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RESEARCH ARTICLE

Research on Arc Length Tracking Control Technology of Tube-Sheet Welding Based on Pulsed TIG

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ABSTRACT During tungsten inert gas welding process, arc length will change due to thermal deformation, uneven surface of workpiece and tungsten electrode loss. Considering the large fluctuation of arc length in all-position annular seam welding under the action of multi-variable coupling, a mathematical model of arc length and arc voltage was established in this paper, and an isolated and high frequency arc voltage acquisition circuit was designed. An improved sliding filtering algorithm was proposed, and after filtering the real-time arc voltage data, fuzzy control algorithm was used to realize the online tracking control of arc length in annular seam welding, in order to improve the reliability and stability of welding quality of tube-sheet. The experimental results show that the dynamic response time of the proposed arc length tracking compensation method is not more than 40*ms*, and the arc length tracking deviation is less than 0.2*mm*, which can fully meet the requerements of welding seam tracking of tube-sheet welding.

INDEX TERMS Arc length tracking, fuzzy control, sliding filter, tube-sheet welding.

I. INTRODUCTION

Pressure vessels such as tube-sheet heat exchanger, condenser and steam generator are the main industrial products to realize heat exchange. They play an important role in many industries related to the national economy and people's livelihood such as petrochemical industry, nuclear power ship, metallurgy and military industry. Currently, in the production of most heat exchange, the welding of tube-sheet adopt semi-automatic single-hole welding, which leads to tedious operation of welders, reducing product productivity and lower welding quality of tube-sheet [1]. However, during the design and manufacturing of large high-parameter pressure vessels such as heat exchangers and reactors, the welding quality of tubes and sheet has an extremely important impact on the safe operation of the en-tire unit of the equipment [2]. In petrochemical equipment, the failure of heat exchanger tube bundle is more than 20% due to improper welding process or lax execution of pro-cess procedures, and the leakage of heat exchanger tube head is more than 90% caused by welding quality defects [3], [4], [5].

The tube joints of heat exchangers are annular welds in all positions, with dense group joints and large thermal de-formation, so robot welding faces many difficulties. In the all-position tube-sheet welding operation, flat welding, down-ward vertical welding, upward vertical welding and upward vertical welding are required to complete a weld [6], as shown in Fig. 1. When the welding gun is in different weld-ing positions, the effect of gravity on weld formation of liquid metal in the molten pool is different and constantly chang-ing. Therefore, the main key technology to realize all-position tube-sheet welding lies in how to control the metal weld pool [7], [8]. Tungsten inert gas welding (TIG) as a high quality welding method has been widely used in tube-sheet welding. The pulse technology is used in TIG welding. The base metal melts under the action of peak current, the metal melt pool expands rapidly, and the stroke has a fixed shape under the action of its own gravity, surface tension

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and elec-tromagnetic force. During subsequent base current periods, the pool rapidly solidifies to form a solder joint, thus forming the weld in a cycle.

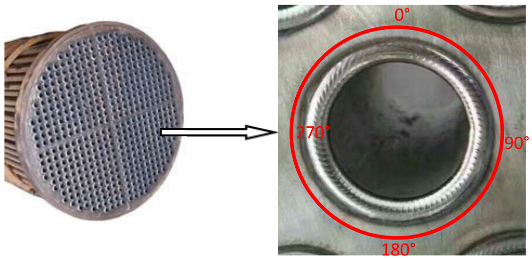

FIGURE 1. Schematic diagram of all-position tube-sheet welding.

In order to reduce the influence of gravity on weld pool, pulsed TIG welding is often used in tube-sheet welding. Pulsed TIG welding has the characteristics of high welding quality, good weld forming quality and uniform grain refinement [9]. Moreover, pulsed TIG welding can independently adjust the peak and base current, pulse width, pulse period or frequency and other parameters, can change the depth to width ratio of the molten pool, improve the stirring effect of the molten pool, etc. Weld energy and its distribution can be precisely controlled by adjusting pulse parameters of TIG welding, which is suitable for all-position welding [10]. The special shape of the workpiece, the unevenness of the workpiece surface or the instability of the moving mecha-nism may cause the change of arc length, so that the heat input and distribution of the workpiece surface will change significantly, leading to the non-fusion or penetration phe-nomenon of the workpiece, and affect the welding quality. Under the condition that welding current, shielding gas flow, tungsten electrode diameter and tip taper are constant, welding arc length has a good linear relationship with arc voltage. Welding arc length affects the width of welding pool, and the width of welding pool has a certain impact on the quality of welding parts [11], [12]. Therefore, welding quality can be controlled according to the feedback value of arc voltage.

