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Decoupling control scheme for pulsed GMAW process of aluminum

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ABSTRACT

A double-variable decoupling control scheme was proposed for GMAW-P process of aluminum helping to efficiently develop welding procedure. Weld pool width and arc length were both measured through vision sensing in welding process. Weld bead shape was improved by changing the current waveforms to adjust the heat input while the arc length was controlled to stabilize the welding process. An experimental system was developed to sense, observe and control the welding process real-timely. Experiments were conducted to verify the effectiveness of the scheme. The results show that good weld bead shape and stable welding process can be obtained through the double-variable decoupling control scheme without complex metal transfer control and considerable trial and error to identify suitable combinations of welding parameters in GMAW-P. This control scheme provides an alternative to obtain proper weld quality for GMAW-P.

1. Introduction

Recent trend in the selection of material for the automotive industry shows there has been a transition from conventional materials to light-weight material like aluminum. Praveen and Yarlagadda (2005) have recently shown achieving good quality with aluminum is a challenging job due to its significant differences from conventional materials like steel. Among the aluminum welding process, automated pulsed gas metal arc welding (GMAW-P) has been recognized as an efficient alternative for minimizing defects. In GMAW-P, the welding current is alternatively and periodically varied between base and peak values. The main setting parameters which influence weld quality or wire melting are base current I_b, peak current I_p, base time T_b, peak time T_p and wire feed rate V_{wire}. As illustrated in Fig. 1, the welding parameters are more numerous than they are in conventional GMAW, and the process is typically more sensitive. Palani and Murugan (2006) have claimed that improper selection of these pulse parameters may cause weld defects including irregular bead surface, lack of fusion, undercuts, burn-back and stubbing-in. Therefore, it is important to select a proper combination of pulse parameters to obtain stable welding processes and better quality welds. However, identifying suitable combinations of welding parameters for use with GMAW-P can be a time-consuming process, involving considerable trial and error, especially for aluminum. Subramaniam et al. (1999) proposed a method of identifying power supply pulsing parameters for GMAW-P based on statistical experimental design. A linear wire feed rate model using data on the values of wire feed rate obtained from the experiments conducted using a two level factorial experimental design was developed. However, in the GMAW-P process of aluminum, even if the welding process is stable, the weld bead geometry may be poor. The weld pool width often become wider and wider, even collapse at constant welding parameters in GMAW-P process due to the strong heat accumulation and small surface tension.

Joseph et al. (2002) have characterized the differences in welding heat input and weld bead shape that could be produced by the pulsed current waveforms. Hirai et al. (2001) proposed a penetration depth model based on vision sensing. During the welding, a fuzzy controller adjusted the welding current waveform so as to get the desired penetration depth. Therefore, adjusting welding current waveform suitably may be an alternative to obtain suitable heat input and improve the weld bead shape. How to sense the weld pool is a problem. Previous studies show that the use of vision sensing to achieve real-time control for weld pool is an effective means. Chen et al. (2002) designed a weld pool width control test through vision sensing and the results showed that the real-time and precision requirements for detecting and control the weld pool changes of GMAW-P could be met.

In GMAW-P, droplets are regularly detached at a fixed frequency and directionally transferred to the workpiece under the influence of the current waveform. The influence of the metal transfer mode on the weld quality and stability is well known for the GMAW-P process. Changing of the current waveform obviously increases the difficulty of identifying suitable combinations of welding

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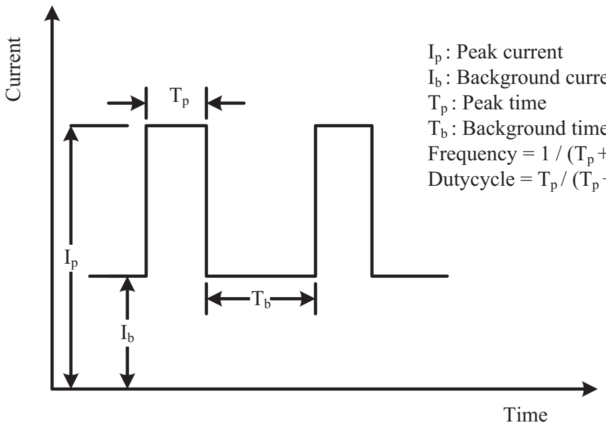

Fig. 1. Current waveform of GMAW-P.

parameters. In GMAW-P process of aluminum, the coupling effect of welding parameters is obvious. Changing one welding parameter may cause variation of other parameters and every parameter is influenced by all other parameters. Ideal control model for aluminum welding should be ensuring the stability of welding process while adjusting the current waveform to improve weld bead shape. Therefore, to obtain a good weld formation and high welding quality on the basis of ensuring the welding process stable, multi-information sensing and multi-variable decoupling control should be adopted for dynamic process of GMAW-P of aluminum.

In this paper, a double-variable decoupling control scheme was proposed. The weld bead shape was improved by changing the current waveforms to adjust the heat input while the arc length was controlled to stabilize the welding process; hence, both the weld bead shape and stability of the welding process were improved. The suitable combinations of welding parameters were identified in the control process and automatically avoiding trial and error.

