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

-Application in Pulsed MIG/MAG Welding-

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Abstract

With the growing development of power electronic devices and welding inverters, the control potential ability and dynamic response of power sources have much been improved. This offers the possibility of controlling the welding arc more accurately and effectively. A new concept for the characteristic of an arc welding power source has been put forward: a modern welding power source should not only play the role of power supply, but also the role of a control system for the welding arc. The different phases of the welding arc require different power source output conditions and characteristics. In order to control a welding arc accurately, a composite characteristic of the power source, consisting of different segments with different slopes from $-\infty$ *to* $+\infty$*, including steep-rising characteristics, has been proposed. The application in pulsed MIG welding has been demonstrated to be effective.*

KEY WORDS: (Welding power source) (Output characteristic) (Arc control system) (MIG/MAG welding)

1. Introduction

With the conventional concept, an arc welding power source acts only as a power supply for the welding arc process, and has only a simple output characteristic, such as constant voltage (CV), constant current (CC) or drooping output characteristic. With the growing development of power electronic devices and welding inverters, the control ability and dynamic response of power sources have much improved. This offers the possibility of controlling the welding arc more accurately. 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 the welding arc [1, 2]. In this sense, in order to improve the arc property, what characteristic should the modern welding power source have?

2. Composite Output Characteristic

Welding arc behavior is the result of the mutual reaction between the power source output characteristic and the welding arc characteristic, namely the volt-ampere characteristic of the welding arc. In order to obtain a satisfactory welding arc property, the power source output characteristic should be designed according to both the arc characteristic and the concrete control requirements for various instantaneous arc phases. The different arc phases require different power source output conditions and characteristics. This implies that the welding arc needs different output characteristics in the different zones of the U-I plane.

So a composite output characteristic for the power source consisting of different segments with different slopes can be proposed for arc control. The intersection point of segments can be used for detecting arc condition. So composite output characteristic can combine detection and control together and result in a self-adaptive control system. In order to receive an accurate connection and fast transform response, a special technique of the connection for different output characteristic segments has been developed.

3. Steep-rising Output Characteristic

In the conventional welding power source, different

† Received on May 31, 1999

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Transactions of JWRI is published by Joining and Welding Research Institute of Osaka University, Ibaraki, Osaka 567-0047, Japan.

output characteristics are used in different process, for example, a constant current for TIGW, constant voltage for MIG/MAG welding and drooping output characteristic for SAW, but their slopes are less than the volt-ampere characteristic of the welding arc, namely

$$\frac{\partial U_p}{\partial I} < \frac{\partial U_a}{\partial I} \quad (1)$$

Where U_a is the arc voltage and U_p is the voltage of power source. It has been generally acknowledged that the output characteristic of a power source which has a greater slope than the volt-ampere characteristic of the welding arc (we call it steep-rising output characteristic) cannot be used in applications to avoid arc current divergence. But from another point of view, arc current divergence means that the current changes very fast and the operating point in the U-I plane has to be forced to move away from the related zone. So in the new control system design, we can use steep-rising output characteristics in some zones of the U-I plane, where we do not wish the operating point to remain.

Under the action of a steep-rising output characteristic of the power source, a typical arc current is shown in **Fig. 1**. Its application will be explained in detail in the following arc control system for pulsed MIG/MAG welding.

In the conventional power source characteristic, we have slope only negative (dropping and constant current characteristic) and zero (constant voltage). With the new development of the steep-rising output characteristic, we have extended the characteristic slope range from $-\infty \rightarrow 0$ to $-\infty \rightarrow +\infty$.

4. Moving Output Characteristic

In a conventional welding power source, the output characteristic is fixed during welding, by pre-setting it as a parameter. But in fact, the welding arc sometimes needs different characteristics at different instant. In order to control the welding arc more accurately, the characteristic segment is required to change with real time in some applications. In the following instance, the authors use the moving output characteristic to control the peak current period and the quantity of wire melted in each current pulse.