Most scholars characterized arc length through sound, light and electric signals in the arc welding process [13], [14], and realized arc length control by studying the correspond-ing relationship between the characterized signals and arc length or indirect control of the characterized signals [15]. Liu et al. [16] studied the influence of groove side wall on arc acoustic signal and the sensitivity of arc acoustic char-acteristics to welding gun deviation. They used arc acoustic signal to adjust arc length and the tracking accuracy of weld seam was 0.6mm. Intelligent Robot Welding Technology Laboratory of Shanghai Jiao Tong University [17] has con-ducted researches on arc length control by using acoustic arc signals for many years. Through the acquisition and processing of acoustic signals, the experimental results based on adaptive PID controller show that the maximum error of arc length control is 0.58mm. Li and Zhang [18], [19] from University of Kentucky in the United States designed an arc length control system composed of arc light sensor, arc length adjusting device and single chip microcomputer, and the arc length control accuracy could reach ±0.2mm.

In the welding process, arc length is controlled by arc voltage control, which is a common method in current industrial application [20]. At present, the commonly used methods for arc voltage control include PI [21], PID [22], feedback linearization [23], fuzzy [24] and adaptive fuzzy control [25], as shown in Table 1.

TABLE 1. Arc voltage control method.

Method	Advantages	Disadvantages
PI control	The principle is simple and e asy to implement	Not suitable for control objects with hysteresis
PID control	Fast dynamic response	Depend on experience
feedback linear control	Convert non-linearity to linear system	Complex control method
fuzzy control	Suitable for solving non-linear problems	rules and membership fun ctions need to be constructed

In this paper, a welding robot is designed based on the pulsed TIG welding arc characteristics and the all-position annular seam welding process, including an isolated high frequency and high precision arc voltage acquisition circuit module. Then the mathematical model of arc length and arc voltage is established, and the relevant filtering algorithm is proposed. Finally, the fuzzy controller is used to realize the arc voltage tracking control, so as to realize the rapid response and high precision online welding arc length control. Data acquisition, filtering algorithm, fuzzy control and other methods are adaptive optimization according to the process requirements, mainly considering the response time and control accuracy, the three methods are combined to ensure the responsiveness and stability of the whole system, and the design and method are verified by experiments.

II. LARGE-SCALE TUBE-SHEET WELDING ROBOT

A. STRUCTURE OF TUBE-SHEET WELDING ROBOT

The tube-sheet welding robot [26] is composed of a three-coordinate robot, TIG DC welding power supply (Panasonic YC-400TX4), laser light source, CMOS camera (DahengMer 2-503-23Gm-P), welding gun mechanism, etc., as shown in Fig. 2. The U axis rotates to control the welding gun to realize the ring seam welding of the tube-sheet, the XY axis movement is used to locate the center of the welded tube, the Z axis adjusts the welding distance from the weld-ing gun to the tube-sheet, the V axis and the R axis respec-tively control the welding Angle and welding radius of the welding gun, the W axis is used to automatically send tung-sten wire, and the other ABC axis can automatically adjust the position of the equipment through the cross laser rang-ing to adapt to the workpiece plane. The control system is composed of industrial computer and bus 10-axis motion controller. The CMOS camera is connected to the industrial computer through Ethernet, and the industrial computer and motion controller are communicated through Ethernet. The customized arc voltage acquisition module is connected to the motion controller through serial port to control the ad-justment of the Z direction welding distance. Among them, XYZ direction is servo motor driven screw drive, repeated positioning accuracy is 0.05mm, the servo motor is equipped with 23-bit absolute value encoder.

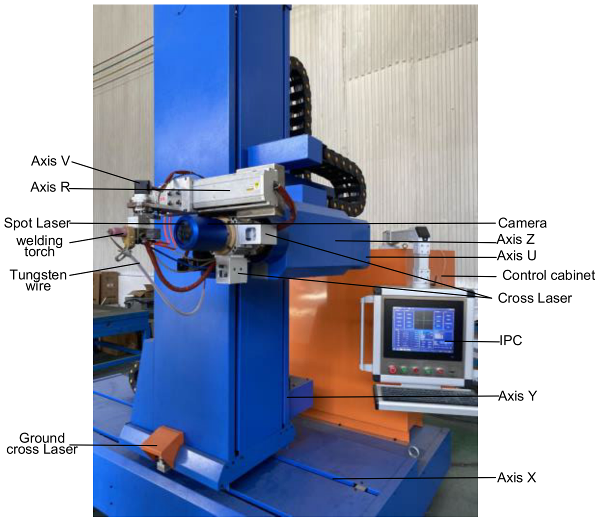

FIGURE 2. Tube-sheet welding robot.

The workflow of automatic welding of tube-sheet is shown in Fig. 3.

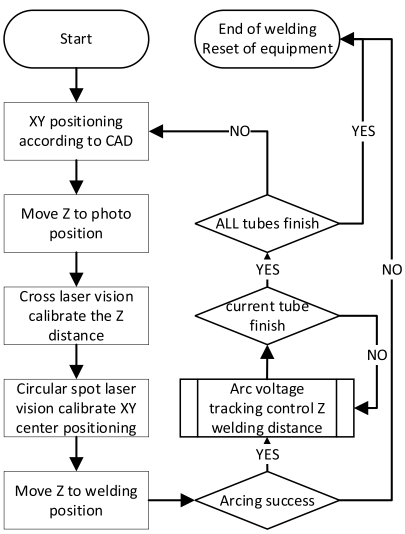

FIGURE 3. The workflow of automatic welding of tube-sheet.

