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Self-adjusting dynamic characteristics of pulsed MIG welding for aluminum alloys①

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Abstract: Pulsed MIG welding is suitable for aluminum alloys welding, because spray transfer and excellent profile can be arrived during whole welding current range, and the energy of droplet can be controlled to overcome losing of alloy elements with lower melting and steam point by controlling pulse current and pulse time. Because of the special physic properties of aluminum alloys, there are different requirements for pulsed MIG welding between starting arc short circuit and drop transfer short circuit, pulse period and base period. In order to satisfy the need of aluminum alloys MIG welding, self-adjusting dynamic characteristics are designed to output different dynamic characteristics in different welding startes. The self-adjusting dynamic characteristics of pulsed MIG welding are achieved through a short circuit controller and a dynamic electronic inductor. The welding machine(AL-MIG 350) with self-adjusting dynamic characteristics has a high rate of successfully starting arc up to 96%, and the short circuit time during transfer is less than 1 ms, in the mean time, the arc is stiffness, spatter is low and weld appearance is good.

Key words: aluminum alloys; MIG welding; self-adjusting dynamic characteristics
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1 INTRODUCTION

With the development of high-speed locomotives and rolling stocks, aluminum alloys are becoming the major materials applied in the high-speed railway trains due to their good extrusion property, excellent weldability and high specific strength. Yamada et al[1] introduced materials used in Japanese high-speed trains are mainly series 6 and 7 aluminum alloys. Aluminum alloys can be welded by many methods. And metal inert gas (MIG) welding is the most important one of them. The models of metal transfer in MIG welding include drop transfer, short circuit transfer, spray transfer and pulsed transfer[2]. As the energy of short circuit transfer is low, however the conductivity, specific heat capacity, latent heat of fusion of aluminum alloys are very high, the bead formed by short circuit transfer has an unsatisfactory shape with poor penetration and high reinforcement. So it is limited in a small scope when MIG welding is used in aluminum alloys' application. Because the arc with globular transfer cannot be controlled very well, the reinforcement of its weld also is high, the bead shape is bad and the penetration is low too, this kind of arc is useless. Only the small droplet or spray transfer is suitable to aluminum alloys' MIG welding[3]. However, there is a transition current linking to the diameter of a wire. Only when the welding current exceeds the transition value, the small droplet or spray transfer can be attained. On the other hand, it is very important to control the input heat to prevent the over heat of drops, too much of metal vapor and much spatter, especially when aluminum alloys composing with lower melting and steam point elements, such as Mg, Zn and Li, are welded. Subramaniam et al[4-6] researched the metal transfer in pulsed MIG welding of aluminum. The pulsed MIG welding not only can arrive small droplet or spray transfer when the average current is beneath the transition value, but also can control the input heat of the drops by controlling pulse current and pulse time. So pulsed MIG welding is very suitable to aluminum alloys welding.

2 IMPORTANCE OF SELF-ADJUSTING DYNAMIC CHARACTERISTICS

Contacting method is often used in MIG arc starting. When arc is being started, the wire is contacted with the work-piece. The current flows through the wire to the work-piece and the heat produced by the contact resistance melts the tip of the wire, then the arc is established. As we know, the thermal conductivity and specific heat capacity of aluminum alloys are very large, such as the heat conductivity is about 150 W/(m·K) that is about three times of steel (53 W/(m·K))[7,8], so a lot of proportion of heat is conducted to the base metal and lose quickly during the arc starting. In other way, because the specific resistance of aluminum alloys is low-

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er than that of steels, the heat produced by resistance in aluminum alloys welding is smaller than that of steels. So that arc starting is more difficult in aluminum-alloy welding than that of steel welding. That is to say, when the same diameter of the wire is used, higher arc starting current with higher increasing rate is needed in aluminum alloys welding[9, 10].

Small droplet or spray transfer is an ideal condition in pulsed MIG welding. However there are a lot of interferences during welding, so that it is unable to avoid short circuit between drop and welding pool. That is to say, there are instant short circuits during welding. In this case, a proper short circuit current and its increasing rate are needed to produce enough electromagnetism pinch force, which can lead the droplet to be detached from the tip of wire. If these parameters are too small, short circuit time will increase. And it is difficult for the droplet to be detached from the tip of wire. This will cause the explosion of the wire along with lots of spatter. As a result, welding arc is difficult to re-ignite, even though the wire dips into the pool to form solid short circuit, which will cause arc extinguished for a long time. On the contrary, if these parameters are too large, lots of small spatter will produce, metal elements will be burned seriously during the welding and bad profile will be formed.