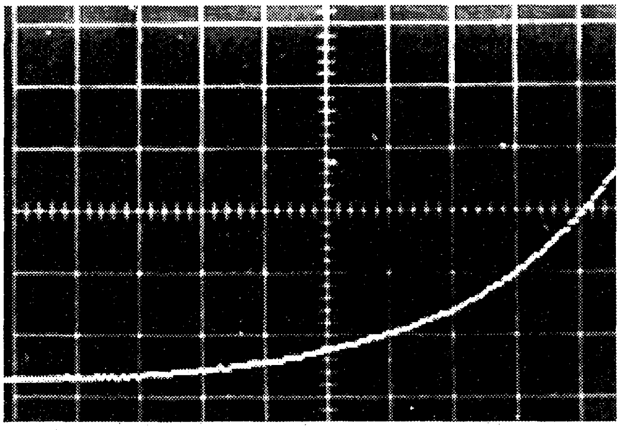

Fig.1 A typical arc current with the action of a steep-rising output characteristic of the power source

5. Application

In order to improve the performance of pulsed MIG/MAG welding, the authors develop a new composite characteristic, consisting of different segments with different slopes, including a steep-rising characteristic, a moving characteristic, which results in a self-adaptive arc control system.

5.1 The problems in conventional pulsed MIG/MAG welding

There are some problems with conventional systems of pulsed MIG/MAG welding. It requires strict and complicated parameter setting. Although recently developed synergic systems have realized one–knob control, by using a computer to finish the parameter setting, it is nevertheless an open-loop control system, the metal transfer mode and the arc length cannot be kept during disturbance.

Compared with normal DC MIG/MAG welding, pulsed MIG/MAG welding system has a very low arc self-adjustment ability, because a constant current or steep drooping output characteristic has to be used for the base period to avoid arc breakdown. There is not much current change during the base period which means the arc length needs a long period to restore itself when disturbance happens.

The typical combination of the power source output characteristics for pulsed MIG/MAG welding requires that a constant current characteristic (CC) is used for the base period and a constant voltage (CV) for the peak period. So the arc length self-adjustment ability of the system is only dependent on the change of peak current during disturbance, but the fluctuation of peak current can result in an unstable metal transfer mode. Thus, it is impossible to meet the requirements both for the metal transfer stability and the arc length stability during disturbances.

In conventional pulsed MIG/MAG welding, to avoid the unstable globular metal transfer mode caused by the peak current decreasing below than the critical current during disturbance, a very high peak current has to be adopted. But this results in very strong light and ozone pollution.

5.2 Operation principle of the new system

A new composite characteristic for a power source shown in **Fig. 2** has been developed for the new control system. It contains 6 segments AB, BC, CD, DE, EF, and FG. The AB is the power voltage, not under control, both BC and CD are the steep-rising characteristic, with slopes larger than the volt-ampere characteristic of the welding arc L_1 or L_2. Characteristic segment BC can be used to improve the arc stability during the base period, in which the arc current, ionizability and stability are very low. Under the control of BC, the current tends to increase with the arc ionizability decreasing, and the operating point will be forced to come back to avoid the arc breaking down. It has been demonstrated to be effective, and especially to improves the arc stability during welding in the deep groove of a thick workpiece, in which the welding magnetic field interferes with arc stability.

