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Research on Compensation Control Technology Based on Arc Length Tracking in the Process of Tube Sheet Welding

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Abstract. During the Gas Tungsten Arc Welding(GTAW) process, the arc length will change along with welding thermal deformation, uneven surface of the work-piece and wear of the tungsten electrode. Considering the large fluctuation of arc length in all positions of circular seam welding under multi-variable coupling, the method of real-time arc length fuzzy control in circular seam welding is studied. In this paper, an isolated circuit of arc length collection is designed, and a real-time arc length tracking algorithm based on DC pulse TIG welding is proposed to implement the calculation of arc voltage in the pulse peak phase and the adjustment of arc length in the pulse base phase. Experiments show that the arc length adaptive method based on the fuzzy control algorithm can significantly improve the arc length stability, and obviously improve the welding quality and stability.

Keywords: GTAW, Arc Length, Tube-Sheet Welding

1. Introduction

Pressure vessels such as tube-sheet heat exchangers, condensers, and steam generators are the main industrial products that complete heat exchange. They play an important role in many industries related to the national economy and the people's livelihood, such as petrochemicals, nuclear power ships, metallurgy and military industries. At present, in the production of most heat exchangers in our country, semi-automatic single-hole welding is adopted for the welding of tube-sheet, which is cumbersome for welding workers, and the productivity and quality of tube sheet welding is low [1]. However, the welding quality of tube-sheets has an extremely important impact on the safe operation of large-scale high-parameter pressure vessels, such as heat exchangers and reactors. In petrochemical plants, the failure of heat exchanger due to improper welding process or lax process regulations exceeds 20%, and more than 90% of tube head leakage in heat exchanger is caused by welding quality defects or deficiencies.

The pipe joints of the tube-sheet heat exchanger are all-position circular welds, with dense group seams and large thermal deformation, and robot welding faces many difficulties[2], as shown in Fig. 1. When the welding torch is in different welding positions, the gravity of the liquid metal in the molten pool has different effects on the welding seam formation, and it is constantly changing. Therefore, the main key technology to complete all-position tube-sheet welding is how to control the molten metal pool.

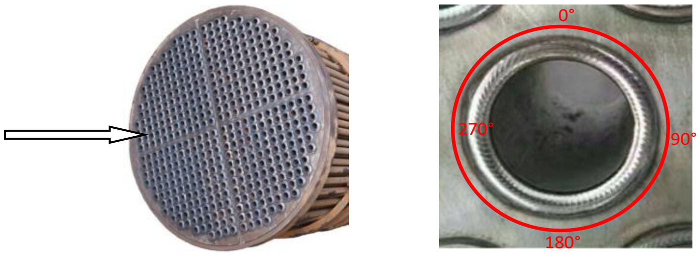


Fig. 1: all-position welding of tube-sheet

Tungsten inert gas welding (TIG) as a high-quality welding method has been widely used in tube sheet welding, pulse technology is used in TIG welding. In order to reduce the influence of gravity on the weld pool, pulse TIG welding is often used in tube sheet welding. Pulse TIG welding has the characteristics of high welding quality, good weld forming quality, and uniform grain refinement [3]. Moreover, pulse TIG welding can independently adjust the peak and base current, pulse width, pulse period or frequency and other parameters, can change the aspect ratio of the molten pool, and improve the stirring effect on the molten pool. By adjusting the pulse parameters of TIG welding, the arc energy and its distribution can be accurately controlled, which is suitable for all-position welding [4]. The welding arc length has a good linear relationship with the arc voltage under certain conditions of welding current, shielding gas flow, tungsten electrode diameter and tip taper. Certain influence [5], so the welding quality can be controlled according to the arc voltage feedback value.