Richardson et al[11] discussed how different waves affect the wire melting rate in pulsed GMA welding. The result showed that power source dynamics have a notable influence on metal droplet detachment. Rise-up and fall-down sides of a wave will affect wire melting rate seriously. In general, smaller droplets are observed under conditions of fast current response (i. e. steep sides, near square wave pulses). This behavior has tentatively been associated with a physical shock mechanism generated by rapid changes occurring in the arc column. During pulsed period, the rise and fall time of the pulsed current become longer, which distorts the current wave and decreases the effect of the pulse, even loses the effect of pulse, as the dynamic characteristics become bad. That is to say, the much faster dynamic response is required during the pulsed period. On the other hand, current employed during base period is very low. It is only several-decades amperes or even more lower. In order to establish a stable arc during base period, current and voltage are expected to change slowly to stabilize the arc.

A conclusion is attained from the above discussion: different dynamic characteristics of the power supply are required by the different states of the pulsed MIG welding for aluminum alloys, such as short circuit of arc starting, short circuits of droplets, pulsed period and base period. Only dynamic characteristics of the power supply can be changed according to different states of arc instead of single dynamic, good operation performance and high quality of weld can be arrived. Such dynamic characteristics changed by the states of arc are defined as self-adjusting dynamic characteristics.

3 HOW TO GET SELF-ADJUSTING DYNAMIC CHARACTERISTICS

Dynamic characteristics of a conventional welding machine are adjusted by changing the number of turns of its inductor. If the number is set, it cannot be changed during welding process. This means that dynamic characteristics cannot be changed during welding, either short circuit or open arc. Such dynamic characteristics cannot meet the requirements of aluminum welding process very well. Welding machines have only one short current with one current increasing rate (dI/dt), which cannot satisfy requirements of starting arc short circuit and drop transfer short circuit respectively, until transistor power supplies are developed. A middle value is set so that welding machines cannot be in the best state. Fig. 1 shows the diagram of the transistor power supply. The GTR works at on-off switch states with pulsed width modulating control. Because transistor can be switched very fast and controlled accurately flexibly, it is possible to control dynamic characteristics with electronic circuits. Current increasing rate (dI/dt) and short circuit current are major parameters of dynamic characteristics, so that self-adjusting dynamic characteristics are performed through a short circuit current controller and a dynamic electronic inductor (see Fig. 1).

There is a unit in the short circuit current controller used to identify the type of short circuit. If a short circuit occurs while an arc is started, the unit will send a signal to the GTR, and the GTR outputs a larger short circuit current with higher dI/dt. If a metal transfer short circuit occurs during welding process, the unit will send another signal to the GTR, and the GTR outputs a middle value short circuit current with lower dI/dt. As a result, the rate of successfully starting arc is improved, spatter is decreased, and the arc can be restarted very fast due to the fact that the energy of the droplet is controlled very well when droplet transfer short circuit occurs.

The dynamic electronic inductor includes an arc state identifying unit, an electronic inductor for pulsed period, an electronic inductor for base period and two electronic inductors for two kinds of short circuit respectively. They are shown in Fig. 2. When welding is operated, the arc state-identi-fying unit

