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Design and Implementation of Integrated Control System for Fixed Spot Welder in Human-machine Fusion Mode

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Abstract: *To address the inefficiencies, high labor intensity, and low precision inherent in traditional fixed manual welding, a dedicated spot welding control system was designed using Siemens S7-1200 series PLC and a touch screen interface. This system operates by controlling three stepper motors which in turn maneuver the welding machine along a cylindrical coordinate system, thus facilitating complex three-dimensional spot welding tasks. The parameters of the spot welding process can be dynamically adjusted through a human-machine interface interacting with the PLC, allowing for real-time modifications based on practical needs during the welding process. This innovative system marks a significant improvement over traditional welding methods. Its use of advanced PLC technology ensures higher control precision and a greater degree of automation. These enhancements not only optimize the welding process but also significantly reduce the physical strain traditionally associated with manual welding tasks. Moreover, the system's adaptability and practical applicability are noteworthy, making it a versatile solution for various industrial welding needs. Overall, the implementation of this PLC-based control system in spot welding machines represents a substantial advancement in welding technology. By automating the process and allowing for real-time adjustments, it addresses the core challenges of manual welding, bringing about a new era of efficiency and precision in industrial welding applications.*

Keywords: *spot welding; stepper motor; process parameters; cylindrical coordinate system; programmable logical controllers (PLC); human-machine integration*

1. Fixed Point Welding Machine Structural Design

The design of the fixed-type, single-point, and motor-driven spot welding machine is developed. The welder structure includes a base and a supporting worktable. The θ-axis stepper motor is placed underneath the worktable to drive its rotational motion, while the r-axis stepper motor is placed on the base connected to the welding arm, driving its radial motion. The z-axis stepper motor is connected to the welding arm and welding gun to drive the welding gun's movement along the z-axis. The entire system's mechanical structure is illustrated in Figure 1.

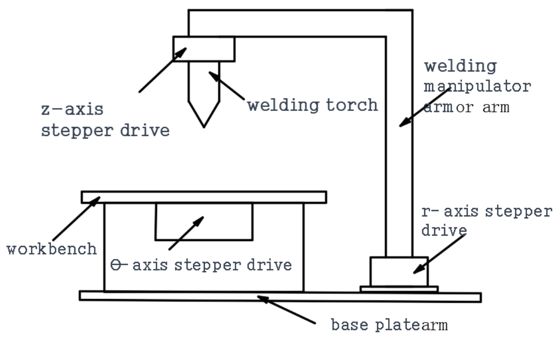

Figure 1: Structural diagram of electric welding machine

It controls the movement and coordination between the workbench and the welding torch. Human-machine interaction is facilitated through a touchscreen. Program parameters can be adjusted based on the specific model and size of the workpiece and downloaded directly to the PLC. The entire system is easy to operate and runs reliably [1,2].

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2. Motion Design

Based on the cylindrical coordinate system, the three-dimensional spatial movement of the fixed, single-point, motor-driven spot welding machine is decomposed into vertical movement in the z-axis direction, radial motion in the r-axis direction, and rotational movement in the θ-axis direction. The θ-axis stepper drive accomplishes the rotational movement of the workbench; the r-axis stepper drive achieves the radial movement of the welding manipulator arm; and the z-axis stepper drive carries out the vertical movement of the welding torch.

2.1 Control of the Workbench's Rotational Angle

Firstly, determine the stepper motor's step angle based on the spot welding process requirements. Then, by considering the micro-stepping count of the stepper motor, one can calculate the total number of pulses required for the motor to make a full rotation[3].

$$n_\Sigma = \frac{360}{B \times C} \tag{1}$$

The number of pulses for a specific rotational angle is:

$$n_x = \frac{n_\Sigma}{P} \tag{2}$$

In the formula: B- Step angle, C -Microstepping count of the stepper motor, P - Number of weld points on a given circumference.

2.2 Control of Welding Arm and Torch

The radial movement of the welding arm and the vertical movement of the welding torch can be achieved through a stepper motor driving a lead screw. Based on the precision requirements of the welding points, determine the microstepping count of the stepper motor and calculate the total pulses for the stepper motor's single rotation. Finally, determine its lead (distance between two threads) based on the selected lead screw. The travel distance for a single step of the stepper motor is:

$$K = \frac{S}{n_\Sigma} \tag{3}$$

$$P_r = \frac{(D_n - D_{n-1})}{2K} \tag{4}$$

$$P_z = \frac{(z_n - z_{n-1})}{2K} \tag{5}$$

In the formula: D_n -Diameter of the larger circle in adjacent turns, D_{n-1} - Diameter of the smaller circle in adjacent turns, Z_n - Current radial processing height for the adjacent turn, Z_{n-1} - Previous radial processing height for the adjacent turn, S - Pitch (lead) of the leadscrew.

