Application of welding robot system in flame brazing of pipe parts for household appliances

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Abstract: Pipe parts are an important part of the interior of household appliances. For the problem of low efficiency of traditional manual brazing and easy generation of welding defects such as blowholes and large welds, the robot flame brazing system has been developed to reduce this situation. It has reduced the dependence of pipe fittings welding on welder skills, while reduced labor intensity and improved production efficiency. It can save a lot of labor costs for enterprises and can be widely used in the household appliance industry.

1. Introduction

In the home appliances industry, the pipeline welding is widely applied in cooling pipes, exhaust pipes, capillary tubes, process pipes, etc. Most of these pipes are small thin-walled copper pipe fittings, this kind of pipes are usually welded by manual flame brazing. Heat source of flame brazing is ignited mixture gas that include combustible gas and compressed air, it can be used to heat base material. Melted liquid solder (welding wire) in the gap between the base materials are wetting, spreading and it fills the seam, and the workpiece is connected by solidification and crystallization [1].These pipes are used in the high temperature and pressure household appliance system and the tightness requirement is strictness. Therefore, Welding defects such as over-burning, solder leakage, blowholes, and large solder joints are always occurred in the welding process, as the figure 1 shows [2].

![Figure 1. Common flame brazing defects](image)

(a.over-burning; b.solder leakage;c. blowholes;d. large solder joints)

To meet the needs of intelligent manufacturing, flame brazing technology should be combined with industrial robotics. This application has two advantages. On the one hand, it improves the consistency of product welding quality, and greatly improves the production efficiency of welding. On the other
hand, it reduces the labor intensity of workers and improves the working environment. Based on the reasons mentioned above, the flame brazing robotic is described in detail in this article [3].

2. Welding robotic system
Figure 2 shows the flame brazing robotic system that applies in household appliance pipe welding. It can be divided into five main parts: robotic controller, quad rotating table, flame brazing system and PLC control system. The flame brazing system is shown in figure 3.

![Figure 2. Flame brazing robot system](image1)

![Figure 3. Flame brazing robot system structure diagram](image2)

2.1. The robotic controller system
Kawasaki RS20N robot is used in the robot system. The maximum load capacity of this type is 20Kg, which can meet the load requirements of double wire feeding mechanism and double flame gun. The repeated positioning accuracy of ±0.05mm can ensure more accurate wire feeding mechanism and reduce defects such as missed welding and virtual welding caused by the deviation of welding wire feeding position. The tough up of welding robot is realized by compiling welding program. The different posture data are used in different welding parts under different corresponding welding program. Users can select the name of welding piece through the PLC control system and call the corresponding welding program and welding parameters. The robot controller is used for storing the welding procedures, controlling the robot's movements and communicating with the PLC control system.

2.2. Quad rotating table
The rotating table of this system has 4 working stations in total, using 4 equal-division CAM divider and the dividing precision is ±15s. It can realize the automatic, manual and semi-automatic control of the table rotation by communicating with PLC control system. The work fixture was fabricated by SUS304 stainless steel which has high temperature-corrosion resistance. Considering that some of the pipe fittings are too long, the installation of the fixtures is carried out by means of the intersection height of each station, maximizing the operation space of the rotary table. The adjustable design of the fixtures has the characteristics of strong applicability, and it can solves the shortcomings of many types of products, which are difficult to weld, and can realize rapid conversion.

2.3. Flame brazing system
The flame brazing system has two main parts, Carrier gas supply and wire feed system.
Carrier gas supply system has the functions of flame heating, nitrogen filling protection and cooling. The flame heating system is part of the gas path system, it is composed of a gas pipeline, a gas flux generator, a flame torch, a gas flow valve, a pressure regulating valve. In this system, The natural gas
and oxygen are regulated and controlled by the automatic voltage regulator to output a stable mixed gas, and that ensures the consistency of the welding quality of the product. The mixed gas enters the gas flux generator through the one-way valve and is mixed with the flux and sent to the welding torch. The size of the flux is adjusted by a ball valve on the gas flux generator. The function of the flux is to assist heat conduction and reduce the surface tension of the welded joints. It is also used to remove oxides, and ensure the aesthetic appearance and welding quality of the product. Oxygen, natural gas pipelines and gas flux generator tanks are equipped with anti-tempering devices to ensure safe. Human-computer interaction is realized by the touch screen of the PLC controller. The flame is adjusted to the neutral flame by setting the flow value of natural gas and oxygen, and the weldment is heated by the outer flame zone with a lower temperature and a larger cross-sectional area. It can be used to prevent the base material and solder are oxidized. The welding gun adopts a detachable porous nozzle. The porous nozzle has a soft flame and a large cross section, which is benefit for ensuring uniform heat input and replacement.

Nitrogen is filled inside the copper pipe through the gas path system to protect the inner wall of the copper pipe from oxidation during the welding process. When the welding machine stops, the welding system will purge the oxygen and natural gas in the pipeline with nitrogen automatically. This achieve the purpose of flame out. The welded products were rapidly cool by the air-cooling device. The air-cooling gas is nitrogen. The compressed air is directly connected to the air cooling device and the propulsion device of the wire feeding system, Meanwhile it supplies air to the respective cylinders. The Oxygen, natural gas and nitrogen can be adjusted in the PLC control system.