Most scholars use the acoustic, optical and electrical signals in the arc welding process to characterize the arc length [6], by studying the corresponding relationship between the characterization signal and the arc arc length or by indirect control of the characterization signal [7]. Control of arc length. Liu et al. [8] studied the influence of the sidewall of the groove on the arc sound signal and the sensitivity of the arc sound characteristics to the torch deviation, using the arc sound signal to adjust the arc length, and the welding seam tracking accuracy is 0.6 mm; Shanghai Jiao Tong University Robot Welding Intelligence Chemical Technology Laboratory [9] has many years of research using arc sound signals to control arc length. Through the acquisition and processing of acoustic signals, experimental results based on adaptive PID controllers show that the maximum error of arc length control is 0.58 mm. Li et al. [10] of the University of Kentucky in the United States designed an arc length control system composed of an arc sensor, an arc length adjustment device, and a single-chip microcomputer. The arc length control accuracy can reach ±0.2 mm. Xu et al. [11] of Shanghai Jiaotong University designed an arc sensor control system for GTAW welding arc length control (height tracking), and established the peak arc voltage and through arc welding experiments with arc lengths ranging from 6mm to 2 mm The linear model error of the arc length is at least 0.218 mm.

In the welding process, controlling the arc length by controlling the arc voltage is a common method in industrial applications at this stage. At present, the commonly used methods of arc voltage control include PI [12], PID [13], feedback linear control[14], fuzzy control[15] and adaptive control [16], as shown in Table 1.

Table 1: Common methods of arc length tracking

Method	Advantages	Disadvantages
PI control	The principle is simple and easy to implement	Not suitable for control objects with hysteresis
PID control	Fast dynamic response	Depend on experience
feedback linear control	Convert non-linearity to non-linear system	Complex control method
fuzzy control	Suitable for solving non-linear Problems such as flexibility, strong coupling, time-varying, lagging	Different fuzzy control rules and membership functions need to be constructed
adaptive control	Establish a mathematical model between threshold voltage and arc length and peak current	The establishment of mathematical model requires a lot of experimental data

Based on the analysis of pulse TIG welding arc characteristics and all-position circumferential seam welding process, this paper proposes a new arc length signal sensing and tracking technology, establishes a corresponding arc length tracking system, and successfully achieves high precision and high precision. Real-time arc length tracking during tube sheet welding.

2. Construction of experiment system

2.1. The automatic tube-sheet welding equipment

An automatic tube-sheet welding equipment is shown in Fig. 2. The equipment is composed of an industrial camera, a welding head, a DC pulse power supply, a three-rectangular coordinate robot, an industrial computer, an arc length control system, peripherals and expansion components, etc.

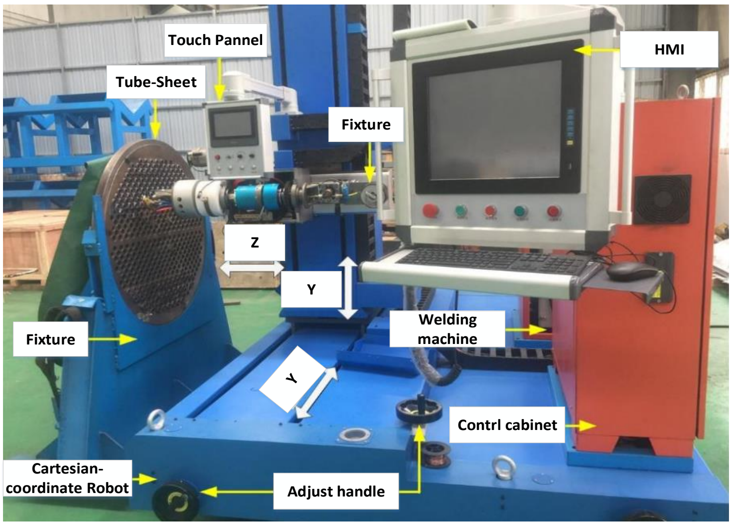


Fig. 2: The automatic tube-sheet welding equipment

Specific technical indicators of equipment: center recognition accuracy ≤0.1mm, XY positioning accuracy ≤0.1mm, positioning processing accuracy ≤1mm, number of continuous welding ≥200, welding tube-sheet size≤12-56mm, arc length control accuracy≤±0.1V.