B. DESIGN OF ARC LENGTH MEASUREMENT MODULE FOR TUBE-SHEET WELDING

The arc length of TIG welding is the distance from the tip of the tungsten pole to the annular seam of the tube-sheet. The wear of the tungsten pole and the thermal deformation of the tube-sheet will lead to the change of the welding dis-tance between the tungsten pole and the annular seam of the tube-sheet, that is, the change of arc length. In this paper, the arc voltage feedback value in the welding process is used to characterize the arc length change, so a high fre-quency and high precision arc voltage acquisition module is designed. According to the process requirements of arc voltage acquisition, the acquisition cycle is 1ms, the collec-tion range is 7.0-15.0V, and the collection accuracy is 0.1V. The acquisition circuit is isolated from the control circuit to avoid damage to the control circuit caused by abnormal arc voltage.

MCU selection: In order to simultaneously meet the re-quirements of multi-channel digital IO signal control, analog signal acquisition, serial communication and fast computing speed, the MCU of GD32F303VGT6(GigaDevice Megaeasy innovation) is selected as the main control chip in this pro-ject, as shown in Figure 3, ARM Cortex-M4 core, with a max-imum main frequency of 120MHz. FLASH memory 256K, 80-channel GPIO, 12bit ADC and DAC, 6 16-bit Timer, 5-channel UART and other configurations can fully meet the requirements.

Offset voltage scaling and isolating circuit design: Arc voltage feedback values range from 7-15V, ADC provided by MCU collects 0-3.3V, so the collected values are con-verted through the circuit as shown in Figure 3. At the same time, in order to reduce the interference of voltage signal acquisition on MCU, linear analog optocoupler is adopted for photoelectric isolation before voltage enters MCU termi-nal to ensure the authenticity and safety of signal, as shown in Fig. 4.

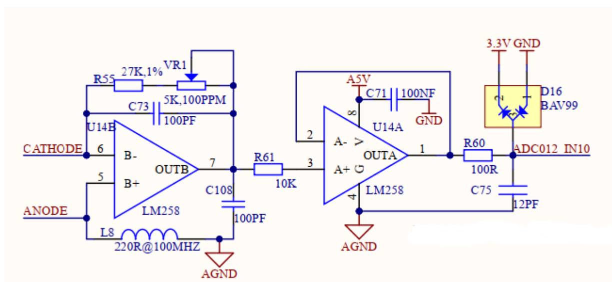

FIGURE 4. Voltage offset and scaling circuits.

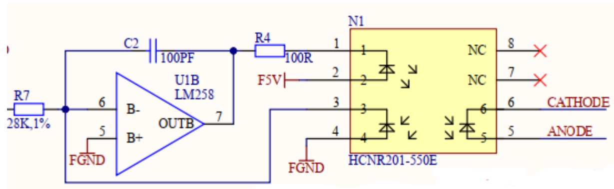

FIGURE 5. The linear optical coupling isolation circuit.

Filter circuit design: Pulse TIG welding is divided into three pulse frequencies: low frequency (0.1Hz-10Hz), medi-um frequency (10Hz-500Hz) and high frequency

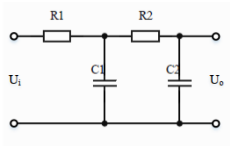

FIGURE 6. The second order RC filter circuit.

(10kHz-20kHz). The pulse frequency used in this paper is 2.5Hz, which belongs to the low frequency band, but in the process of arc voltage acquisition, high-frequency interference sig-nals will be accompanied, which need to be filtered by low-pass filtering circuit. For the second-order RC low-pass filter circuit shown in Fig. 5, resistors R_1 and R_2 are connected, capacitors C_1 and C_2 are connected, and the filter cutoff frequency is set as f_c, which calculation is shown in (1) and (2).

$$f_c = \frac{w_c}{2\pi} \tag{1}$$

$$w_c = \frac{0.3742}{RC} \tag{2}$$

Therefore.

$$C = \frac{0.3742}{2\pi R f_c} \tag{3}$$

III. DATA ACQUISITION AND PROCESSING OF ARC VOLTAGE BASED ON TIG WELDING

A. ANALYSIS OF ARC VOLTAGE CHARACTERISTICS OF DC PULSE SQUARE WAVE WELDING

Typical characteristics of DC pulsed arc welding: In the welding process, the welding current alternates periodically with peak current and base current, and both the peak cur-rent and base current are positive. As shown in Fig. 7 (a), the peak current is 200A and the base current is 90A. Theo-retically, the collected arc voltage data should also show periodic step changes, as shown in Fig. 7 (b).

