

# Research on Arc Length Control Technology of Double Closed-loop for Pulsed MIG Welding

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**Abstract.** This paper presents a pulsed MIG welding arc length control method based on fuzzy control, which can better realize the dynamic control of arc and ensure arc length stability. In this system, a double-closed-loop control scheme is proposed, a variable-parameter PI control method is used, and a two-dimensional fuzzy controller of an arc-length loop is designed. Both the simulation and the experimental results show that when the distance between the welding gun and the workpiece changes, the arc length can reach a new balance and stable state after 9 pulse periods. The arc length control technology of double closed-loop for pulsed MIG welding is verified feasible in this paper.

## 1. Introduction

Welding wins the reputation of “steel tailor” in industrial production. Pulsed MIG welding applications are particularly extensive, with a wide range of current parameter adjustments, precise control of arc energy segmentation, and application to all-position welding and other advantages<sup>[1,2]</sup>. Compared with the traditional analogy pulsed MIG welding power source, the digital pulsed MIG welding power source can significantly improve the welding performance and it has become the current mainstream research direction.

At present, pulsed MIG welding arc length control methods have been extensively researched all over the world. The British Welding Institute proposed a Synergic arc length control method<sup>[3]</sup>. Japanese scholars used open-loop and closed-loop control methods to control pulsed MIG welding arcs<sup>[4]</sup>. Han Zandong, Du Dong, etc. achieved control of the arc length through a threshold control method<sup>[5]</sup>. In addition, some researchers have considered the uncertainty of the welding process, and have also achieved certain results by using robust control and fuzzy control to study the arc length stability. In this paper, the digital welding technology is further studied with fuzzy control.

## 2. Pulsed MIG welding arc long simulation model

### 2.1. The theoretical formula of wire melting speed.

In the welding process, the arc is time-varying nonlinear as a load. A time-varying dynamic model of the arc length can be obtained from the relationship between the melting speed of the welding wire and the wire feed speed. The theoretical formula of wire melting rate can be approximated as<sup>[6,7]</sup>:



$$V_m = \frac{1}{(H_0 + B)} \left[ \emptyset \frac{4i_f}{\pi D^2} + AL_g \left( \frac{4i_f}{\pi D^2} \right)^2 \right]. \quad (1)$$

In formula (1),  $V_m$  refers to the melting rate of the wire;  $A$  and  $B$  are constants related to the wire material;  $\emptyset$  is the arc cathode equivalent voltage,  $L_g$  is the dry extension of electrode,  $H_0$  is a parameter related to the droplet itself. For 1.2mm thick mild steel wire,  $H_0 = 12.36\text{J/mm}^3$ ,  $A = 0.0013\Omega/\text{mm}$ ,  $B = 5.0\text{J/mm}^3$ ,  $\emptyset = 5.2\text{V}$ .

## 2.2. Arc length simulation model.

Figure 1 is the diagram of the welding wire and arc in the welding process, where  $V_f$  is the wire feed speed,  $L_a$  is the arc length,  $L_g$  is the dry elongation, and  $L_c$  is the distance between the torch tip and the base metal<sup>[8]</sup>.

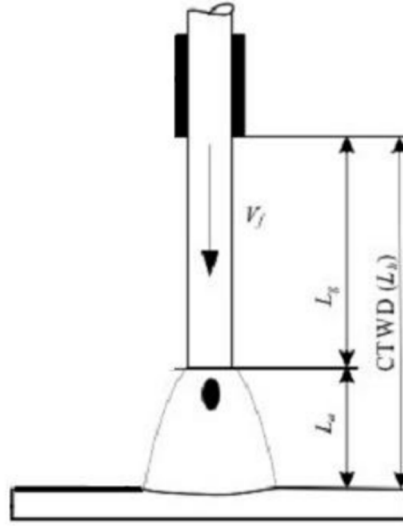


Figure 1. Welding wire and arc diagram in the welding process.

When the wire feeding speed and melting rate, there is;

$$L_a(s) = L_c(s) - L_g(s) - \frac{V_f(s) - V_m(s)}{s} \quad (2)$$

According to Eq.(2), the simulation model of the arc length is established in Simulink, as shown in Fig. 2, the input quantity includes welding current, wire elongation and wire feed speed, and the output is the arc length.

