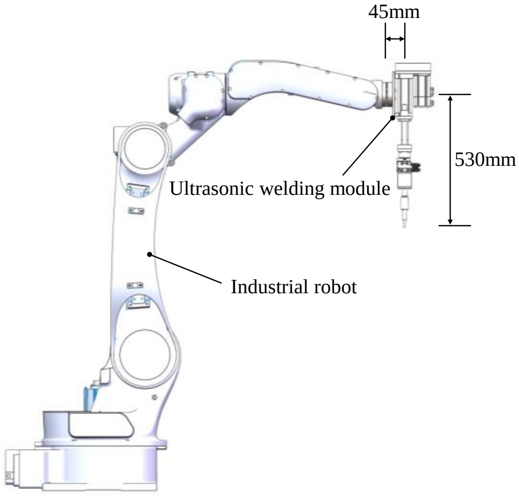

Figure 2: Three-dimensional model of ultrasonic welding robot

The ultrasonic welding industrial robot is modeled using the D-H method and the workspace analysis is carried out using MATLAB Robotics Toolbox and Monte Carlo method, and the results obtained are shown in Figures 3 - 6.

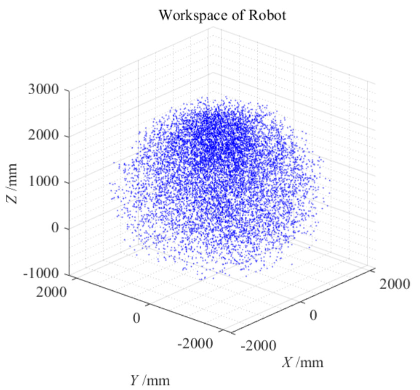

Figure 3: Workspace of robot

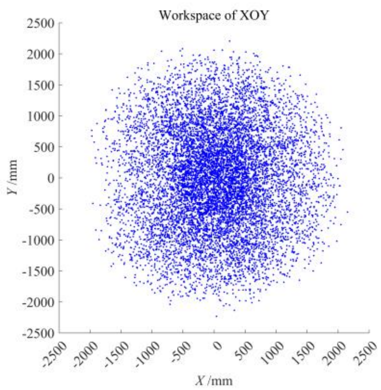

Figure 4: Workspace for XOY planes

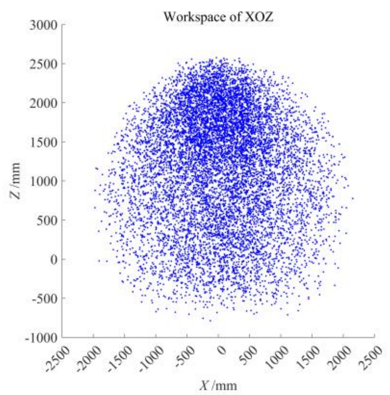

Figure 5: Workspace for XOZ planes

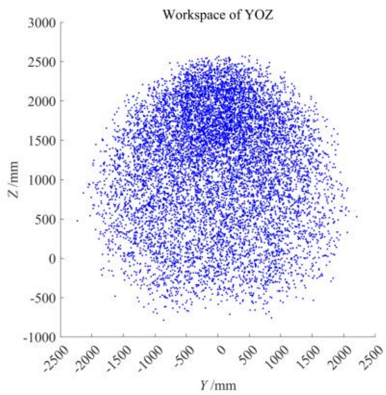

Figure 6: Workspace for YOZ planes

According to the above figure and analysis, the workspace of the robot is approximated as a spherical space with origin (0, 0, 500) and radius r = 2000 mm. The base of the robot is generally fixed to the workbench or the ground, and the accessibility of the area below the base is low, and the location of the workpiece to be welded should be avoided in the area of z<-500 mm. In the radius of 1500 - 2000 mm area, the points are sparse, indicating that this space corresponds to the joint configuration is small, and the region at the boundary of the workspace is prone to odd configurations, making it difficult to control the robot. Therefore the workpiece to be welded should be placed in a space with a spherical workspace radius r < 1500 mm to ensure that there are preferred joint configurations to weld the workpiece.

3. Ultrasonic Welding Industrial Robot Control System Design

3.1 Ultrasonic Welding Industrial Robot Control Program Design

Ultrasonic welding industrial robots mainly work in places with poor environment, which requires high stability and reliability. Therefore, this paper adopts Siemens PLC (S7-200smart) as the main controller, selects the weinview touch screen (MT6071IP) as the human-machine interaction device, selects Delta B3 AC servo drive as the servo motor drive, and selects the ultrasonic generator as the ultrasonic transducer drive. The composition of the control system is shown in Figure 7.