2.2. The experimental parameters

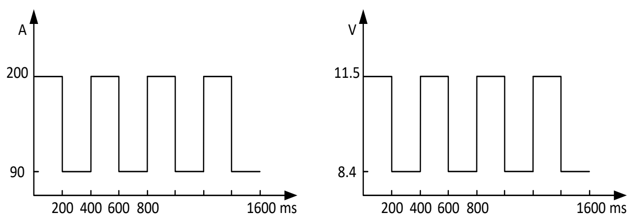
The experimental parameters were shown in Table 2.

Table 2: Experiment parameters of GTAW

Parameter	Value	Parameter	Value
Pulse frequency	2.5HZ	Sample frequency	1kHZ
Peak current	200A	Base current	90A
Tungsten anode diameter	3mm	Duty cycle of pulse duration	50%
Argon flow	15L/m	Welding speed	9°/s
Workpiece material	Q235	reference arc length	13.20V

2.3. Arc length sampling data

DC argon arc welding is welding in which the current is kept constant during the welding process. Pulse argon arc welding is welding in which the welding current changes periodically during the welding process. Fig.3 shows the welding current and arc in the pulse argon arc welding process. The theoretical current and voltage signals are both square waves.



(a) current (b)voltage

Fig. 3: The theoretical current and voltage

The complete welding cycle consists of three processes: arc starting, arc burning and arc closing. The arc starting process is the process of the air between the tungsten electrode and the tube sheet under high pressure. The air breakdown discharge between the tube plate and the tungsten electrode under high pressure 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. 4. 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.

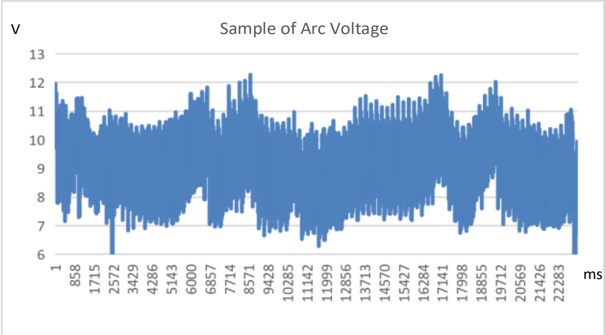


Fig. 4: Original sample of arc voltage

Experiments were performed for many times, and the Z coordinate position was adjusted regularly. The arc voltage data obtained is shown in the Fig. 5. When Z is 26.8mm, the arc voltage value is 11.3V, and when Z is 28.8mm, the arc voltage value is 14.0V. The linear relationship between the arc voltage and the Z coordinate can be obtained as shown in the formula(1).

$$Y = 1.35Z - 24.88 \tag{1}$$

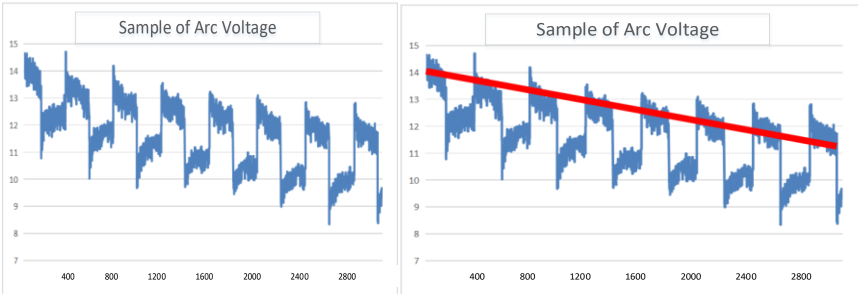


Fig. 5: Arc voltage data varies with Z coordinate

2.4. Welding Control

The execution of the welding process is shown in the Fig.6.