A self-adaptive pulsed MIG/MAG welding is realized by means of the composite characteristic. At the beginning we suppose that after starting the arc condition is in the base period. Since the base current is small with melted metal transfer, the instantaneous arc length and the arc voltage will decrease with the wire feeding, and the arc operating point is going downward along the characteristic segment BC. When it reaches point C and the steep-rising characteristic BC, the arc current will increase very fast in a divergent mode. With this current fast increasing, another steep-rising characteristic CH with greater slope has been triggered. Under the action of CH, the arc operating point cannot stay in the middle zone of the U-I plane and is forced to jump from C to K, and the arc current increases very fast from base current to

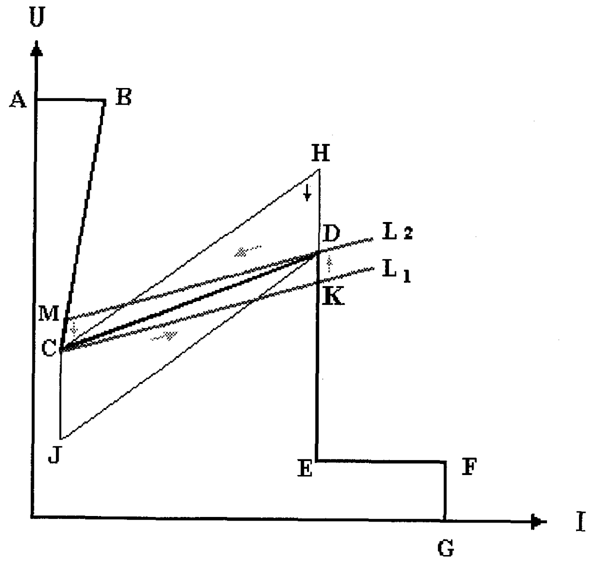

Fig.2 A multi-segmental output characteristic of a power source for pulsed MIG/MAG welding

peak current. With the peak current, the wire melting rate is larger than the wire feed rate, and the operating point goes upward along DE. The CH is also a moving characteristic, when the operating point finishes the jump from C to K, it will move downward from CH to JD at an exponential rate. After the metal droplet transfer, the operating point will meet the moving steep-rising characteristic, JD, and will jump back from D to M in a similar way, and the arc current decreases automatically from peak current to base current. The above cycle will repeat again and again, during which the arc length has been controlled within the minimum arc length L_1 and maximum arc length L_2.

In the peak period, since

$$T_p = \frac{L_2 - L_1}{V_m - V_f} \qquad (2)$$

Where T_p is peak period, L_2 is maximum arc length at the end of peak period, L_1 is minimum arc length at the beginning of peak period, V_m is wire melting rate during peak period, V_f is wire feed rate, and $L_2 - L_1$ is arc difference. From the above equation we can find that if the arc difference is fixed, the peak period will increase in an exponential rate with the wire feed rate or average welding current increase. In order to control the peak period and the metal quantity melted in each current pulse, the arc difference during peak period should decrease at an exponential rate. To meet this requirement, the segment CH has been designed as a moving characteristic. It moves downward with the same exponential rate after the operating point reaches point K. The smaller wire feed rate, the faster the operating point moves up and the higher it will meet the moving characteristic segment CH, but the peak period or metal quantity melted in each current pulse is about the same.

5.3 Experiment result

The trajectory of the operating point during welding has been shown in **Fig. 3**, the top part is limited by the power voltage. The system is self-adapting and the waveform of the arc voltage shown in **Fig. 4**, is the moving result of the operating point under the action of the composite characteristic of the power source. It indicates the arc length has been controlled very well by the system. It is a real closed-loop control system for pulsed MIG/MAG welding, the arc length and the drop transfer mode can be maintained when disturbance occurs. Since the system has a very fast dynamic response during disturbance and constant current characteristic has been used in both the base period and peak period, so the base current and peak current and the drop transfer mode can be maintained during a transit period. The new system is also a reliable one-knob control system, the arc length and the metal transfer mode can be kept even when the wire feed rate changes. This advantage has been used to develop a program of pulsed wire welding for pulsed MIG/MAG welding. It is very useful in the applications of penetration control and all-position welding. A typical application of pulsed wire feeding for pulsed MIG/MAG welding is shown in **Fig. 5**. The result of pulsed MIG/MAG welding with low frequency pulsed wire feeding is showed in **Fig. 6**.