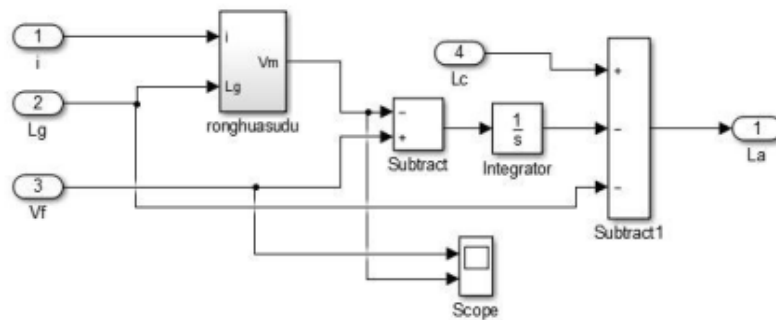


Figure 2. Arc length simulation model.

### 3. Pulsed MIG welding arc long fuzzy control.

The system uses two-dimensional fuzzy controller<sup>[9,10]</sup>. The input signals of fuzzy controller are the deviation and the deviation change rate of arc voltage and the given voltage, the output is the base time increment. The adjustment of the arc length is achieved by adjusting the base time and adjusting the output current.

#### (1) Input - output variable universe

Take the deviation  $E$ , the deviation change rate  $EC$  and the output  $U$  of the universe  $[-3,3]$ , dividing into seven levels, as follows:

$$E = \{-3, -2, -1, 0, +1, +2, +3\};$$

$$EC = \{-3, -2, -1, 0, +1, +2, +3\};$$

$$U = \{-3, -2, -1, 0, +1, +2, +3\};$$

#### (2) establish fuzzy control rules

The system uses fuzzy controller, which can take into account the system's static and dynamic properties, making the system performance to achieve the best. The basic design principle is: When the deviation is large, to eliminate the deviation-based; when the deviation is small, then try to make the system stable, reducing system overshoot or shock. The basic control rules for the average arc voltage and base time are:

(1) Average arc voltage is too large and significantly increases, greatly increase the base time

(2) Average arc voltage is too small and significantly reduces, greatly reduce the base time

(3) Average arc voltage is too large and significantly reduces, slightly increase the base time

(4) Average arc voltage is too small and drastically increases, slightly reduce the base time

(5) Average arc voltage size is suitable and significantly increase, increase the base time

(6) Average arc voltage size is suitable and significantly reduces, reduce the base time

According to the above basic principles of control, you can get Table 1:

Table 1. Fuzzy control rules table.

| Control amount U |    | Deviation rate EC |    |    |    |    |    |    |
|------------------|----|-------------------|----|----|----|----|----|----|
|                  |    | -3                | -2 | -1 | 0  | 1  | 2  | 3  |
| Deviation E      | -3 | 3                 | 3  | 3  | 3  | 2  | 1  | 0  |
|                  | -2 | 3                 | 3  | 2  | 2  | 1  | 1  | 0  |
|                  | -1 | 3                 | 2  | 1  | 1  | 0  | -1 | -1 |
|                  | 0  | 1                 | 0  | 0  | 0  | 0  | 0  | -1 |
|                  | 1  | 1                 | 1  | 0  | -1 | -1 | -2 | -3 |
|                  | 2  | 0                 | -1 | -1 | -2 | -2 | 3  | -3 |
|                  | 3  | 0                 | -1 | -2 | -3 | -3 | -3 | -3 |

(3) Connect the waveform generation module, two-dimensional fuzzy controller module, current controller module, power arc module, arc voltage calculation module and arc voltage load module, simulate the entire welding system, shown in Figure 3. The waveform generation module generates the input current given signal and current status from the base time, peak time, and sampling time; the current control module generates the duty cycle of the power switch tube according to the current given signal and the feedback signal and the current state; the average arc voltage calculation module generates the average arc voltage from the arc voltage, base time and other signals; the fuzzy control module generates a base time increment according to the calculated value of the average arc voltage and the given value, thereby completing the adjustment of the base value time and the control of the arc length.

