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Automatic welding system design for transformer station grounding steel based on PLC

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Abstract. Based on the analysis of the type of grounded flat steel welding, the transformer station grounding flat steel automatic welding system is designed by using the XDM PLC as the main controller, and the three-axis motion mechanism and the R-axis rotation mechanism as actuators. According to working requirements, such as four-dimensional space degree of freedom welding requirements, system hardware configurations, the actuator design, system hardware selection, and the hardware connection form of the system are determined at first. The paper introduces the composition and working principle of the automatic welding system, focusing on the coordinate transformation relationship in the visual measurement, and gives the calibration process. The compensation methods after the rotation of the welding torch at each inflection point are discussed, and the different welding parameters are used according to different seam types during the welding process. The flow chart of control program is given out for the welding gun attitudes adjustment. The testing welding result shows this designed system can track the welding seam quite well and welding quality is satisfying, the more, this system can improve the welding efficiency greatly.

1. Introduction

Transformer station grounding flat steel is an important part of the transformer station grounding system. The resistance of the flat steel directly determines the electrical conductivity of the grounding system, and the welding of flat steel is the key factor affecting the resistance of the grounded flat steel[1-3]. At present, the welding of domestic grounded flat steel is normally carried out manually, and there are defects such as low welding quality and low efficiency[4-6]. The automation of the welding process has advantages such as high welding efficiency and good welding quality[7-8], therefore, the automatic welding of grounded flat steel is an effective means to reduce the labor intensity, improve the welding efficiency and ensure the welding quality.

There are many ways of splicing the grounded flat steel and the weld path is not continuous. In order to enable the automatic welding control system to automatically identify the flat steel lap joint form and weld path and automatically complete the arcing and arc-extinguishing operation of the welding torch[9]. The smart camera is used to collect the welding information. The PLC is used as the main controller and three-axis motion mechanism combined with the R-axis rotation mechanism as the actuator. The paper introduces the welding system structure and working requirements, and gives out the control flow chart, focusing on the problems of coordinate conversion, camera calibration and torch rotation compensation.



2. Introduction to the working principle of the system

The automatic welding system for transformer station grounding flat steel is mainly composed of mechanical parts and electrical control[10]. The mechanical parts include X, Y and Z three-axis coordinate motion mechanism, R-axis rotation mechanism, as well as a mobile trolley, which is used as a mounting platform for the welding system. The electrical control elements include a PLC controller and four stepping motor drivers, all these parts are shown in Figure 1. Among them, the quick-pressing pressure pliers are threaded on the bottom plate, and the flat steel is fixed by the pressure clamp handle; the X, Y and Z-axis stepping motors drive the screw to rotate, and control the three-dimensional movement of the three-axis motion mechanism, combining The R-axis rotating mechanism can achieve welding requirements for different spatial poses.

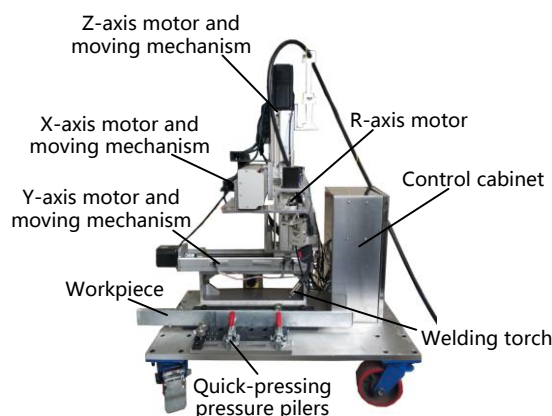


Figure 1. Schematic diagram of transformer station grounding flat steel automatic welding system.

This system is designed for the flat steel welding in transformer station, mainly for the overlapping forms shown in figure 2. Before welding, the coordinate information of welding and the overlap type of the flat steel are obtained by the smart camera with the image-processing algorithm. By the help of key points of welding, and the space curve linear interpolation-fitting algorithm, the welding trajectory is determined, so that the torch can be moved exactly to the joint point with a certain angle to confirm the welding in a precision degree.



Figure 2. Grounding flat steel lap joint form.