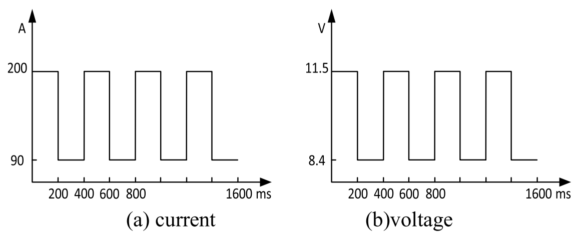

FIGURE 7. The theoretical current and voltage.

The complete welding cycle consists of three processes: arc starting, arc burning and arc closing. The arc starting pro-cess is the process of the air between the tungsten electrode and the tube sheet under high voltage. The air breakdown discharge between the tube-sheet and the tungsten electrode under high voltage forms a loop. After the arc is started successfully, the circuit that generates the high frequency and high voltage current is disconnected, and the arc voltage drops to the normal welding arc voltage. During the arcing phase, the current periodically changes from the peak value to the base value, and the arc voltage also periodically changes accordingly. The original arc voltage is shown in Fig. 8. It can be seen that the arc voltage signal during the welding process fluctuates sharply and the periodicity is not obvious. This is the result of the arc voltage signal plus the high frequency interference signal. In the arc closing stage, the current gradually decreases, the arc voltage decreases, and the arc is extinguished. Welding is not performed in the arc starting and arc extinguishing phases, so arc length control is not required.

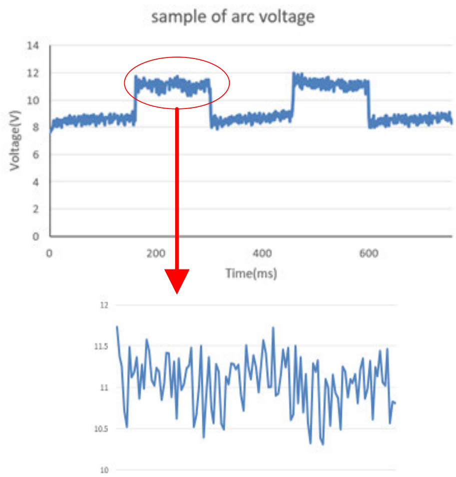

FIGURE 8. Original sample of arc voltage.

B. DIGITAL FILTER ALGORITHM OF ARC VOLTAGE

In the welding process, both the peak voltage and the base voltage fluctuate, indicating that the arc length during weld-ing is also in constant change. In order to further filter the interference and make the signal more valuable for ref-erence, this paper adopts the sliding median filter algorithm and sliding mean filte algorithm for digital filter. The specific implementation process is:

(1) The peak voltage and the base voltage were separated, and only the peak voltage was filtered;

(2) Select the appropriate time window, the larger the win-dow, the more computation, the longer the processing time; The shorter the window is, the worse the filtering effect is. Therefore, an appropriate window size should be selected.

(3) During the welding process, when the base current and the peak current switch, the overshot signal will be generat-ed, as shown in Fig. 9. When entering the peak stage, one end of the time is delayed, and then the filter process starts. The actual test shows that the time is 10ms;

(4) After selecting the window period and before filtering, remove the maximum and minimum values in the window, and then carry out the mean or median algorithm.

The experimental parameters were shown in Table 2.

The acquisition cycle is 1*ms*, and the welding cycle of peak value and base value is 200ms, so there are about 200ms peak data in each cycle. Considering that the data in

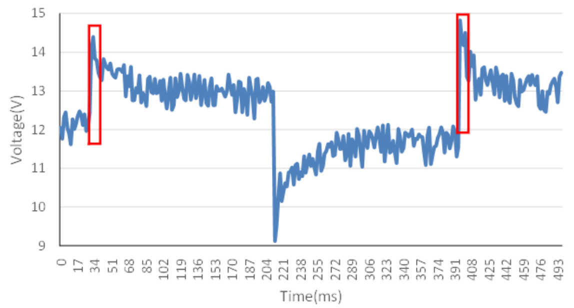

FIGURE 9. Arc voltage at base-peak current switch.

TABLE 2. Experiment parameters of TIG oelding.

Parameter	Value	Parameter	Value
Pulse frequency	2.5*HZ*	Sample frequency	1*kHZ*
Peak current	200*A*	Base current	90*A*
Tungsten anode dia meter	3*mm*	Duty cycle of pulse duration	50%
Workpiece material	Q235	Welding speed	9°/s

the window period T should not be too small, four window periods $T_1 = 10$, $T_2 = 15$, $T_3 = 20$ and $T_4 = 25$ were used to con-duct a series of tests. The original data and filtered data are shown in Fig. 10.

According to the data, the period of the sliding window is almost identical with the delay generated by the filtering algorithm, so the smaller the period, the smaller the delay. However, when $T_1 = 10$, the curve fluctuation after mean filter-ing and median filtering is still relatively large, which is not conducive to the subsequent control and tracking. When $T_3 = 20$ and $T_4 = 25$, on the one hand, the delay is relatively large. On the other hand, after filter, the original change rule is too smooth, which is not conducive to tracking and ad-justment. Therefore, in overall consideration, $T_2 = 15$ is more appropriate as the serial port period. While reflecting the changes of the original curve, the mean filter is slightly smooth, which can avoid the oscillation of control mitigation. Therefore, it is more reasonable to choose the mean filter.