2. Coupling analysis for control model

According to the identification test, the transfer function of TITO variable control system was obtained as follows:

$$\begin{bmatrix} y_w \\ y_L \end{bmatrix} = \begin{bmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{bmatrix} \begin{bmatrix} \delta \\ V_{wire} \end{bmatrix} = \begin{bmatrix} \dfrac{0.1845}{5.0459s+1}e^{-1.1364s} & \dfrac{0.96}{1.1691s+1}e^{-0.4174s} \\ \dfrac{-0.24}{0.0242s+1}e^{-0.0253s} & \dfrac{0.9594}{0.2663s+1}e^{-0.4928s} \end{bmatrix} \begin{bmatrix} \delta \\ V_{wire} \end{bmatrix} \quad (1)$$

where s is differential operator; G_{11} is the transfer function of duty cycle δ and weld width y_w; G_{12} is the transfer function of wire feed speed V_{wire} and weld pool width y_w; G_{21} is the transfer function of duty cycle δ and wire extension y_L; G_{22} is the transfer function of wire feed speed V_{wire} and wire extension y_L.

In the welding process, keep contact-tube-to-work distance (CTWD) constant, namely the arc length can be expressed by wire extension and a constant. Therefore, coupling degree of the control model can be analyzed through Eq. (1).

For MIMO control system, relative gain array (RGA) theory can be used to determine the degree of coupling. First, the first amplification factor Φ and the second amplification factor P must be determined. The first amplification factor is the steady-state gain matrix:

$$\Phi = \begin{bmatrix} 0.1845 & 0.96 \\ -0.24 & 0.9594 \end{bmatrix} \quad (2)$$

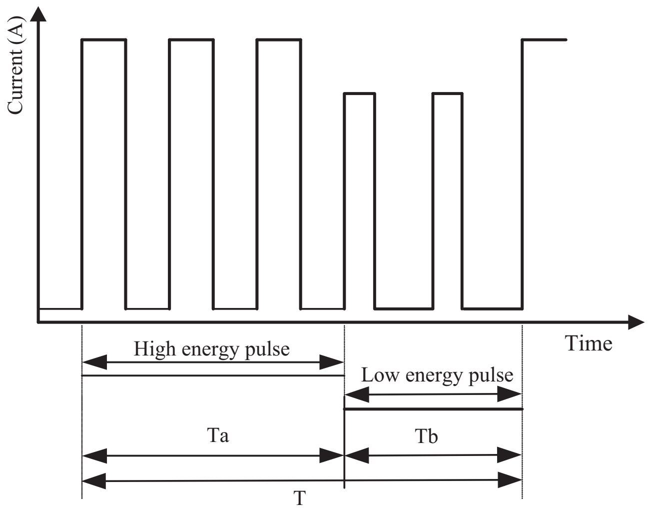

Fig. 2. Current waveform of double-pulsed GMAW welding.

Niederlinski index (NI) is obtained according to the steady-state gain matrix.

$$\mathrm{NI} = \frac{|\Phi|}{\prod_{i=1}^{2}\Phi_{ii}} = \frac{0.1845 \times 0.9594 - 0.96 \times (-0.24)}{0.1845 \times 0.9594} = 2.3017 > 0 \quad (3)$$

The second amplification factor can be calculated by the first amplification factor. There is:

$$\mathrm{P} = \begin{bmatrix} 0.4247 & 1.6975 \\ -0.4244 & 2.2080 \end{bmatrix} \quad (4)$$

RGA can be obtained as follows:

$$\Lambda = \begin{bmatrix} 0.4345 & 0.5655 \\ 0.5655 & 0.4345 \end{bmatrix} \quad (5)$$

The coupling index D is obtained after calculation:

$$D = \frac{0.5655 \times 0.5655}{0.4345 \times 0.4345} = 1.6939 > 1 \quad (6)$$

As for the above control system, it can be judged that system stability can be achieved using a controller with integrator, but the coupling index does not meet the requirements. Change of single input signal may cause changes of multiple outputs, and each output is affected by more than one input. Therefore, decoupling design can only be taken to eliminate or reduce the coupling effect among the parameters.

3. Control scheme

Double-pulsed GMAW is that the welding current waveform changes from a group of high-energy pulses (large average current) to a group of low-energy pulses (small average current) alternately, as shown in Fig. 2. T is a double-pulse period; T_a is high-energy pulse time in a double-pulse period; T_b is low-energy pulse time in a double-pulse period. T_a/T (the ratio of high-energy pulse time in a period) is defined as double-pulse duty cycle.

The double-pulsed GMAW technique is a variation of the P-GMAW. Tong and Tomoyuki (2001) discussed the double-pulsed GMAW technique and claimed that this welding process provided beautiful scaly bead, improved gap-bridging ability for lap joint, restrained blowholes for formation, refined grain size, and decreased crack sensibility. Further, Silva and Scotti (2006) proved