Study on the Control Strategy of Commutation Process in Variable Polarity Plasma Arc Welding

Li Zhining, Du Dong, Wang Li, Chang Baohua, and Zhang Hua

Department of Mechanical Engineering, Tsinghua University, Beijing 100084, P.R. China

Abstract. The peak of resonance current during commutation greatly influences the safety of commutation component in variable polarity plasma arc welding (VPPAW). It is necessary to study measure to restrain the current peak. Phenomenon of arc resonance current is studied by experiments. Analysis shows that the arc resistance is time variable. Model of commutation circuit is set up and simulated. Results indicate that adjusting damp ratio of system is valid to restrain peak of resonance current. Then a new commutation strategy is presented based on variable structure control method. The commutation circuit is redesigned to apply new commutation strategy. Experimental result shows that the peak of resonance current is restrained while commutation speed unchanged. This paper is instructive to design high power supply of VPPAW.

1 Introduction

Variable polarity plasma arc welding (VPPAW) is suitable to join thick plate of aluminum alloy and can be used for aerospace manufacture [1~6]. Commutation progress influences arc stability, reliability of power supply and welding quality in VPPAW. Ref [7, 8] presented the debugging method about commutation. Ref [9] studied the common conducting and blocking time. Ref [10] studied different control strategy while commutation devices are in common conducting and blocking status. In practice, the phenomenon of resonance current is often observed after arc current commutes. The peak value differs with polarity. When welding is in high power, the resonance current greatly affects the safety of commutation device. But above references did not study the problem. It is necessary to solve the problem without changing commutation speed.

This paper is organized as follows. Section II delineates the phenomenon of resonance current in commutation. A designed experiment is done and the reason about phenomenon is analyzed by arc theory. In section III, the model of commutation circuit is set up and the resonance current phenomenon is simulated. In section IV, a new commutation strategy is put forward based on variable structure control (VSC) method. Then experiment is done to verify the strategy. Finally, conclusions are summarized in section V.

2 Phenomenon of Resonance Current in Commutation

2.1 Experiment Study

In order to study the resonance current during commutation, welding experiment parameters, shown in Table 1, was adopted to eliminate influence of current's

T.-J. Tarn et al. (Eds.): Robot. Weld., Intellige. & Automation, LNCIS 362, pp. 163–170, 2007.
springerlink.com

amplitude and time span of different polarity. The welding position was flat. The workpieces were 4mm thick LD10 aluminum alloy. A self-made welding high-power supply which can accurately regulate current was used. The current sensor's type is KT500A.

Table 1. Welding parameters for experiment

Parameters type	Unit	Value
DCEN current（I_+）	A	120
DCEP current（I_-）	A	120
DCEN time（T_+）	ms	12
DCEP time（T_-）	ms	12
Plasma gas (Argon) flow rate	L/min	2.4
Welding speed	m/min	0.28

DCEN- Direct current electrode negative, DCEP - Direct Current electrode positive *

Fig.1. is arc current waveform while welding aluminum alloy. The peak current of positive polarity I+max=230A and ΔI+＝I+max－I+＝110A. The peak current of negative polarity I-min =-175A andΔI-＝I-－I-min＝55A. ΔI＝ΔI+－ΔI-＝55A. Obviously, resonance current peak differs with polarity. To investigate the reason, fixed resistance load was used. Resonant current peaks are $I_{+max} = 376A$, $I_{-min}= -368A$, and $\Delta I \approx 0$. Obviously, the peak of resonance current is equal when load is fixed resistance. The difference of resonance current peak is only observed while using AC arc load. So the reason relates to arc characteristic in commutation process.

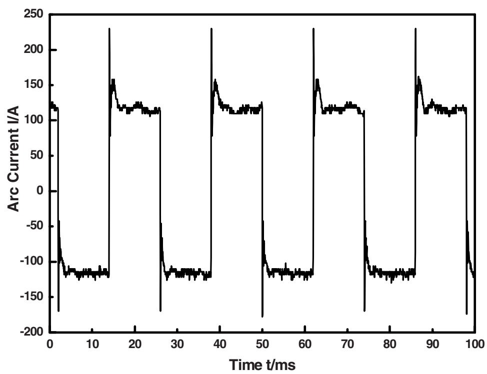

Fig. 1. Arc current waveform while welding LD10 aluminum alloy

2.2 Mechanism Analysis

According to Ref [11], the conductance of arc can be described as the following equation:

$$\sigma \propto \frac{n_e \cdot \sqrt{T}}{Q_n} \tag{1}$$

Where σ denotes conductance of arc column; n_e denotes electron density; Q_n, Q_i denote section of neutrality ion and positive ion; T is temperature of arc column.