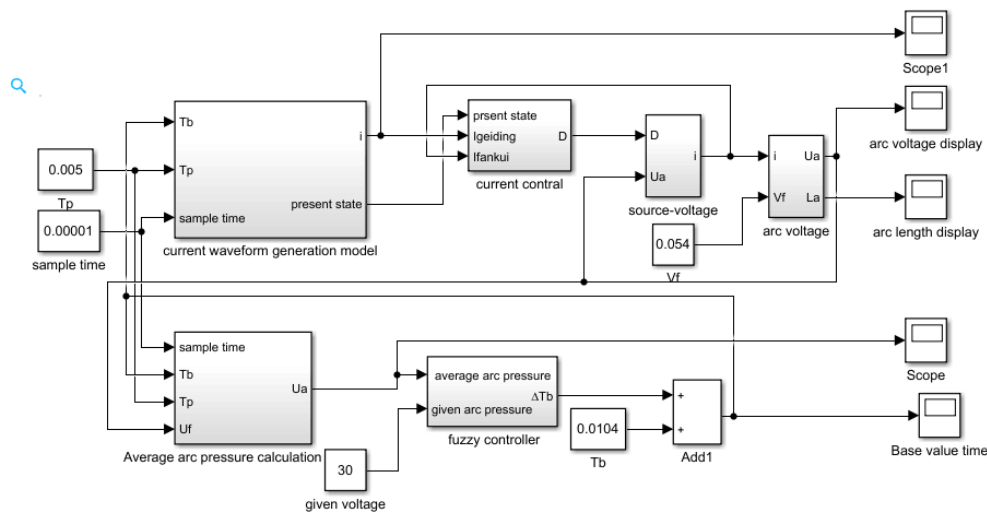


Figure 3. System simulation diagram based on fuzzy control.

#### 4. Pulsed MIG welding arc length simulation results.

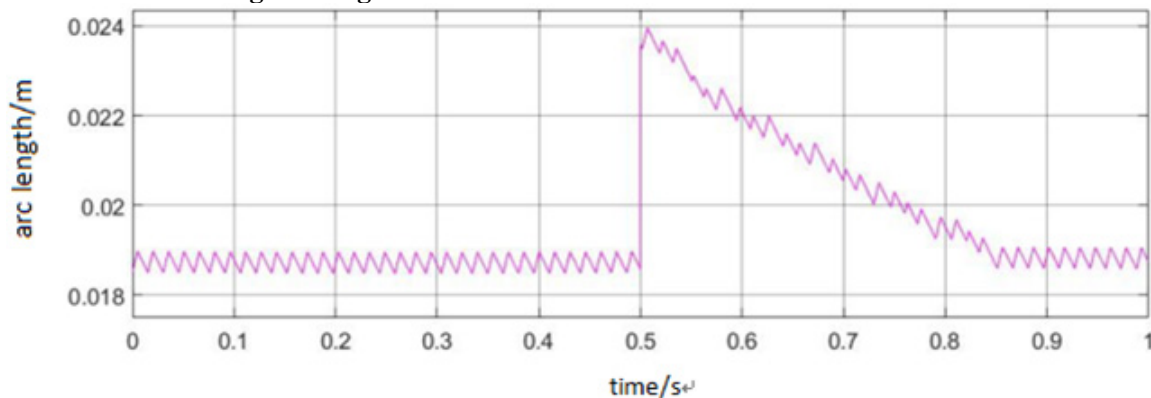


Figure 4. Arc length simulation waveform diagram including one jitter of welding gun.

When one jitter of welding gun occurs, pulsed MIG arc length simulation waveform shown in Figure 4. In order to simulate the response of a step change in the distance between the welding torch and the workpiece in the welding process, a step-change signal was used to simulate the torch elevation. At the time of 0.5s, the distance parameter  $L_c$  of the welding torch and the workpiece is set to be changed from 0.019m step to 0.024m, and the simulation waveform of the arc length automatic adjustment process is shown in Figure 4.