Using formula (4), one can calculate the radial travel distance per step, and formula (5) provides the axial travel distance per step. The machining process parameters can be set via the touchscreen and sent to the PLC. After calculations, the PLC sends the corresponding pulse count to the driver. The driver then operates the stepper motor according to the machining parameters [3,4].

2.3 Motion Structure Design

Achieving the rotational motion in the θ-axis direction for the spot welding machine is relatively straightforward. The θ-axis stepper motor can be coaxially aligned with the workbench's main shaft. By driving the θ-axis stepper motor to rotate, the workbench is turned, achieving the rotational motion in the θ-axis direction. The vertical motion in the z-axis direction and the radial motion in the r-axis direction require the stepper motor to convert rotational motion into linear motion through a leadscrew. The structural principle is shown in Figure 2.

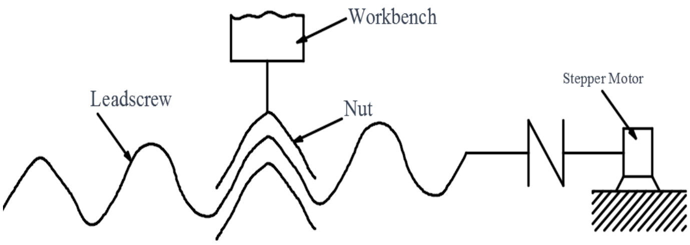

Figure 2: Radial Motion Mechanism

3. Control System Hardware Configuration

The stationary, single-point, motor-driven spot welding machine uses cylindrical coordinate system parameters to control its complex motion in three-dimensional space. Siemens S7-1200 series PLC is used as the main controller. The PLC issues cylindrical coordinate system parameters (r, θ, z) to the driver. Drivers A, B, and C drive three stepper motors to achieve welding at any point in three-dimensional space. The spot welding process parameters (such as the specific model of the workpiece and the size change program parameters) are set by the touch screen and communicated to the main controller. Functional modules are used for position information collection, auxiliary logic control, etc. When drivers A, B, and C receive pulse signals issued by the PLC, they convert these pulse signals into angular displacement of the stepper motor. The speed of the stepper motor is directly proportional to the frequency of the pulse signal[5]. By controlling the frequency of the step pulse signal, precise speed control of the motor is achieved; and by controlling the number of step pulses, precise positioning of the stepper motor is achieved. The schematic diagram of the control system of the entire stationary, single-point, motor-driven spot welding machine is shown in Figure 3.

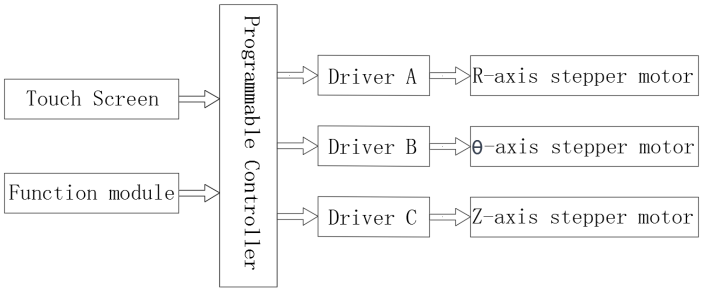

Figure 3: Schematic of the Stationary Spot Welding Machine Control System

4. Spot Welding Machine Control Scheme Design

4.1 Control Flow

The overall workflow of the spot welding machine is as follows: Firstly, based on the HMI (touch screen), set the process parameters (such as: welding point circle radius "r_i", single circle welding point number "n_i", welding point circle z-axis coordinate "z_i", number of welding point circles "q"), then the system initializes. The purpose of initialization is to return the welding gun to the origin and clear the parameters from the previous processing session. The spot welding machine starts processing from the inner circle. The PLC issues commands to drive the r-axis stepper motor to move the welding gun to the inner circle. The z-axis stepper motor works in conjunction with the θ-axis stepper motor to complete the single circle spot welding. Then, it proceeds to the outer circle to complete the spot welding in sequence. The entire system's spot welding process flow is shown in Figure 4.

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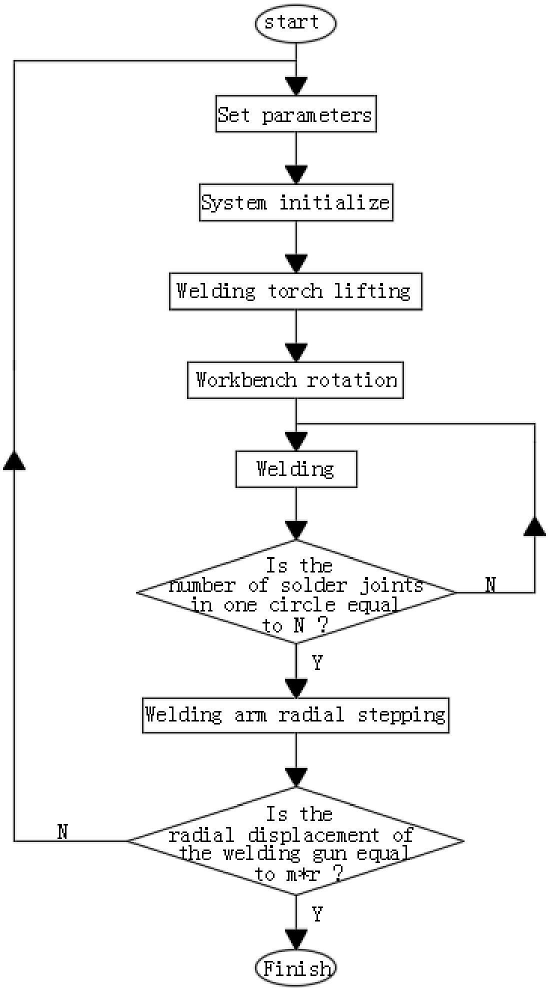