3. Hardware design

When the grounding flat steel is welded, the three-axis motion mechanism X, Y and Z motors and the R-axis rotating mechanism need to cooperate to meet the welding requirements of different positions. The controller selects the Xinjie XDM-60T4 PLC including four-axis drive and high-speed pulse output terminal for path interpolation operation as the system control core, and outputs control quantity, including electric welder, wire feeder, smart camera and motor driver. Waiting for the start and stop. A visual sensing system consisting of an In-Sight 7600 smart camera with a resolution of 800 pixels×600 pixels and a focal length of 5 mm and an auxiliary light source is used to collect weld image data to provide control parameters for the PLC. According to the size requirements of the welding workpiece, the motion subsystem adopts a four-macro 86BYGH stepping motor with a resolution of 20000 pulses/r, that is, a module with a pulse equivalent of 1um/pulse, a combined stroke of 300mm and a lead screw lead of 20mm. X, Y, Z three-axis coordinate motion mechanism to ensure the amount of space required for welding. According to the "lightweight, digital" requirements of the

system, Otto NBC-200i welding machine is used which is easy to control with touch panel. The hardware block diagram of the welding system is shown in Figure 3.

According to the above content, design and connect the hardware wiring diagram of the PLC system, as shown in Figure 4.

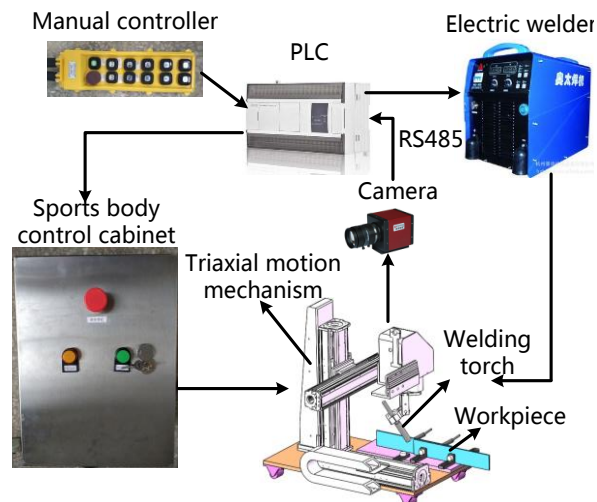


Figure 3. Hardware block diagram of the welding system.

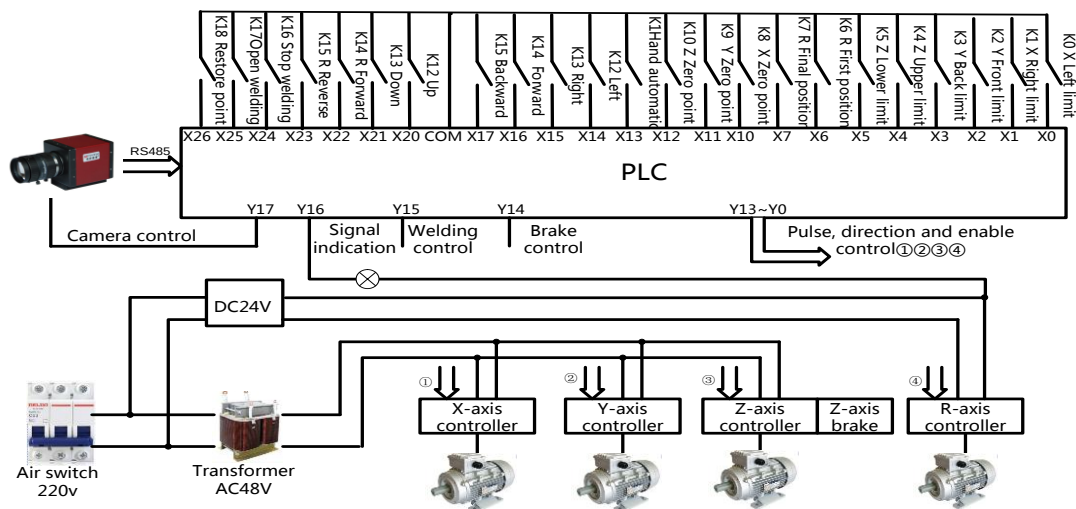


Figure 4. Control system hardware wiring diagram.

4. Control system design

4.1. Camera calibration and coordinate conversion

The main task of the automatic welding system based on visual sensing is to convert the weld coordinate points of the space target position into the robot base coordinate system. The implementation of this process requires the establishment of a coordinate transformation relationship[11]. The relationship between the three-axis motion mechanism and each coordinate system is as shown in Figure 5. Let P as the exact welding feature point, H is the transformation

matrix of pixel coordinates and image coordinates, and S is the transformation matrix of image coordinates and camera coordinates. M is the transformation matrix of the camera coordinates and the world base coordinates, and D is the transformation matrix of the camera coordinate system and the robot base coordinate system. The coordinate transformation relationship is established based on the principle of small hole imaging. The specific steps are as follows:

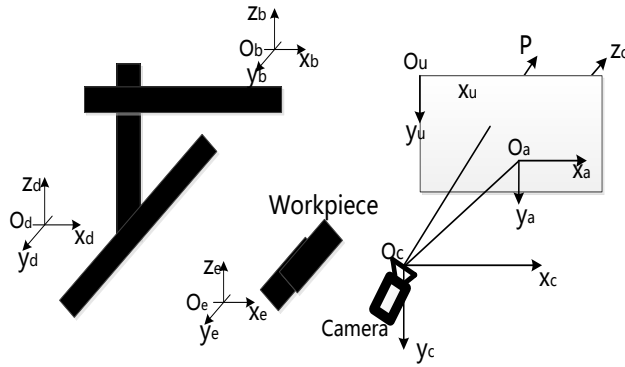


Figure 5. The relationship between the three-axis motion mechanism and each coordinate system.