C. ESTABLISH MATHEMATICAL MODEL OF ARC VOLTAGE AND ARC LENGTH

As shown in Fig. 11, the initial collected arc voltage data shows that the welding arc length moves uniformly from 4mm to 1mm, and the arc voltage value changes periodical-ly, which is caused by periodic changes in the peak current and base current. The base voltage corresponding to the base current mainly maintains the arc, and the peak volt-age determines the welding quality. So peak voltage is the vari-able that needs to be controlled. The peak voltage is ex-tracted from the original data, and then filtered through the sliding mean filter algorithm with window period of 15. Since the relationship between arc length and arc voltage is linear, the linear fitting of the filtered arc voltage can be seen as the linear function of arc length and arc voltage, as shown

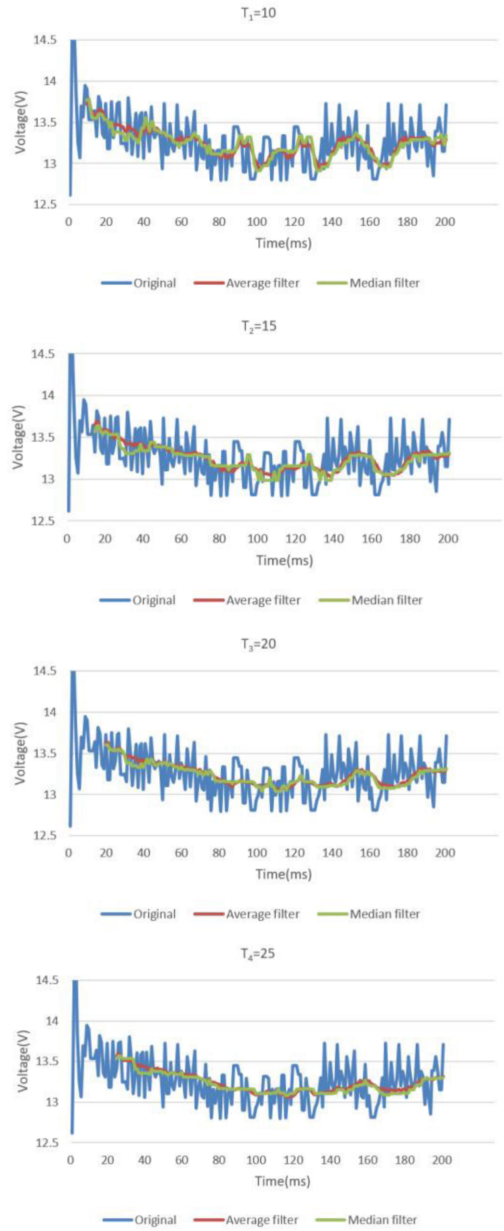

FIGURE 10. Sliding mean filtering and median filtering with different periods.

in (4).

$$y = 0.38x + 11.87 \tag{4}$$

IV. ONLINE COMPENSATION CONTROL BASED ON ARC VOLTAGE TRACKING

Because the linear equation of arc length and arc voltage is established, arc voltage control is equal to arc length con-trol, and the control flow of arc voltage tracking is shown in Fig. 12.

A. PROCESS ANALYSIS OF TUBE-SHEET WELDING

Different from straight seam welding, full-position circu-lar seam welding can be divided into flat welding, upward