Figure 4: Welding Process Diagram

4.2 Touch Screen Interface Design

The control mode based on the human-machine interface requires a comprehensive touchscreen interface function. In this article, the HMI interface is designed using the configuration software SIMATIC Protool[6-9]. This includes HOME (main interface). Under the HOME state, it is divided into four sub-screens: automatic processing flow, manual processing flow, process parameter setting, and process monitoring. The main interface is shown in Figure 5.

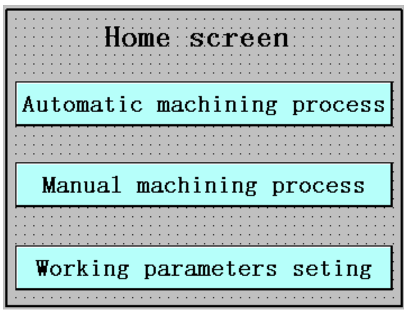

Figure 5: Main Interface Diagram

Switching to the manual processing flow screen, you enter the corresponding interface. This includes functions such as raising the welding gun, lowering the welding gun, worktable forward rotation, worktable reverse rotation, welding arm forward, welding arm retreat, welding, stop, and return. The Manual Processing Flow Interface is shown in Figure 6. In manual mode, the z-axis stepper motor drives the welding gun and the r-axis stepper motor drives the welding arm to move 1mm each time. The θ-axis stepper motor drives the worktable to rotate by 1 degree each time.

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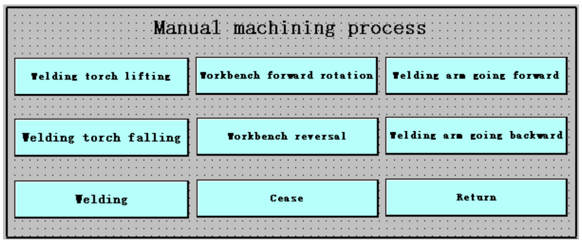

Figure 6: Manual Processing Flow Interface Diagram.

The process parameters can be modified in the "Process Parameter Setting" interface. Taking the workpiece processing in Figure 8 as an example, the outer circle diameter is 240mm, with 20 welding points, and the z-axis height is 460mm[10-15]. The inner circle 1 has a diameter of 160mm, with 10 welding points, and a z-axis height of 320mm. Inner circle 2 has a diameter of 80mm, with 6 welding points, and a z-axis height of 260mm. Inner circle 3 has a diameter of 0mm, with 1 welding point, and a z-axis height of 200mm. Parameter setting starts from the outer circle, and the editing interface is shown in Figure 7 below.

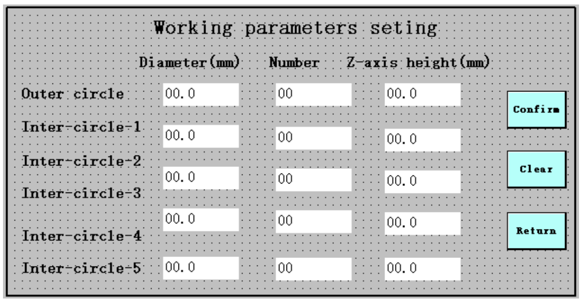

Figure 7: Parameter Setting Interface Diagram

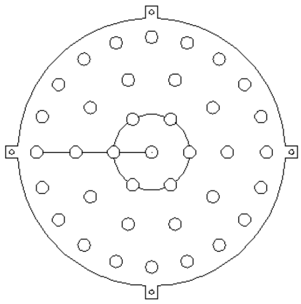

Figure 8: Workpiece Spot Welding Interface

5. Conclusion

The human-machine interactive interface and the PLC-designed automated stationary spot welding machine control system can achieve human-machine interaction and are simple to operate. It can meet the processing needs of workpieces with different parameters, with high processing accuracy and strong technological adaptability. It also meets the requirements of manual/automated processing with a high level of automation. Furthermore, it can satisfy the working requirements of stationary spot welding machines under complex technological conditions, possessing widespread practical value and significance for promotion.

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