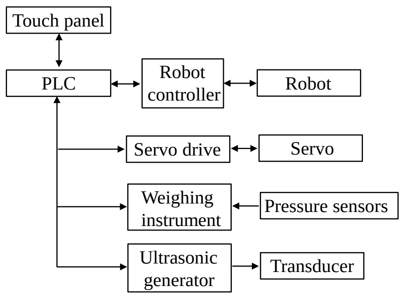

Figure 7: The composition of the control system

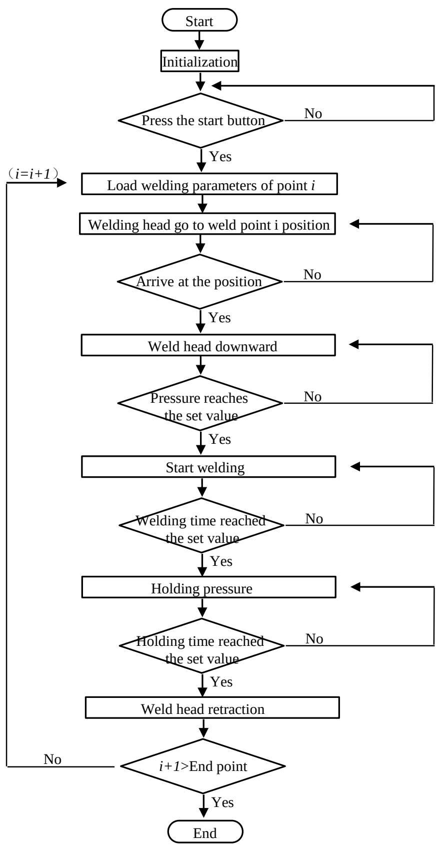

Figure 8: The detailed workflow of control system

ISSN 2706-655X Vol.5, Issue 9: 42-48, DOI: 10.25236/IJFET.2023.050908

During the work process, the robot motion path needs to be written according to the points position of the workpiece to be welded. When the welding head reaches the position of the welding point, PLC controls the servo motor to press down. After reaching the set welding pressure, PLC controls the ultrasonic generator to produce high-frequency current and drive the transducer to produce high-frequency mechanical vibration to realize the welding of the workpiece. Hold pressure after welding is completed, when the holding time is up, the servo motor is controlled to lift the welding head, thus completing the welding task of a point. The detailed workflow is shown in Figure 8.

3.2 Ultrasonic Welding Industrial Robot Control Principle Design

In this paper, the PLC is used as the main controller, and the pressure value of the weighing instrument is collected through the analog expansion module (AM03); the servo motor is set to the torque mode, and the communication between the PLC and the servo motor driver is established through the Modbus communication protocol; the pressure sensors, servo motor, PLC and so on are composed of a closed-loop control system, and the welding pressure is realized by using the PID control algorithm to realize the high accuracy of welding pressure control. The welding pressure control accuracy can reach 1 N. The control principle is shown in Figure 9.

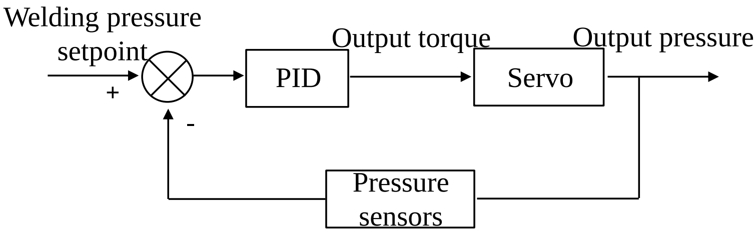

Figure 9: The control principle of pressure control

The ultrasonic generator communicates with the PLC via Modbus communication protocol for communication and control of the welding amplitude. The control of the welding time is realized through the timer and IO port inside the PLC. PLC and the industrial robot have established two-way IO communication. The function of the first channel: when the robot reaches the position of the weld joint, send a pulse signal to the PLC, informing the PLC that the robot has been in place, should control the servo motors to carry out the downward pressure action. The function of the second channel: after completing the current weld joint, the PLC sends a pulse signal to the industrial robot, informing the robot to move to the next weld joint for operation.

3.3 Ultrasonic Welding Industrial Robot Human-Machine Interaction System Design

In order to realize the human-machine interaction of the ultrasonic welding industrial robot, the touch screen is adopted as the human-machine interaction device. The number of welding points, welding pressure, welding time, holding time, welding amplitude, PID parameters, and working mode can be set through the touch screen. The main interface of the system is shown in Figure 10. The human-computer interaction system can set up to 30 welding point parameters respectively, which can meet the needs of most welding workpieces, and the welding point parameter setting interface is shown in Figure 11.