We know that n_e will increase while increasing T, so do σ. On the contrary, σ decreases. So the arc resistance is a time-varying parameter.

Arc current alternates periodically in VPPAW. Then the electron density, ion density, arc cross section area, arc temperature and arc conductance change accordingly. Also, the cathode's thermionic emission capability is periodically changed. As cathode is tungsten electrode, the thermionic emission capability is 456A/cm^2. When cathode is aluminum workpiece, it is only 10^{-15} A/cm^2. The huge difference of thermionic emission is reason of the phenomenon.

When arc current commutes from positive to negative, arc conductance decreases. On the contrary, arc conductance increases. Fig 2 shows the change of arc resistance during welding. The arc current waveform is shown in Fig 1. When arc current commutes from positive to negative, arc resistance increases from 0.18Ω to 0.4Ω. On the contrary, arc resistance decreases from 0.28Ω to 0.11Ω. The change results in different peak of resonance current during commutation.

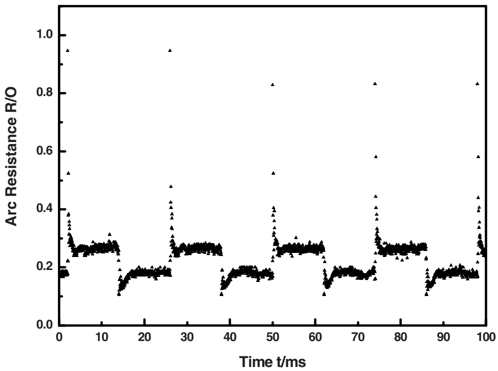

Fig. 2. Arc resistance in VPPAW

3 Commutation Circuit Model and Simulation

In order to study the measure to restrain peak of resonance current, it is firstly necessary to model and simulate commutation circuit. We assume that arc current is continuous.

Fig 3 (a) shows commutation circuit. Fig 3 (b) shows equivalent commutation circuit model. The resonance circuit consists of C, L and R_a in parallel. I is square wave current source; C is equivalent capacitor of commutation system; L is equivalent inductance of welding loop and R_a is equivalent arc resistance. State-space model of commutation system can be set up. Select $V_c(t)$ (Capacitor voltage), $i_L(t)$ (inductance current) as state variable and I (square wave current source) as input variable. The circuit model can be described as equation (2).

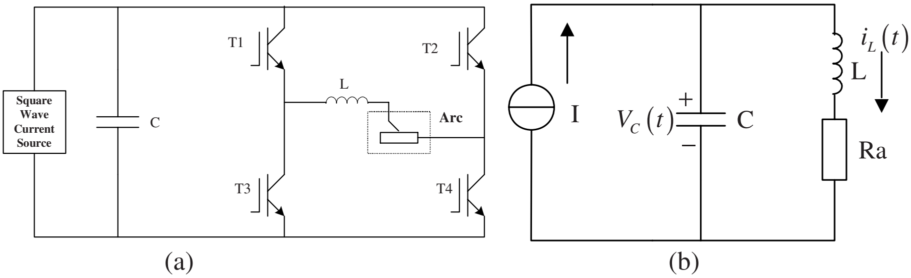

Fig. 3. Model of commutation circuit (a) schematic of commutation circuit (b) equivalent circuit model

$$\begin{bmatrix} \frac{dV_C}{dt} \\ \frac{di_L}{dt} \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{C} \\ \frac{1}{L} & -\frac{R_a}{L} \end{bmatrix} \begin{bmatrix} V_C \\ i_L \end{bmatrix} + \begin{bmatrix} \frac{1}{C} \\ 0 \end{bmatrix} I \tag{2}$$

If the initial energy of L and C are neglected, the transfer function of input and output is described as:

$$G(S) = \frac{I_L(S)}{I(S)} = \frac{\omega_n^2}{S^2 + 2\xi\omega_n S + \omega_n^2} \tag{3-a}$$

$$\omega_n = \sqrt{\frac{1}{LC}}, \xi = \frac{R_a}{2}\sqrt{\frac{C}{L}} \tag{3-b}$$

Equation (3) shows that the model is a second-order system. System natural frequency is determined by L and C. Damp ratio is not only affected by L and C, but also R_a, a time-varying parameter. Then damp ratio ξ is time-varying parameter.

In this paper, $L=8\mu H$ and $C=60\mu F$. In order to simplify the problem, based on the experiment results shown in Fig 2, let $R_a=0.18\Omega$ ($\xi=0.2465$) when current polarity commutates from negative to positive and $R_a=0.28\Omega$ ($\xi=0.3834$) when current polarity commutates from positive to negative. Then simulation was performed to verify the above model. Let $I_+=120A$, $I_-=120A$, $T_+=T_-=12ms$.