Figure 4. Human-computer interaction interface of flame brazing robot system
The brazing material used in the wire feeding system is a BCu91PAg standard wire with a diameter of Φ1.2~Φ1.6mm. The two sets of wire feeding mechanisms are simultaneously fed by a servo motor to ensure production efficiency. The feeding of the welding wire is sent by the PLC to the cylinder, and it advances the wire feeding gun to the welding point, and then the servo motor wire is controlled. The wire feeding speed and the wire feeding time can be adjusted through the PLC control system. The flame gun is connected with the cam mechanism controlled by the stepping motor. During the welding process, the stepping motor is used to control the flame gun to swing to ensure uniform heating of the weldment. To prevent the welding wire and the weldment after welding, the function of automatic reverse spinning is set when the wire feeding completed, and the speed and length of the reverse spinning can be set on the touch screen [4].

2.4. PLC control system
The PLC is used in the flame brazing robot system as the central control device. The robot body, the rotating table, the human-computer interaction tough screen and the sensing system are integrated by Fieldbus, Ethernet and remote-control module. These are based on the I/O module. Therefore, the flame brazing system are centralized management and controlled. The selection of welding procedures, the setting of welding parameters, the manual or automatic control of all motors and valves, the monitoring of welding parameters and alarms can be realized through the touch screen. Fig.4 shows the human-computer interaction interface [5].

3. Flame brazing parameters
Figure 5 shows the pipe assemblies with outer diameters of Φ7mm and Φ9mm, and materials are the copper. The flame brazing position which is located in the connection between the pipe and tee.

![Figure 5. The pipe assemblies with outer diameters of Φ7mm and Φ9mm](image)

3.1. Flame brazing process flow
The rotating brazing table of the welding system has four stations, and each set is equipped with four sets of fixtures. Double flame guns are used in this system, and the four sets of process pipe assemblies installed in one station are welded twice. The welder stands in the operation equipment. First, the equipment is energized, all the gas path valves are opened, and the components to be welded are installed according to the position angle and installation depth that the process required. Then, the flame brazing starts.

After the robot system is powered on, return to the working origin in the waiting command state and click the ignition button, the robot completes the torch ignition action. The type of workpiece to be welded is selected through the touch screen. According to the selection of the touch screen, the system automatically calls the welding parameters of the corresponding workpiece. The system judges whether there is any action during the waiting time. If not, the flame brazing system is switched to the energy-saving mode, and the flame gas flow rate is automatically adjusted to a minimum value. On the contrary the turntable rotates, and the PLC control system is fixed on the workbench. The PLC sends a command to the welding robot control system to call the welding workpieces that contains the corresponding station and pose data, and the welding robot performs the welding operation. During the welding, the system judges whether there is an interruption. If not, the welding operation is completed, the program
is reset, and the welding robot is waiting for the command position; On the contrary, the robot stops, the welding torch is turned off, the welding program is reset, and the robot is back to home waiting for instructions after receiving the reset signal.

3.2. The process parameters
The main process parameters of flame brazing include natural gas flow, oxygen flow rate, preheating time, welding time, wire feeding speed, cooling time, wire return speed, and wire return length. Through repeated welding, the optimal parameters of the tube assemblies of Φ7mm and Φ9mm are finally obtained, as shown in table 1.

Table 1. Process tube assembly welding process parameters

| Model               | Process parameters |
|---------------------|--------------------|
|                     | natural gas flow   |
|                     | L/min              |
|                     | oxygen flow rate   |
|                     | L/min              |
|                     | preheating time    |
|                     | s                  |
|                     | welding time       |
|                     | s                  |
|                     | wire feeding speed  |
|                     | mm/s               |
|                     | cooling time       |
|                     | s                  |
|                     | wire return speed   |
|                     | mm/s               |
|                     | Wire return length |
|                     | mm                 |
| Φ7mm Process tube assembly | 11  | 12.5 | 7.5  | 3   | 18  | 15  | 15  | 10  |
| Φ9mm Process tube assembly | 12  | 14.5 | 6.9  | 3.2 | 24  | 15  | 15  | 10  |

The process tube assembly is produced by the flame brazing process parameters shown in Table 1. The product qualification rate is over 99%, the welding quality is stable, the penetration reaches 80% of the matching depth, the welding joint is full, and there is no welding defects such as virtual welding, over-burning, blowholes or lack of welding, as shown in figure 6.

3.3. Flame brazing process analysis
The defects such as over-burning, insufficient penetration and leakage welding are usually to occur during the robotic flame brazing. These welding defects are caused by the following reasons: First, the welding process parameters are not set properly. For example, excessive oxygen, longer preheating time. These will lead to defects. The reasonable welding parameters can be determined through multiple tests. Second, the fluidity of the molten state metal is affected by the reasons that the material is Uneven distribution, the dirty surfaces, the large gap. It results in insufficient penetration, leakage welding and other defects. This can be avoided by uniform material and surface cleanness. Third, if the consecutive
welding defects occurred in the welding position, the heating position of the welding heating may be unreasonable, and the welding quality can be improved by modifying the corresponding welding position data by the robot.

4. Conclusion
The developed flame brazing robot system realizes the precise control of welding heating time, gas flow rate, filling position, filling time and filling amount through the automatic control of flame brazing process. It ensures the stability and consistency of welding quality, reduces the dependence of pipeline welding on welder's skills, at the same time reduce the labor intensity. The production efficiency has increased from 123 pieces per hour to 260 pieces per hour. The production efficiency has increased by 110%. The qualified rate of products is high. It saves a lot of manpower cost for enterprises and produces good benefits. The equipment can be widely used in household appliances industry.

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