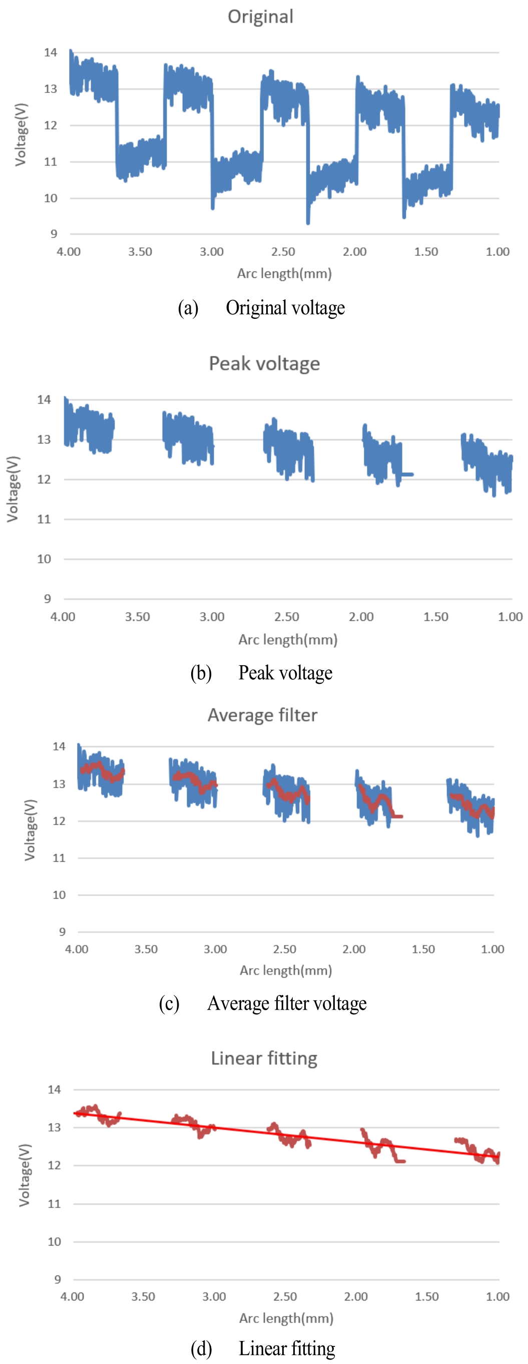

FIGURE 11. Arc length and arc voltage linear fitting.

weld-ing, uphill welding and downward welding, which is one of the remarkable characteristics of automatic welding process of tube-sheet. The weld pool metal will be affected by gravi-ty, arc blowing force and surface tension and constantly change with the change of welding position, which directly affects the weld formation. Therefore, the current in the welding process can be divided into three stages: current rise, pulse welding and current fall. In the current rise stage, the current rises to a given value with a certain slope to pre-vent the current impact from affecting the welding effect. In the

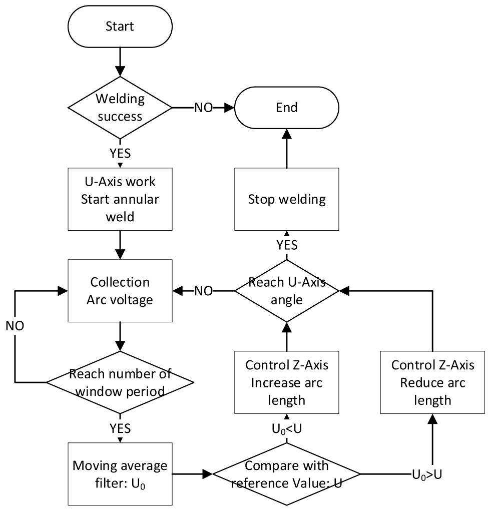

FIGURE 12. Arc voltage tracking control process.

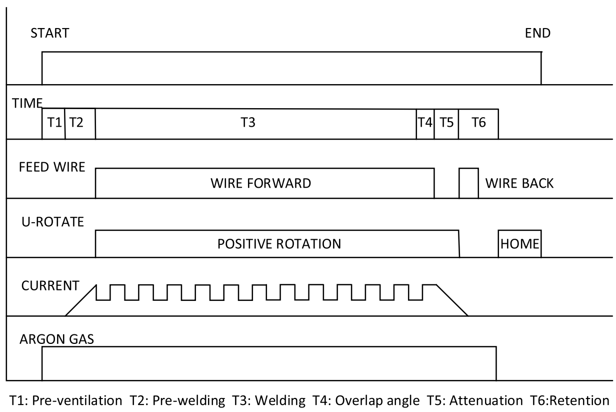

FIGURE 13. Welding flow sequence diagram.

pulse welding, the metal is melted at the peak current, and the arc is kept stable at the base current. In the current decline, the welding current drops to zero with a certain slope, and arc closing is controlled, as shown in Fig. 13. This welding can realize the control of heat input, make the weld pool deep and narrow, stable arc, reduce the heat af-fected zone.

Another remarkable feature of automatic tube-sheet weld-ing is that the changing process of welding current should cooperate with the movement of the machine head. After suc-cessful arc initiation, the current start rising, and the ma-chine head rotates at the same time. After entering the nor-mal welding, the machine head has turned a certain angle; After that, the head continues to rotate a week to reach the arc position, the annular seam has been welded, but be-cause the beginning of a section of weld is formed in the current rise stage, the forming effect is not ideal, need to continue welding, at this time begin the current down stage, which can repair the start welding, improve the forming, so far the end of the whole welding process. The nose stops spinning. Therefore, in the welding process of each annular seam, the rotating movement of the machine head is more than one circle.The workflow of arc voltage tracking control is shown in Fig. 14.

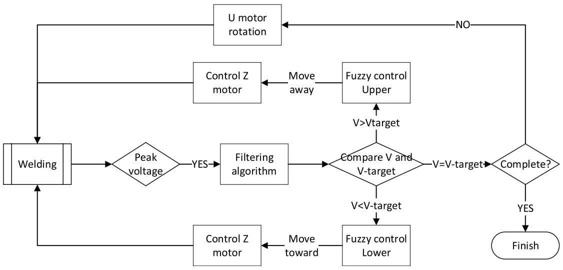

FIGURE 14. **Voltage control algorithm process.**

B. DESIGN OF FUZZY CONTROLLER

Arc voltage tracking system is a nonlinear problem, we expect the greater arc voltage deviation, the faster adjustment, the smaller deviation and the relatively slow adjustment, in order to ensure that the system are both fast response and no overshoot or oscillation. Moreover, the fuzzy control is simple in calculation and fast in response, which is suitable for the arc voltage tracking system.