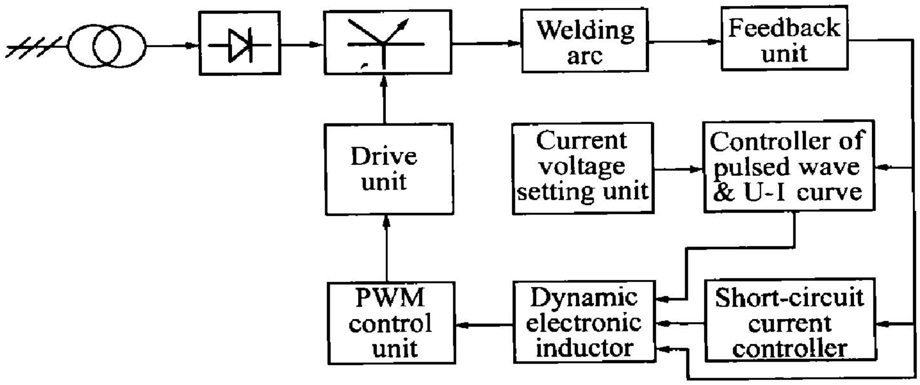

Fig. 1 Diagram of transistor power-supply for MIG welding

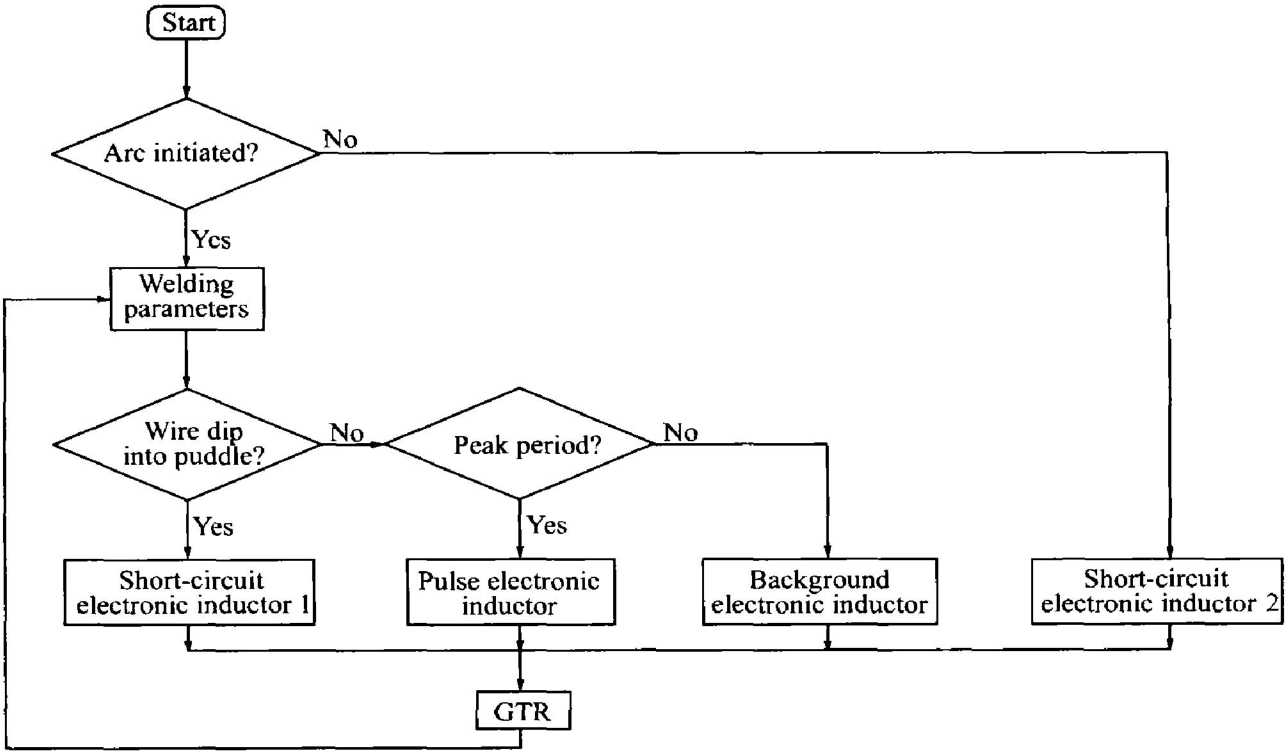

Fig. 2 Illustrating principle of dynamic electronic inductor

checks states of the arc. If it is in starting arc state, the short circuit electronic inductor 1 controls the GTR to output a short circuit current with higher dI/dt to meet the need of start arc. If it is in normal arc state and a drop transfer short circuit is checked, the short circuit electronic inductor 2 controls the GTR to output a short circuit current with lower dI/dt, whenever the arc is during pulsed or base period. As the short circuit electronic inductor 2 has a large characteristic time as well as cooperating with the short circuit current controller, the arc can be restarted quickly with fewer spatters. If it is in normal arc state and short circuit does not happen, then the electronic inductor for pulsed period works during pulsed period and the electronic inductor for base period works during base period to control the GTR to output currents with two kinds of dI/dt to meet needs of pulsed and base period respectively.

Electronic inductor is a PI or PID regulator basically. Its operating principle has been discussed in Refs. [12, 13].

4 EXPERIMENTAL RESULTS

The short circuit current controller and dynamic electronic inductor are used in an Al-MIG350 pulsed welding machine, so that the machine owns self-adjusting dynamic characteristics[14, 15]. Experiments have been done with this machine.

4.1 Starting arc test

Starting arc test was performed on a plate with a mechanical fixture. Two kinds of wire, 5356 and 4043, were used and the diameter of wires was 1.2 mm. The torch was at right angle to the work-piece. After setting a welding current, arc was started 50 times. The interval between every arc starting was more than 5 min, so that the work-piece and the wire were all cool when every arc was started. The results are listed in Tables 1 and 2. It can be seen that the starting arc success rate is more than 96%. The reason for this result is that the short circuit current for starting arc is set very high and with very fast increasing rate. When the end of wire is contacted with work-piece, the end is molten very fast by the high short circuit current. As a result, the arc is formed at once.