(1) Establish the relationship between the pixel coordinate system and the camera coordinate system

$$P_u = HSP_c, HS = \begin{bmatrix} g & 0 & u_0 & 0 \\ 0 & h & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \quad (1)$$

In equation (1): P_u and P_c are the coordinates of P in pixel coordinates and the coordinates in camera coordinates, g and h are the equivalent parameters of the image in the u and v axes, and (u_0, v_0) is the coordinate of O_a in the pixel coordinates.

(2) Establish the relationship between the camera coordinate system and the world coordinate system

$$P_e = M P_c, M = \begin{bmatrix} R_{ec} & t_{ec} \\ 0 & 1 \end{bmatrix} \quad (2)$$

In equation (2), R_{ec} and t_{ec} is the rotation transformation matrix and the translation vector of the camera coordinate system to the world coordinate system.

In order to be able to obtain the coordinates of the weld at the target position in the coordinates of the robot base coordinate system, it is necessary to determine the conversion relationship between the established camera coordinate system and the robot base coordinate system. The specific steps are as follows:

(3) Relationship between camera coordinate system and robot base coordinate system

$$P_d = DP_c, D = \begin{bmatrix} R_{dc} & t_{dc} \\ 0 & 1 \end{bmatrix} \quad (3)$$

In equation (3), R_{dc} and t_{dc} is the rotation change matrix and the translation vector of the camera coordinate system to the robot base coordinate system.

Through the above three equations, the coordinate transformation relationship during visual measurement is established. In order to determine the unknown parameters in the equation, the system

uses a 9-square grid calibration camera for calibration, and the calibration process is shown in Figure 6.

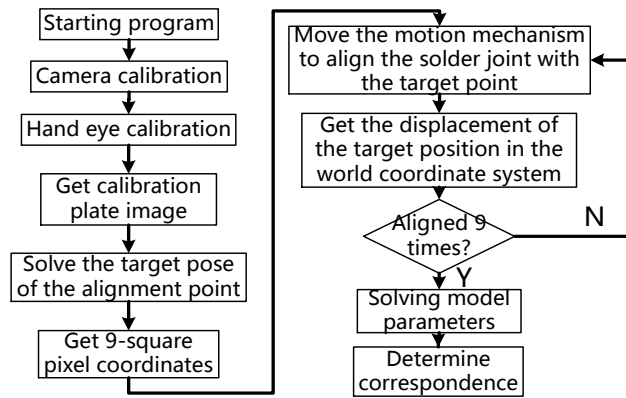


Figure 6. Calibration flow chart.

4.2. Torch rotation compensation

During the welding process, since the welds are not in the same spatial orientation, the welding torch needs to be turned at the inflection point of each weld. However, the center of the rotating shaft and the welding point of the welding gun do not coincide, so after the rotation, the welding gun needs to be compensated. The compensation process is shown in Figure 7.

With the center of rotation as the center, the welding point of the welding torch is a point on the arc to establish a compensation model. Where α is the angle between the front and the horizontal direction of the welding torch, R is the distance from the rotation axis to the welding torch, and θ is the angle of conversion. The specific steps are as follows:

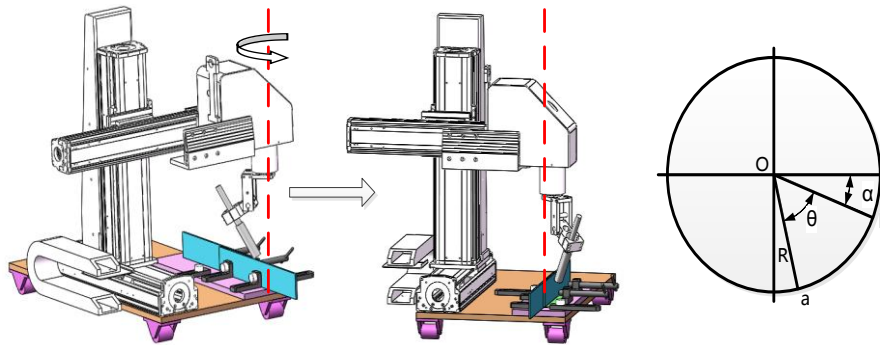


Figure 7. Torch rotation and compensation schematic.

