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New Concept for the Characteristic of an Arc Welding Power Source (Report II)†

-New Development of Arc Control System for CO_2 Welding-

Zhiming OU*, Yong WUANG**, Masao USHIO*** and Manabu TANAKA****

Abstract

High spatter levels and shallow weld penetration are the two critical problems during CO_2 shielded arc welding. Differing from previous control methods, a new composite control characteristic for a power source is proposed. It provide in a self-adaptive close-loop control system for the welding arc. With this control method, a softer arc with less spattering, controllable weld penetration and higher metal transfer frequency can be obtained.

KEY WORDS: (CO_2 arc welding) (Welding spatter) (Welding penetration) (Welding arc control)

1. Introduction

CO_2 gas shielded arc welding is a highly efficient process with low cost. It is widely applied in industry, especially, for thin workpieces and all-position welding. In this process, the short-circuiting metal transfer mode leads to high spatter levels and shallow weld penetration, which restricts further application of the process.

It has been generally accepted that the spatter is mainly caused by explosions through the small necking section of the liquid bridge at the end of the short-circuiting period[1, 2]. The amount of spatter is related to the current value at the moment. A higher current during the detachment causes higher levels of spatter during welding. Furthermore, at the beginning of the short-circuiting period, when the metal drop contacts the weld pool at a relatively high current, it may also cause spatter. Other problem occurring in CO_2 welding are shallow welds and lack of penetration, which are generally considered to be caused by insufficient energy during the arcing period. On the base of the above mechanisms, much research work has been done and various wave control methods have been proposed in order to reduce the output current of the power source during both the beginning and the end of short-circuiting period. However, all these control methods are more or less related to time-based given current waveforms, which belong to open loop control in essence. But in fact, every cycle of the droplet transfer is different, be cause of the different conditions and the disturbance. The instantaneous current of the given waveform cannot provide the defferent requirements for different phases of the welding arc. Because of this , it is difficult to obtain satisfying results.

2. The Composite Output Characteristic of A Power Source

The welding arc behavior is the result of the mutual reactions between the power source output characteristic and the welding arc characteristic. In conventional CO_2 arc welding, the welding power source has only a simple constant voltage (CV) output characteristic, so acts only as a power supply. With the development of electronic devices, a new concept for the welding power source design can be proposed: the welding power source should not only play the role of power supply, but also the role of control system for welding arc.

In order to obtain satisfying welding arc properties, the power source output characteristic should be designed according to both the arc characteristic and concrete control requirements of various instantaneous arc phases [3, 4]. In contrast with other metal transfer methods, the CO_2 gas shielded welding arc includes various different phases such as the arcing period, the beginning of the

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short-circuiting period, the contracting and rupturing period of the short-circuiting liquid bridge and the re-ignition of the arc. These different phases require different power source output conditions and characteristics. In order to reduce welding spatter, the output current of the power source at both the beginning and the end of the short-circuiting period should be limited to a very low level. On the other hand, it has been proved that weld penetration depends on the contribution of the energy during the arcing period in CO_2 welding. In the conventional CO_2 welding machine, the energy during the arcing period is illustrated in **Fig. 1**. The energy has been stored during the short-circuiting period and released during the arcing period from the inductance of the power source. In order to improve and control the weld penetration, the arcing period energy should be increased, and under control according to the different requirements. To summarize the above analysis the ideal arc current waveform in CO_2 welding is shown in **Fig. 2**, in which the detaching current Id has been controlled and limited to a very low level. Furthermore, the arc length should be well controlled in order to obtain a proper size of metal drop. On the base of these considerations, a new composite power source output characteristic is proposed, to control the different phases of the CO_2 welding arc. The composite characteristic is made up of seven sections with different slopes on the I-U plane, shown as **Fig. 3**. Every section of this composite characteristic is designed according to the requirement for different arc phases. The output characteristic of the power source can be adapted to the different instantaneous arc states automatically, and the welding arc has been well controlled to meet the requirements in real time.