The initial value of state variables is $\begin{bmatrix} V_C(0) \\ i_L(0) \end{bmatrix} = \begin{bmatrix} 21.6 \\ 120 \end{bmatrix}, \begin{bmatrix} 33.6 \\ -120 \end{bmatrix}$.

And the simulation current result (Fig 4) are I+max =227A, I-min= -184A,ΔI＝43A. The results show that the model can describe arc current resonance during commutation progress.

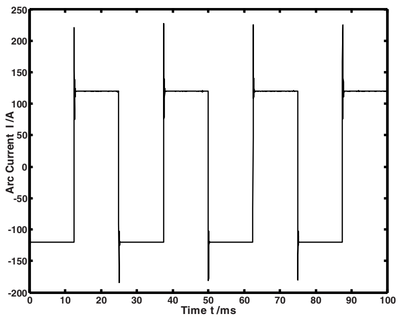

Fig. 4. Simulation waveform of arc current when damp ratio is different

4 Commutation Strategy and Application

According to the analysis, we know that the current resonance peak can be restrained by changing damp ratio of system during commutation. From equation (3), system's damp ratio is determined by *L, C,* R_a. If resistance of resonance loop increases to R_a+R1, system's damp ratio increases. The resistance in resonance circuit can consume energy stored in *L* and *C*, and the current peak will be greatly reduced. If we simply increase system's damp ratio, the commutation speed will also be decreased. It is a contradiction to balance the commutation speed and decreasing current resonance peak. So in this paper a new commutation strategy, which changes damp ratio of system, is presented based on VSC thought. The slide equation of damp ratio is described as equation (4):

$$\xi = \begin{cases} \dfrac{R_a}{2}\sqrt{\dfrac{C}{L}} & I_{-ref} < I < I_{+ref} \\ \dfrac{R_a + R1}{2}\sqrt{\dfrac{C}{L}} & I \le I_{-ref}, I \ge I_{+ref} \end{cases} \tag{4}$$

Equation (4) shows new commutation strategy as follows: Damp ratio of system is small during commutation; when the arc current is greater than set level, the system damp ratio is increased immediately. The set level of arc current can be acquired based on working parameters and automatically set by D/A converter controlled by microprocessor.