(1) The compensation amounts $H_{\Delta x}$ and $H_{\Delta y}$ in the X and Y directions after the torch is rotated are:

$$\begin{aligned} H_{\Delta x} &= R[\cos \alpha - \cos(\alpha + \theta)] \\ H_{\Delta y} &= R[\sin(\alpha + \theta) - \sin \alpha] \end{aligned} \quad (4)$$

The position of the welding torch after the rotation is calculated according to the above formula, and the welding point can be moved to the inflection point.

4.3. Control system software design

The control system not only needs to complete the trigger the working of welding machine, the feeding of the welding wire, but also needs to trigger the smart camera to extract the weld information, and trans relative information to PLC. The stepping motors are driven in a manner of "pulse + direction" , so as to drive the torch moving along the seam.

The system adopts automatic/manual welding. In the automatic welding mode, the system origin flag HM0 is detected. After the system returns to the origin, the camera is triggered to take a picture of the weld seam and processed. The coordinate values of the weld feature points and the lap joint form of the weld are stored in the PLC data memory via the RS485 bus in HD0~HD30 and HD40, the PLC moves the welding torch to the welding point accordingly, and at the same time, the welding path planning is performed by the linear interpolation algorithm, the pulse control amount of each axis is calculated, and the X, Y and R axis motors are driven to cooperate and weld. After welding to the first section of the weld and the second section of the weld inflection point, the welding torch is arced and the angle is adjusted to compensate. The specific control process is shown in Figure 8.

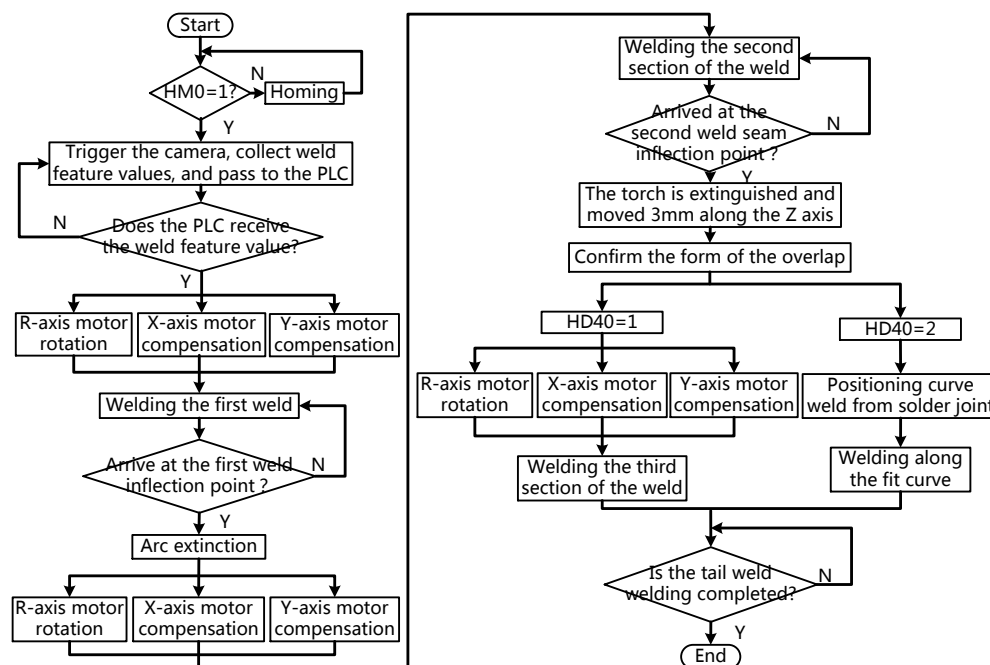


Figure 8. System flow chart.

5. Conclusions

Based on the engineering practice, this paper designs a set of transformer station grounding flat steel automatic welding system based on PLC control. In order to ensure the performance of the automatic welding system, manifesting tests are carried out by this welding system. The experimental welding parameters are as follows: torch wire length is 1~2mm, welding current is 85A, welding voltage is 14.5V and welding speed is 1.6mm/s.

Figure 9 shows the results of the field test. The experimental results show that the automatic welding system based on PLC control realizes the tracking welding of the flat steel weld. When the welding speed is 1.6mm/s, the tracking error is less than 0.5mm, and the weld is well formed, which ensures the welding quality. The experimental results illustrate the feasibility and reliability of the transformer station grounding flat steel automatic welding system based on PLC control.



Figure 9. Welding test effect chart.

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