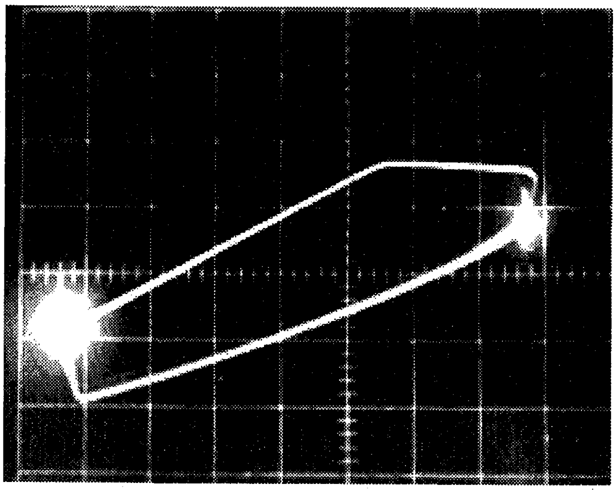

Fig.3 The trajectory of the operating point during welding

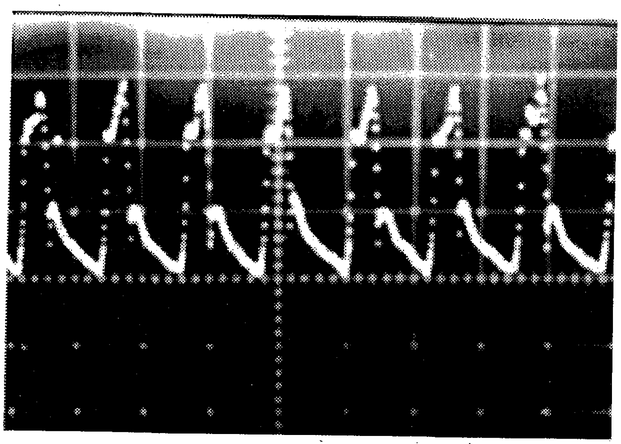

Fig.4 The waveform of the welding voltage with the new system

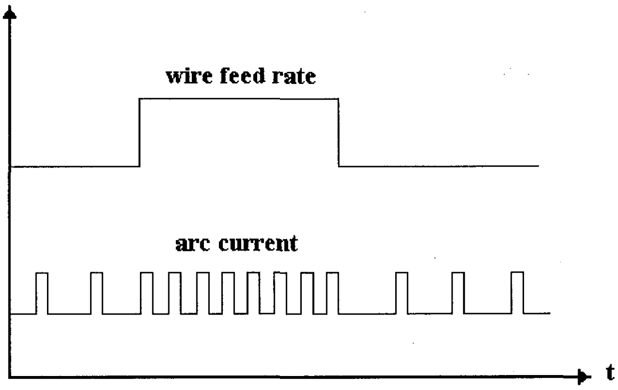

Fig.5 A pulsed wire feeding welding for pulsed MIG/MAG welding

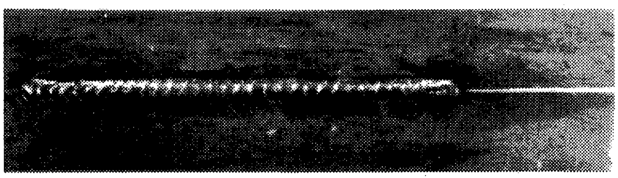

Fig.6 A welding result of pulsed MIG/MAG welding with Pulsed wire feeding

6. Conclusions

A new concept for the characteristic of arc welding power source has been put forward: a modern welding power source should not only play a role as power supply, but also a role as control system for the welding arc. Since different phases of the welding arc require different power source output conditions and characteristics, in order to control welding arc accurately, a composite characteristic power source, consisting of different segments with different slopes from $-\infty$ to $+\infty$, including steep-rising characteristics and moving characteristics, has been proposed for modern welding power source design. Its application in pulsed MIG/MAG welding has been demonstrated to be effective.

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