Firstly, establish the relational expression between the target value and the real-time value as (5)., where the real-time voltage is U, and the target voltage is U_0.

$$e = \Delta U = U - U_0 \tag{5}$$

The deviation e is divided into five fuzzy sets: negative large (NB), negative small (NS), zero (O), positive small (PS), and positive large (PB). According to the variation range of the deviation e, it is divided into seven levels: $-4, -3, -2, -1, 0, +1, +2, +3, +4$. Obtain the arc voltage change fuzzy Table 3.

TABLE 3. **Arc voltage variation division table.**

Membership		Level of change								
		-4	-3	-2	-1	0	1	2	3	4
Fuzzy Set	PB	0	0	0	0	0	0	0	0.5	1
	PS	0	0	0	0	0	0.5	1	0.5	0
	ZO	0	0	0	0.5	1	0.5	0	0	0
	NS	0	0.5	1	0.5	0	0	0	0	0
	NB	1	0.5	0	0	0	0	0	0	0

The control quantity Z is the distance from the tungsten electrode to the sheet. Divide it into five fuzzy sets: negative large (NB), negative small (NS), zero (ZO), positive small (PS), positive large (PB). And the variation range of u is di-vided into nine levels: $-0.4, -0.3, -0.2, -0.1, 0, +0.1, +0.2, +0.3, +0.4$, The value of Z in the fuzzy domain is $[-4, 4]$, and the quantization factor K=10. The fuzzy division of the control quantity is shown in Table 4.

The fuzzy control is shown in the Table 5.

The fuzzy control rule is a multi-sentence, and the fuzzy relationship R is shown in (6).

$$R = (PBe \times NBz) \bigcup (PSe \times NSz) \bigcup (ZOe \times ZOz) \bigcup (NSe \times PSz) \bigcup (NBe \times PBz) \tag{6}$$

Be available:

$$R = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.5 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0.25 & 0.5 & 0.5 & 0.5 \\ 0 & 0 & 0 & 0 & 0 & 0.5 & 1 & 0.5 & 0 \\ 0 & 0 & 0 & 0.25 & 0.5 & 0.5 & 0.5 & 0.25 & 0 \\ 0 & 0 & 0 & 0.5 & 1 & 0.5 & 0 & 0 & 0 \\ 0 & 0.25 & 0.5 & 0.5 & 0.5 & 0.25 & 0 & 0 & 0 \\ 0 & 0.5 & 1 & 0.5 & 0 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0.5 & 0.25 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0.5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \tag{7}$$

Fuzzy decision as shown in (8).

$$Z = e \circ R \tag{8}$$

In this paper, the center of gravity method is used to solve the ambiguity, and the calculation is shown in (9).

$$Z = \frac{\sum_{i=1}^{n} Z_i u_z(Z_i)}{\sum_{i=1}^{n} u_z(Z_i)} \tag{9}$$

TABLE 4. **The fuzzy division of the control quantity.**

Membership		Level of change								
		-4	-3	-2	-1	0	1	2	3	4
Fuzzy set	PB	0	0	0	0	0	0	0	0.5	1
	PS	0	0	0	0	0	0.5	1	0.5	0
	ZO	0	0	0	0.5	1	0.5	0	0	0
	NS	0	0.5	1	0.5	0	0	0	0	0
	NB	1	0.5	0	0	0	0	0	0	0

TABLE 5. **Fuzzy control rules.**

IF	NBe	NSe	ZOe	PSe	PBe
THEN	PBz	PSz	ZOz	NSz	NBz

V. TUBE-SHEET WELDING TEST BASED ON ARC VOLTAGE TRACKING

A. ON-LINE WELDING TEST BASED ON ARC VOLTAGE TRACKING CONTROL

The workpiece is a tube-sheet (material Q345R) whose diameter and thickness are 950*mm* and 40*mm* respectively. The tube size is 19*mm* inside diameter and 2.5*mm* wall thickness. Peak welding current 175*A* cycle 200*ms*, base current 75*A* cycle 200*ms*. The welding time of the single pipe is 40s, the reference arc length is 2*mm*, and the corresponding arc voltage is 12.6*V*.

Firstly, several tubes were selected for welding tests, and real-time arc voltage data were collected. It was found that the variation rule of arc voltage data was almost the same, which was firstly smaller and then larger and then smaller. The reason was that the arc voltage changes caused by the influence of gravity in the weld pool such as flat welding, downward welding and upward welding. The arc voltage data of any welded tube is shown in the Fig. 15, and its peak

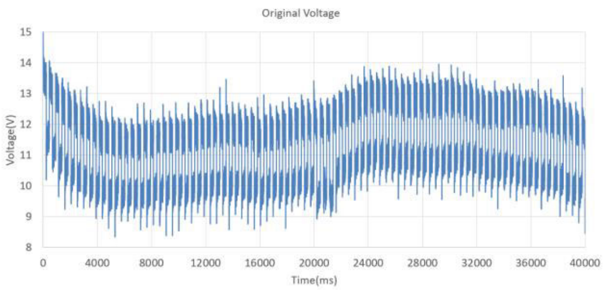

FIGURE 15. The original arc voltage data.