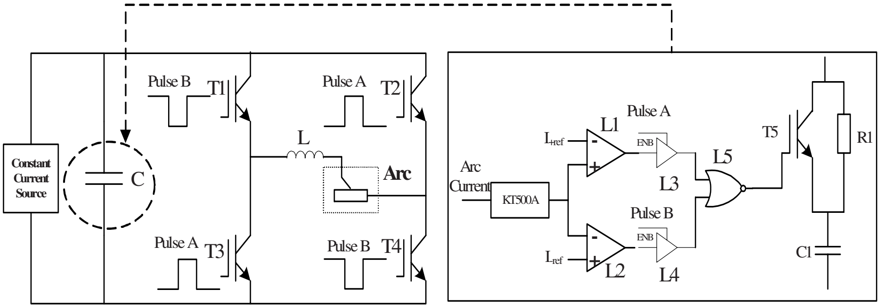

Fig. 5. Schematic of new commutation circuit

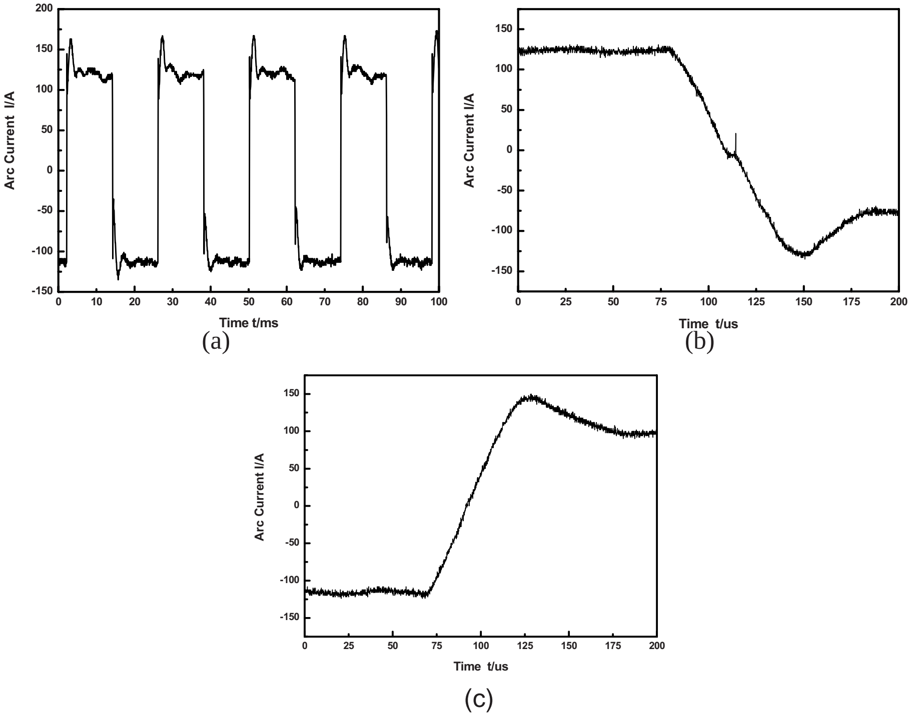

Fig. 6. Arc current waveform of welding LD10 (a) arc current after adjusting commutation circuit (b) commutation process from I_+ to I_- (c) commutation process from I_- to I_+

Because the commutation progress is always short than *70μs,* the key of applying this strategy is how to switch circuit structure in high speed. Certainly, the commutation circuit has to be redesigned. Fig 5 shows the schematic of new commutation circuit. A nonlinear control circuit was adopted to substitute linear capacitor C (shown in Fig 5).

We analyze the working progress to explain how to switch circuit structure, for example, from negative polarity to positive polarity. The pulse A is high level and the pulse B is low level. When arc current is small than the set current level I_{+ref}, comparator L1 outputs low level. And the L3 output low level. At the same time, the L3's output is high resistance because the pulse B is low level. Then the L3 output high level to open IGBT T5. So *R1* is short circuit. When current is greater than I_{+ref}, T5 cut-off. Then *R1* is in series with *L, C1,* R_a. In this paper, *R1* is1.2 Ω and mean of Ra is 0.25Ω. According to equation (3) and (4), the system is stable however the structure of system. The measure only affects the transient performance of system.

The effect of new commutation strategy is verified by experiment. Working parameters adopted is same as section II. The arc current waveform is shown in Fig 6. The peak of resonance current is less than overshoot-current produced by PI controller of inverter power supply. Comparing the waveform of arc current of Fig.6 and Fig.1, the resonance peak decreases sharply after adopting new commutation strategy. Commutation interval, from +120A to -120A, is 60 μ s, and from -120A to +120A, is 50 μ s. Fig 6 (b) and (c) also indicate that the arc is stable during welding.

5 Conclusions

1. Experimental results show that resonance peaks are different with polarity, i.e., the welding system has variable damp ratio.
2. Different of cathode thermionic emission capability is main reason that produces time-varying arc resistance.
3. Commutation circuit was modeled and simulated. Results show that adjusting damp ratio of system can restrain peak of resonance current during commutation.
4. A new commutation strategy is presented based on VSC. And the commutation circuit is redesigned to apply the strategy.
5. Experiment proves that the new control strategy is valid and can improve working conditions of commutation component.

Acknowledgements

This work is funded by Specialized Research Fund for the Doctoral Program of Higher Education (No.20050003041). The authors greatly thank Doctor Lin Tao for his valuable advice to this paper.

References

1. Nunes A C. Variable polarity plasma arc welding in space shuttle external tank [J]. Welding Journal, 1984, 63(9):27-35.
2. Anon. Variable polarity plasma arc reduces welding costs [J]. Welding and Metal Fabrication, 1984,52(7):276-277.
3. M.Tomsic, S. Barhorst. Keyhole Plasma Arc Welding of Aluminum with Variable polarity Power [J]. Welding Journal, 1984,63(2): 25-32.
4. Barhorst S. The Cathodic Etching Technique for Automated Aluminum Tube Welding . Welding.Journal[J], 1985, 64(5):28-31.
5. Craig E. The Plasma Arc Process - A Review. Welding Journal, 1988,67(2):19-25.
6. Woodward H . U.S. contractor for the International Space Station [J] . Welding Jounal, 1996 , 75(3):35-40.
7. Ding zhiming, Qi Bojin. Study on multi-function arc welding dual inverter [J]. Electric Welding Machine, 1995(2):20-2.(in Chinese)
8. Li Zhongyou, Liu Xiuzhong, Cheng Maoai etc. Study on Commutating Process and Its Control of Variable Polarity Square Waveform Power Source [J]. Transactions of The China Welding Institution, 2002, 23 (2):68—71.(in Chinese)
9. Hang Zhenxiang, Ying Shuyan, Huang Pengfei etc. Variable polarity process of inverter AC arc welding power source [J]. Electric Welding Machine,2003,33（6）:13—15,38. (in Chinese)
10. Xie Xingkui, Wang Li, Li Zhining etc. Variable polarity plasma welding power supply with self-adjusting commutation mode [J]. Electric Welding Machine, 2005(12):45－46,55.(in Chinese)
11. 安藤弘平， 長谷川光雄. 溶接ア-ク现象[M].產報. 1978