With this characteristic, the background current is

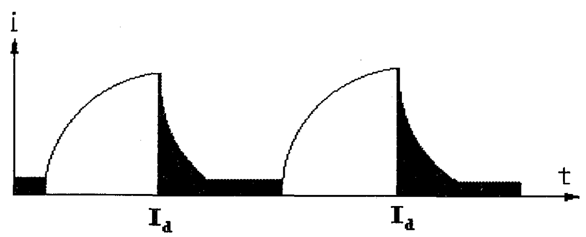


Fig.1 The detaching current I_d and arc energy contributing to weld penetration in conventional CO_2 arc welding

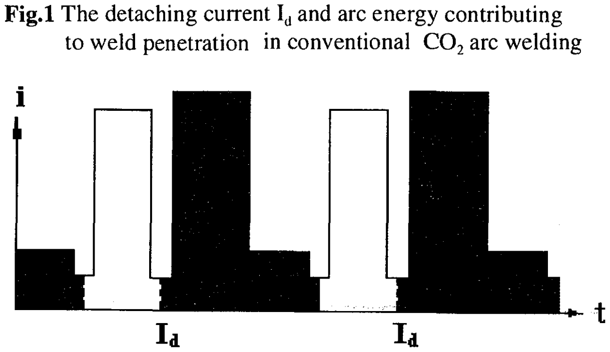


Fig.2 Ideal current waveform for CO_2 arc welding

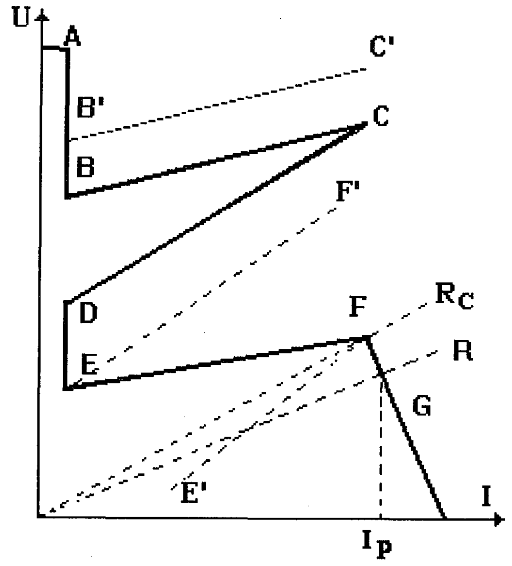


Fig.3 The schematic of the composite output characteristic of power source

determined by section AB, a characteristic with constant current output, to avoid arc extinction during the drop detachment. Section BC, an output characteristic with approximately the same rising slope as the arc characteristic, provides an intensive self-adjustment function for the welding arc and controls the arc length so that the drop size is controlled correspondingly. As the droplet develops and the arc length shortens, the arc operating point will move from C to DE, jumping fast across section CD, in which the operating point cannot stay because characteristic CD has a higher slope than the ampere-voltage characteristic of the welding arc. The output current must be reduced quickly to a very low value, which is designed by section DE. Section DE also provides the current value at moments of both the beginning and the end of short-circuiting period. Section EF and FG have been designed for the contracting process of short-circuiting liquid bridge. When short-circuiting takes place, the arc voltage drops. Under the function of section DE, the current is restricted to a low level, which is advantageous for the soft contacting between the drop and the weld pool so that no spatter is caused at this moment. After contacting, a short-circuiting liquid bridge is formed. The load characteristic of the welding loop resistance is shown as line R in Fig. 3. Under the function of section EF, the current increases rapidly. This rapidly increasing rate will excite a differential circuit device, resulting in a larger slope characteristic EF' instead of EF, and a faster current increase rate. The short-circuiting current rises to the peak value I_p, which is enough for the pinch effect to contract the bridge and the neck the drop down. Theoretical analysis shows that under the actions of both electromagnetic force and surface tension, the rate of the contracting process varies exponentially. When the contracting reaches a certain level, the bridge can keep contracting, even without any electromagnetic force, until it is ruptured. The resistance of the welding loop increases with the liquid bridge contraction. When the loop resistance reaches the critical value Rc shown in Fig. 3, the current will decrease more rapidly under the action of the characteristic EF. This rapid change of current will also excite the differential circuit device, and another characteristic EF' with larger slope will appear instead of EF. A much larger current decrease rate is available, and the output current will decrease to a very low level determined by DE before the rupture of the bridge. So it can result in a soft detachment under a very low current to avoid explosive spattering.