According to the simulation results, at the time of 0.5s, the torch suddenly rises, and the distance  $L_c$  between the welding torch and the workpiece mutates. At the time of 0.5s, the arc length also abruptly changed. After 9 pulsed cycles, the arc length reached a steady state again and remained basically unchanged, indicating that the arc length control scheme in this paper realizes the dynamic adjustment of the arc length and the arc arc length control scheme based on fuzzy control is feasible.

#### 5. Pulsed MIG welding test results

In the welding test research, step test is a common method to verify the effectiveness of control system, The purpose of the test is to verify that when the distance between the welding torch and the workpiece changes abruptly (the arc length changes suddenly), whether the wire elongation can automatically adjust the length under the control of the control system, or maintain the arc length and the arc voltage stable.

The test conditions for this step welding test are: Use a H08Mn2SiA wire with a diameter of 1.2 mm, weld the 3mm thick carbon steel plate, use the protective gas 80% Argon + 20% CO<sub>2</sub>, the inflow rate is 15L/min, The wire feed speed is set to 3.24m/min, which is 0.054 m / s, set the peak current of the welding current to 450A, the base current to 30A. Figure 5 is a schematic diagram of the step welding test, at point B, the welding gun suddenly rose about 5mm, before rising, the distance between the torch and the workpiece is 20mm, after rising, the distance between the torch and the workpiece is about 25mm. The welding direction is from point A to point C.

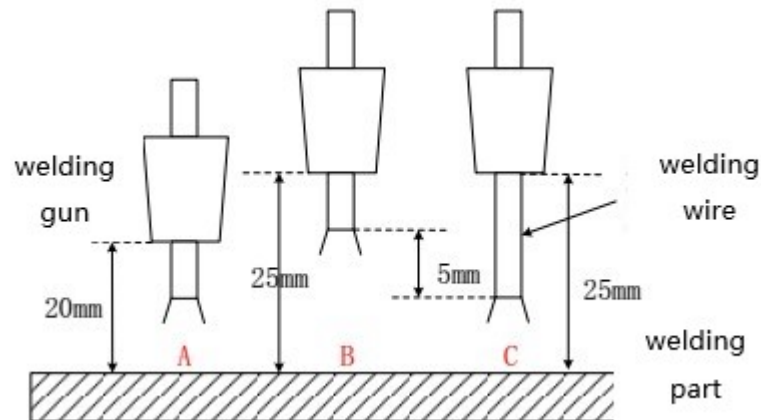


Figure 5. Sudden 5mm jitter of welding gun during welding.

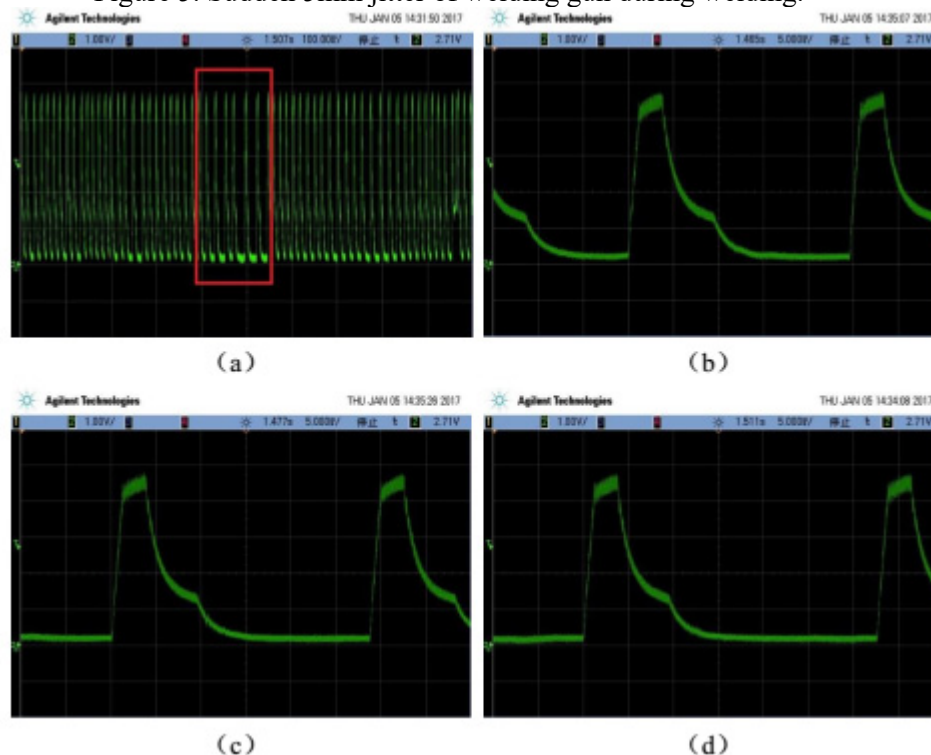


Figure 6. Welding current waveform diagram when welding gun jitter occurs.