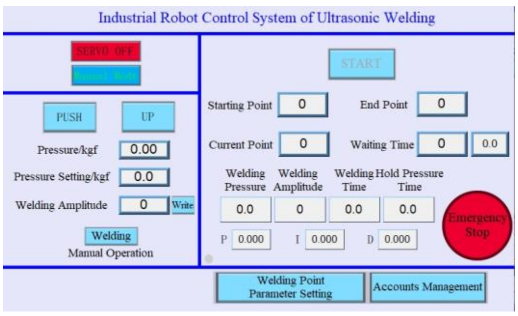

Figure 10: Main interface of the control system

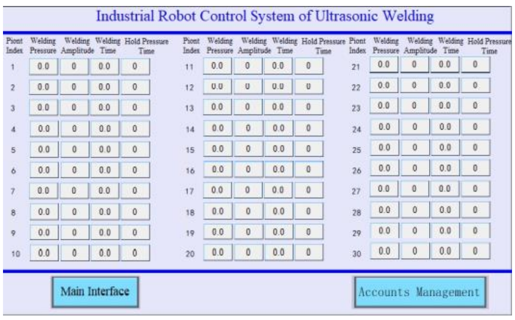

Figure 11: Parameter set interface of the control system

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4. Welding Experiment And Analysis

In order to verify the performance of the device, this paper carried out welding experiments, the experimental equipment is shown in Figure 12. In the experimental process, the rear door interior panel of the car was used as the welding workpiece. Each workpiece contains 8 welded joints, and the welded joints were completed as shown in Figure 13. According to the results of welding, it can be seen that the quality of the welded joints is good and the strength is high, showing that the device has good welding performance.

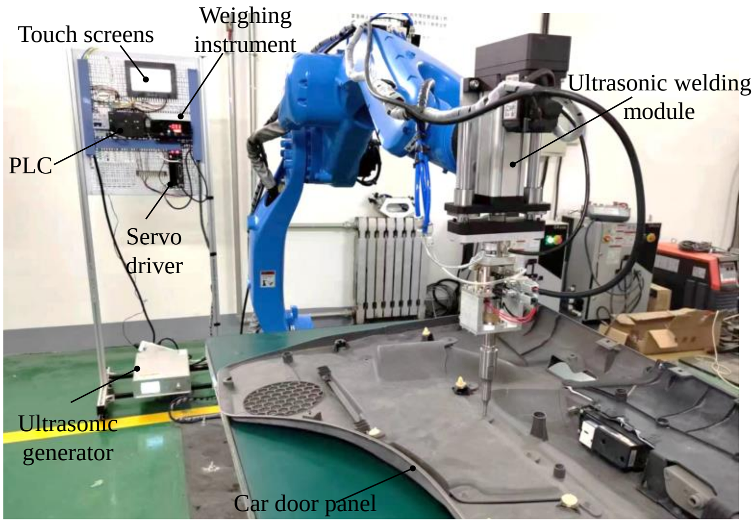

Figure 12: Experimental equipment

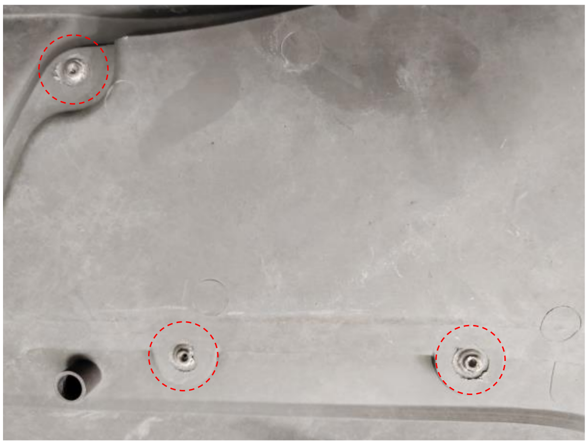

Figure 13: Ultrasonic welding effect of door panels

5. Summary

Aiming at the problem of poor welding pressure control accuracy of ultrasonic welding industrial robots, this paper carries out the structure and control system design of ultrasonic welding industrial robots. It is summarized as follows: (1) The mechanical structure is designed. The mechanical structure of the ultrasonic welding industrial robot is mainly composed of a 6-axis industrial robot and an ultrasonic welding module. The overall weight of the ultrasonic welding module is 12 kg, which can be installed at the end of most industrial robots, and the module can quickly change different welding heads through the quick-change disk, which has good adaptability. (2) The working space of the ultrasonic welding industrial robot is analyzed, and the workpiece to be welded should be placed in a space with a spherical working space radius $r < 1500$ mm. (3) The control process, control system working principle and human-machine interaction system of the ultrasonic welding industrial robot are described. In order to improve the welding pressure control accuracy of the ultrasonic welding industrial robot, the PID control algorithm is adopted, and the PLC, servo motor and pressure sensors are composed of a closed control systems, and the welding pressure control accuracy is 1 N. (4) The welding ability of the device

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was verified through welding experiments.

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