Table 1 Success rate for arc igniting with wire of 5356

Welding current/ A	Total igniting number	Success igniting number	Success rate/ %
80	50	48	96
120	50	49	98
160	50	50	100
200	50	48	96
240	50	49	98
280	50	50	100
320	50	50	100

Table 2 Success rate for arc igniting with wire of 4043

Welding current/ A	Total igniting number	Success igniting number	Success rate/ %
80	50	49	98
120	50	50	100
160	50	48	96
200	50	50	100
240	50	49	98
280	50	50	100
320	50	50	100

4.2 Wave analysis

The waves of welding current and voltage are observed through a dual trace oscilloscope. The waves show that the welding current and voltage are very stable and repeat regularly, and short circuits happen in welding occasionally. When a short circuit occurs during drop transfer, its time is very short (less than 1 ms). Fig. 3 shows a typical photo of welding current and voltage while a droplet transfer occurs. There is a short circuit in the end of the pulse. The short circuit current increases very fast to reach about 320 A. Then this value is kept. This short circuit current is much lower than that in arc starting, so that the droplet can be detached from the end of wire softly during short circuit without spatter.

4.3 Result of welding

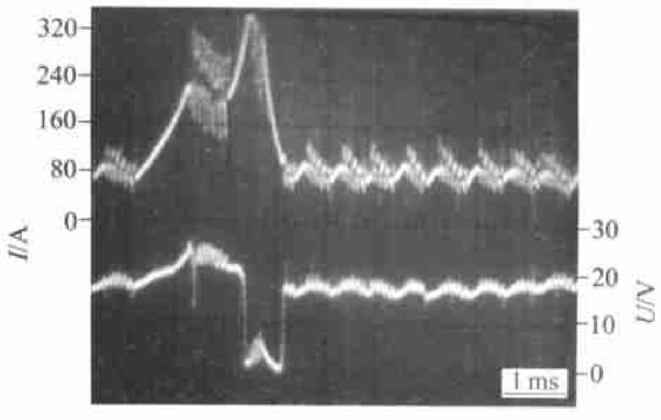

Fig. 3 Short circuiting during metal transfer

During the whole range of mean current (60 − 350 A), stable small droplet transfer is arrived, the arc is stiffness, spatter is lower and weld appearance is good. For example, a profile of bead is shown in Fig. 4, where both the welding pulsed current and wire feeding pulsed rate are used. The wire is 5356. The mean welding current is 220 − 280A, and the mean welding voltage is 24 − 27V. It can be seen that the bead is uniform and there is no spatter in both sides of the bead.

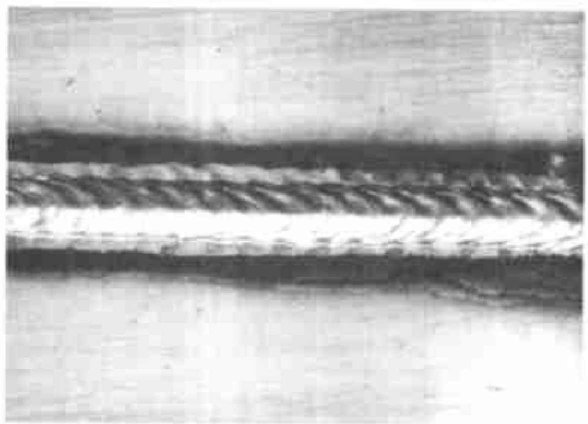

Fig. 4 Profile of bead

5 CONCLUSIONS

1) Pulsed MIG welding is suitable for aluminum alloys, because spray transfer and excellent profile can be achieved during whole welding current range, and the energy of droplet can be controlled to overcome losing of alloy elements with lower melting and steam point by controlling pulse current and pulse time.

2) Because of the special physic properties of aluminum alloys, there are different requirements for pulsed MIG welding between starting arc short circuit and drop transfer short circuit, pulse period and base period. Self-adjusting dynamic characteristics can output different dynamic characteristics according to different welding states, so that it can satisfy the need of aluminum alloys MIG welding. The self-adjusting dynamic characteristics of pulsed MIG welding is

achieved by a short circuit controller and a dynamic electronic inductor.

3) The AL-MIG350 welding machine with self-adjusting dynamic characteristics has high rate of successfully starting arc, stiffness of the arc, lower spatter and good weld appearance.

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