Just after the bridge is ruptured, the characteristic section AB provides the successful arc re-ignition process. At the same moment, characteristic section B'C' results in a current pulse to control and increase the weld penetration. The pulse energy can be changed by presetting the width or pulse amplitude to obtain different penetrations even at the same welding current and welding speed.

After the pulse period, section BC functions automatically, so that the arc length is being detected and controlled. When the droplet grows to a proper size, short-circuiting will take place again.

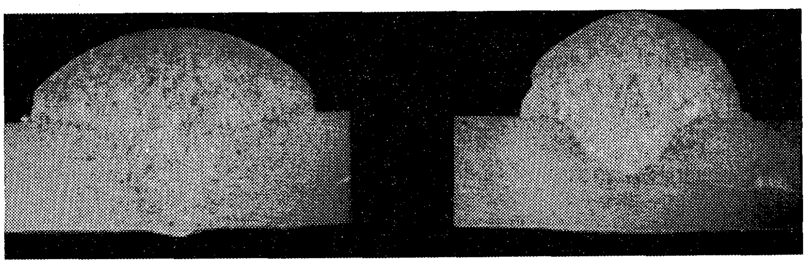
3. Welding Experiments and Results

The welding experiments showed that when the output current of the power source reduced to 40 A for about 0.5 ms during the beginning of the short-circuiting period, the spatter could be avoided at this moment and the metal drop would contact softly with the surface of the weld pool. Then, the output current increased to a suitable peak value so that the liquid bridge contracted at a suitable rate.

It is important to choose a suitable current value for the characteristic section DE to repress spatter generation. In physical essence, the explosive spatter at the end of a short-circuiting period is the result of resistance heating caused by the short-circuiting current at this moment. When the current is controlled below 40A, the resistance heating is not large enough to cause explosive spatter.

The section B'C', which is called weld penetration control characteristic, is available just after the moment of liquid bridge rupture. Because of the short arc length and high voltage at this moment, a large arc current is produced. On the other hand, after detachment of the droplet, the smallest anode spot is restricted at the end of the electrode. Thus, with the high current density, and very short arc length, a concentrated arc force is produced, resulting in a strong "digging" action to the weld pool, so that a deep weld penetration can be achieved. Furthermore, weld penetration can be controlled by changing the amplitude and period of the characteristic B'C'. Significantly different weld appearances and penetrations can be obtained even with the same average welding current, same wire feed rate and same welding speed. **Figure 4** is a comparison of the bead cross-sections under the same welding conditions. The design of the composite characteristic makes every phase of the CO_2 welding arc controlled by different characteristic sections, resulting in a new process for CO_2 arc welding with much less spatter, controllable weld depth and higher droplet transfer frequency.

It is much different from conventional CO_2 arc welding, at both the beginning and the end of the short-circuiting period, and the current has been decreased to a very low level, to avoid explosive spatter. The arcing energy has been increased and controlled by the 'weld penetration control characteristic, resulting in controllable weld penetrations. Excellent experimental results have been obtained and the arc current and voltage waveforms detected in the welding experiments are shown in **Fig. 5**, and are seen to be similar to the ideal waveform in Fig.



a) Pulse amplititue: 300A, pulse period: 1.6ms   b) No penetration control pulse

(Wire diameter: 1.2mm, wire feed rate: 40.7m/hr, welding speed: 19.2m/hr)

Fig.4 A comparison of the bead cross-sections under the same welding conditions but different penetration control parameters.