Figure 6(a) is the overall waveform of the welding current when welding gun jitter occurs, the square in the figure refers to the welding base time adjustment process. Figure 6(b)(c)(d) are enlarged views of the current waveform in the square when welding gun jitter occurs. Each vertical axis represents 100A, and each horizontal axis represents 5ms.

The subject arc length loop controller adjusts the pulse energy by changing the base time, in order to achieve the arc voltage control. Figure 6 (b)(c)(d) are enlarged views of the square of Figure 6(a),

the base time of the current in the three graphs gradually increases. When the distance between the welding torch and the workpiece increases abruptly, the arc voltage suddenly increases due to the thermal inertia of the arc, while the elongation dose not change yet, so the arc length suddenly increases. Under the action of the voltage controller, the base time increases leading to the pulse duty cycle's decrease, the average pulse current's decrease and the melting rate slowing down, so that the elongation grows until the arc length returns to a stable state. In Figure 6(a), both the current base time and the average welding current are constant before the square, so the arc length is also constant. Square is the adjustment process of the arc length. It can be seen that the current waveform re-stabilizes after 9 welding current cycles (about 150ms) and the adjustment of the arc length is completed which basically agrees with the simulation results. The control system designed in this paper has basically realized the adjustment function of the arc length to meet the welding control system design requirements.

## 6. Conclusion

An arc length control technology of double closed-loop for pulsed MIG welding is proposed in this paper. The arc length can quickly reach a new balance and remains stable state after the time of 9 pulse cycles when the distance between the welding gun and the workpiece changes. It is proved that the arc length control technology of this paper has a good dynamic and stable performance for arc length control of pulse MIG welding by simulation and experimental results.

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## References

- [1] Weman K, Lindén G. MIG welding guide[M]. Woodhead Pub, CRC Press, 2006.
- [2] Weman K. Occupational health and safety in MIG welding - Mig Welding Guide - 10[J]. Mig
- [3] Amin, M. Ahmed, N. Synergic control in MIG welding. 1. Parametric relationships for steady DC open arc and short circuiting arc operation[J]. Metal Construction, 1987, 19(1): 331-340
- [4] Ueguri, Shigeo et al. European Patent Application. Application N0.81105288.5
- [5] Nie J, Meng X F, Shi Y. Study on Evaluation Method of Aluminum alloy Pulse MIG Welding Stability Based on Arc Voltage Probability Density[J]. Journal of Signal & Information Processing, 2011, 2(3):159-164.
- [6] Sha D, Liao X. Digital control of switch-mode pulsed GMAW welding power[C]// Energy Conversion Congress and Exposition, 2009. Ecce. 2009:2746-2749.
- [7] Janez Tušek. Mathematical modeling of melting rate in twin-wire welding[J]. Journal of Materials Processing Technology, 2000, 100(1-3):250-256.
- [8] Yao P, Xue J, Meng W, et al. Influence of processing parameters on weld forming in double-pulse MIG welding of aluminum alloy[J]. Transactions of the China Welding Institution, 2009, 30(3):69-72.
- [9] Li J, Li H, Wei H, et al. Effect of torch position and angle on welding quality and welding process stability in Pulse on Pulse MIG welding-brazing of aluminum alloy to stainless steel[J]. International Journal of Advanced Manufacturing Technology, 2016, 84(1-4):705-716.
- [10] Li J, Li H, Wei H, et al. Effect of pulse on pulse frequency on welding process and welding quality of pulse on pulse MIG welding-brazing of aluminum alloys to stainless steel[J]. International Journal of Advanced Manufacturing Technology, 2016, 87(1-4):51-63.