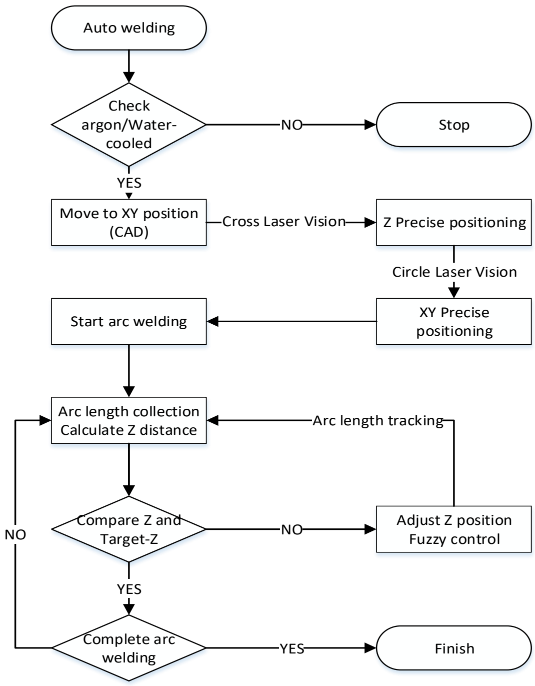
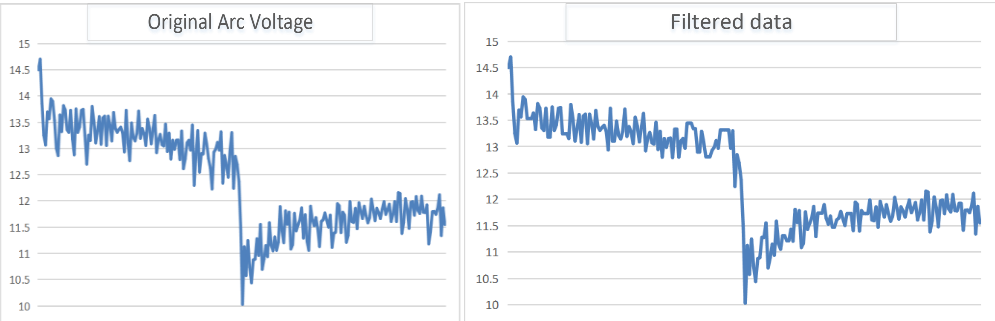


Fig. 6: The execution of the welding process

3. Filter algorithm

The sliding filter algorithm regards the consecutive N sampling values as a cyclic sequence, the length of the queue is fixed at N, each time a new data is sampled and placed at the end of the queue, and the original data at the head of the queue is thrown away (first in, first out principle)), the data output by the filter each time is always the arithmetic average of the N data in the current queue. Its advantages are that it is suitable for high-frequency oscillation systems, and it has good suppression of periodic interference, high smoothness. It is suitable for filtering of arc length collection during welding.

The pulse control cycle is 400ms, and the arc length acquisition cycle is 1ms. Through many experiments, it is known that the sliding filter window is set to 20. The original collected data and sliding filtering data is shown in Fig. 7.



(a) Original data (b)filtering data

Fig. 7: Comparison of data processing

4. Fuzzy control

Firstly, establish the relational expression between the target and the real-time value as formula(2), where the real-time arc voltage is U and the target arc voltage is U0.

$$e = \Delta U = U - U_0 \tag{2}$$

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: -3, -2, -1, 0, +1, +2, +3. Obtain the arc voltage change fuzzy table 3.

Table 3: Arc voltage variation division table

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

The control quantity Z is the distance from the tungsten electrode to the plate. 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 divided into nine levels: -4, -3, -2, -1, 0, +1, +2, +3, +4. The fuzzy division of the control quantity is shown in table 4.

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

According to the arc voltage control algorithm process, as shown in Fig. 8. The fuzzy control is shown in the table 5.