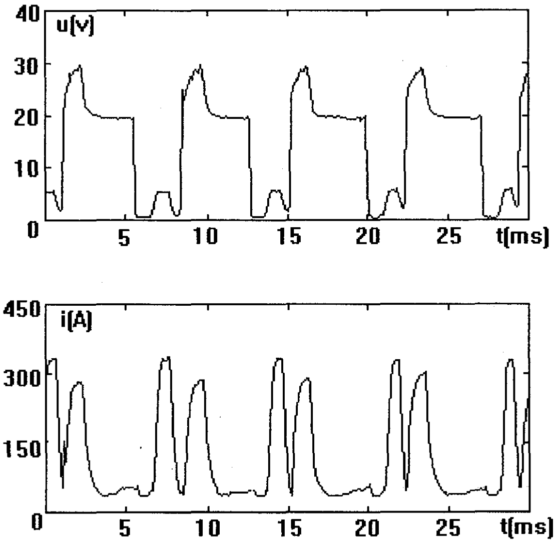


Fig.5 The waveforms of the arc voltage and current during welding

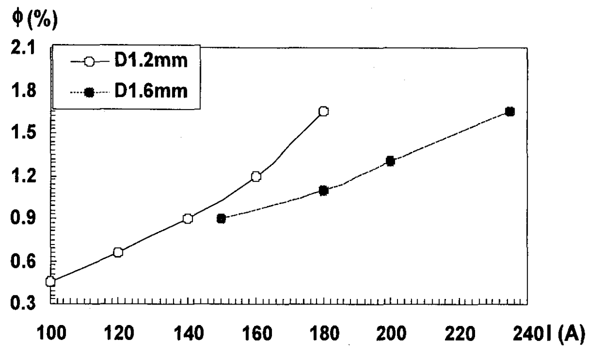


Fig.6 Spatter rate during different welding current

2. This shows that the contacting and detaching current have been restricted to very low levels to avoid explosive spatter, and the arcing period involves much more energy to improve welding penetration. Furthermore, the arcing time and short-circuit time are both shortened because of higher arc energy, higher short-circuit current and greater current increase rate. Therefore the frequency of metal transfer is increased, resulting in finer ripple on the weld surface. The waveform in Fig. 5 shows that the frequency of the metal transfer is about 150 Hz, double that of the conventional process.

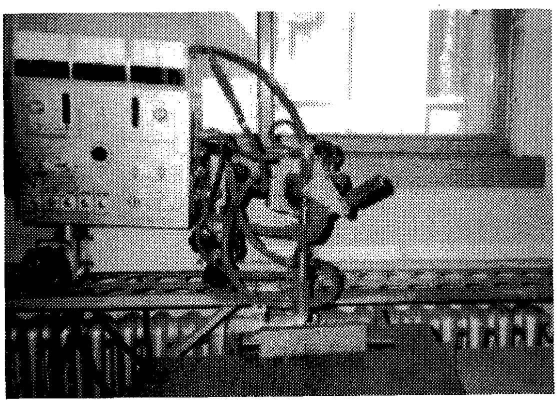


Fig.7 The CO_2 arc welding process with the new system (Electrode: $H08Mn_2Si$, 1.2mm diameter, 100% CO_2, welding current 150 A)

Figure 6 shows the welding spatter rates for different conditions. For a welding current from 100 A to 240 A, the corresponding spatter rate is only between 0.45 % and 1.8 %, much less than that under conventional CO_2 arc welding conditions. **Figure 7** shows the welding equipment for the new system.

4. Conclusion

In order to improve the properties of CO_2 arc welding, a new composite output characteristic for the power source has been developed. With this control system, a soft welding arc with much less spatter, improved and controllable weld penetration and higher metal transfer frequency is made available.

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