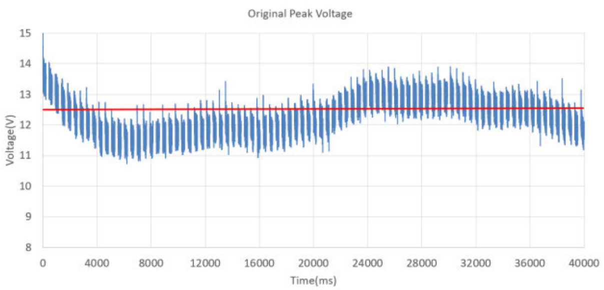

FIGURE 16. The original peak-voltage data.

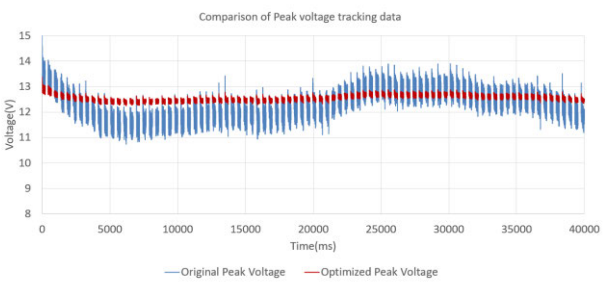

FIGURE 17. The original peak-voltage and optimized peak-voltage.

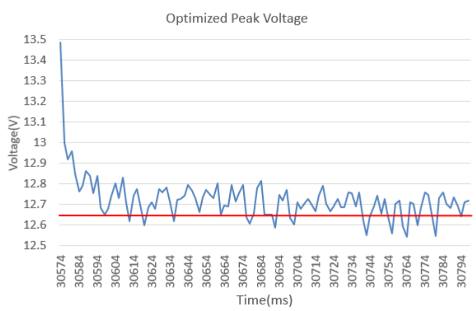

FIGURE 18. Single period peak arc voltage data.

voltage is shown in the Fig. 16. The red line is the reference arc voltage value of 12.6V.

Then select a welded tube for the arc voltage tracking test. The sliding window is 15 for average filtering. Compare the filtered value with the reference value 12.6V, calculate the Z-value adjustment according to the output of the fuzzy con-troller, and carry out dynamic adjustment compensation. The test data are shown in the Fig. 17.

B. ANALYSIS OF TESTS

From the comparison data between the original peak value and the peak value of arc voltage tracking, it can be seen

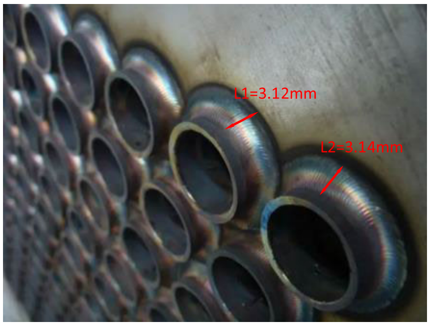

FIGURE 19. The welding quality.

that the online arc voltage tracking makes the welding arc length relatively stable, and the overall fluctuation is smaller. Further, the arc voltage data of a single peak period of 200ms is selected from Fig.17 randomly. As shown in the Fig. 18, the peak arc voltage rapidly decreases from 13.5V at the beginning to 12.6V at the reference arc voltage. In this process, the arc voltage still fluctuates, which may be caused by the rough surface of the welded tube and sheet. The reference arc voltage reaches 12.6V in 35ms to 45ms, and fluctuates slightly around the reference value in the subsequent welding. Therefore, the arc voltage tracking control technology can make the system adjust to the target arc voltage (namely arc length) at about 40ms, and the arc voltage fluctuation in the welding process is between 12.5V and 12.7V. Accord-ing to the relationship between arc voltage and arc length, the corresponding arc length can be calculated to be 1.8mm-2.2mm, and the maximum deviation is 0.2mm. The actual welding quality under arc voltage tracking control is shown in the Fig. 19.

VI. CONCLUSION

Aiming at the all-position annular seam welding based on pulsed TIG welding, a robot welding platform based on laser and vision fusion was built, and a mathematical relationship model of arc length and arc voltage was established through tests. A filter algorithm suitable for high frequency arc voltage data and a variable step size compensation control algorithm based on fuzzy control were proposed. Finally, through multiple test data. It can be seen that, the response time of the on-line arc length tracking control method proposed in this paper is about 40ms, and the arc length control accuracy is less than 0.2mm, which is suita-ble for this kind of tube-sheet welding equipment. In the future research, we will strive for the tracking method with faster response and higher precision through the guidance of simulation tests.

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