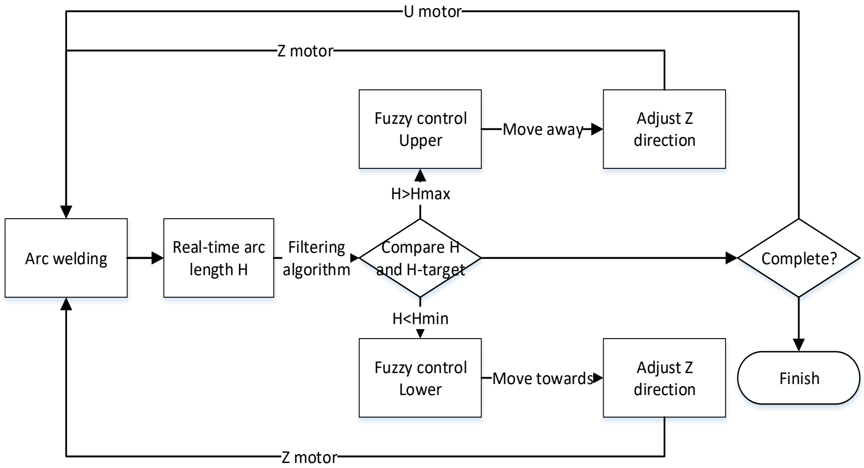


Fig. 8: Voltage Control Algorithm Process

Table 5: Fuzzy control rules

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

The fuzzy control rule is a multi-sentence, and the fuzzy relationship R is shown in the formula (3).

$$R = (NBe \times NBz) \bigcup (NSe \times NSz) \bigcup (Oe \times Oz) \bigcup (PSe \times PSz) \bigcup (PBe \times PBz) \tag{3}$$

Fuzzy decision as shown in formula (4).

$$z = e \circ R \tag{4}$$

According to the "principle of maximum degree of membership" for defuzzification, the control quantity Z is selected for rapid adjustment to ensure that the arc voltage value is within a certain range of U_0.

5. Experiment

In the process of tube-sheet welding, after filtering the collected arc voltage data using the sliding filter algorithm, the distance Z from the tungsten electrode to the plate is adjusted in real time through the fuzzy control algorithm to obtain better welding quality and stability. The arc voltage data is shown in the Fig.9, and the welding quality is shown in the Fig 10. Comparing Fig. 9 and Fig. 4, it is obviously found that the overall arc voltage value tends to be stable in a certain interval, which proves that the online adjustment method is effective.

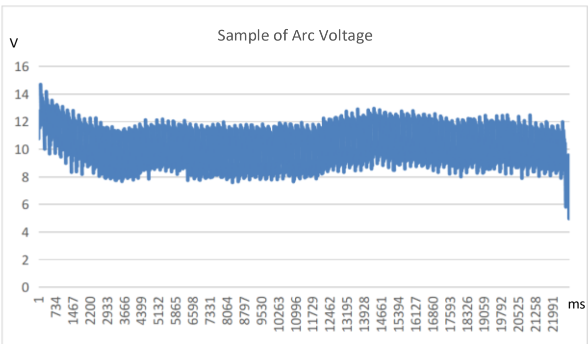


Fig. 9: Arc voltage data obtained by fuzzy control

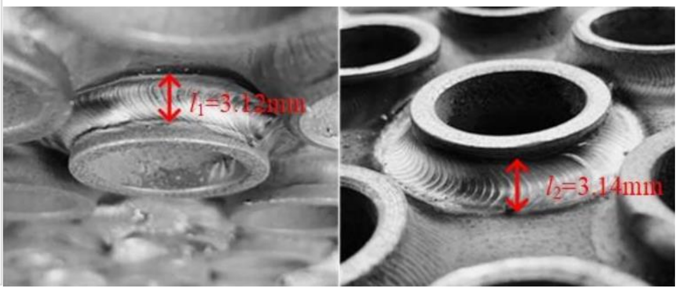


Fig.10: The welding quality

6. Conclusions

Under the platform of the Cartesian coordinate welding robot, the relationship between arc length and Z-direction position is established. After the collected arc voltage data is filtered by the sliding filter algorithm, the Z-direction position is feedback controlled by fuzzy control to obtain a stable arc voltage. Feedback to improve the quality and stability of tube-to-sheet welding, experiments show that it is effective. However, tube-to-sheet welding usually uses 12 different welding parameters. The experiment in this paper is carried out under the same set of welding parameters. Follow-up should study the continuous multi-segment arc voltage tracking algorithm.

7. Acknowledgements

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