Penetration-Self-Adaptive Free-Frequency Pulsed Plasma Arc Welding Process Controled with Photocell Sensor†

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Abstract

A penetration-self-adaptive free-frequency pulsed plasma arc welding process controlled by photocell sensor has been developed and is described in this report.

The method of measurement for the penetration quality and the control circuit which adjusts adaptively the pulsed current duration depending on the results of penetration quality with on-line measurement is presented. Adaptive potential of the control system is analysed. Results of welding experiment are also discussed finally.

KEY WORDS: Plasma Arc Welding, Automatic Control, Pulse Arc, Photocell, Sensor

1. Introduction

The major advantage of plasma arc welding is that one-sided single pass penetration weld can be obtained by means of keyhole effects without backing plate in certain thickness region for some kinds of steel and alloys, it is very useful for several applications, for example, small diameter circumference weld which requires uniform penetration quality. However, practical application indicates that keyhole stability is disturbed easily by a series of random affairs such as:

(1) Variation in weldment mismatch, gap and height of torch relating to the weldment.

(2) Deviation of the central position of plasma arc relating to the weld line.

(3) Displacement of cathod spot due to excess heating or burned-consuming of electrode and nozzle of torch.

(4) Change in heat transmission from plasma arc to weld due to composition change of arc plasma caused by impurity of gas or contaminating substance on the surface of the weldment.

In order to overcome this problem, several kinds of automatic control system have been presented.[1)–4)] In this study a new self-adaptive penetration control system for pulsed plasma arc welding is developed, in which penetration quality is measured by PSD or SPD photoelectric sensor and pulsed current duration is adjusted depending on the results of penetration quality real-time measurement. Therefore the pulsed current duration is variable and penetration quality becomes uniform.

2. Method of Measurement for Penetration Quality

It is well known that plasma flux throughout the weld pool is a visible indication for weld penetration and can be easily detected by photoelectric sensor such as photodiode and phototransistor during keyhole plasma arc welding process.[2)–4)] A new sensing system consisting of a camera with a long focal lens, silicon photodiode (SPD) and IC operational amplifier is designed and set up as **Fig. 1**. The advantages of this sensing system comparing with others are as following.

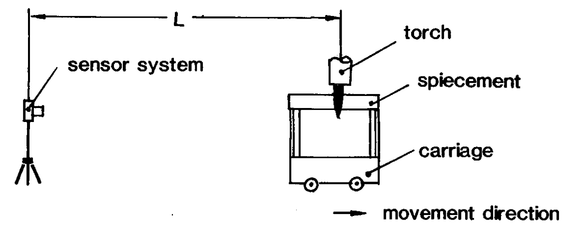

Fig. 1 Setting up methoh of sensor

(1) It is possible to measure the area size of plasma flux throughout the weld pool 1–10 [m] or more away by means of adjusting amplifier gain.

(2) The ratio of signal and noise (S/N) is larger than others because the thermal radiation from back area of weld pool is emitted to the different direction and the received thermal radiation, which is noise, by sensor can be limitted within small possibility.

(3) It is possible to obtain a sensor output signal (V_{sos}) proportional to area size of plasma flux throughout the weld pool. The experiment indicates that the area size corresponds to the width and height of the back bead. The shape of the plasma flux is almost same as that of nontransforming plasma arc, its area size is proportional to current value and flow rate of plasma gas. So the former can be simulated by the latter at the calibration of the sensing system shown in **Fig. 2**. These results show that the sensing system can

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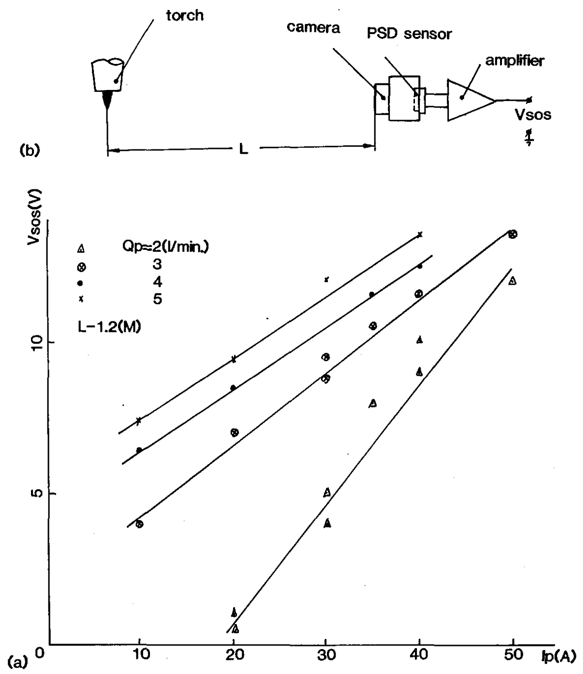

Fig. 2 Characteristics (a) & detecting method (b) of sensor system

detect the change of penetration indirectly during keyhole plasma arc welding process.

Position sensitive diode (PSD) can also be used as the sensor, but there is no evident advantage comparing with SPD sensor in this experiment.

3. Design of Control Circuit

If the keyhole is formed and its diameter is not too large at every pulse duration during pulsed plasma arc welding process, almost uniform weld penetration quality will be ensured. However, it is difficult to get this condition and imcomplete penetration or excess-protuberance are sometime found out because of above mentioned random disturbing affairs during ordinary constant frequency pulsed plasma arc welding process. In order to surment this disadvantage, a free-frequency pulsed plasma arc welding provess is developed in this research work. Every pulse current duration (t_p) is adjusted adaptively

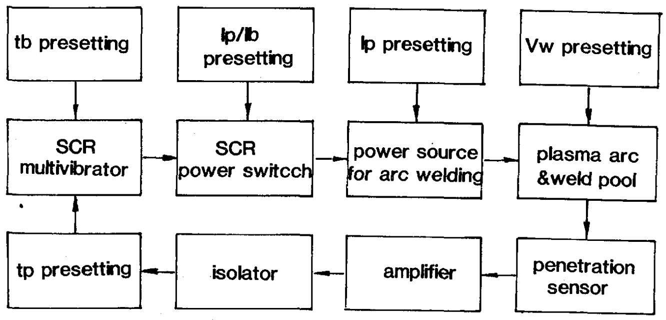

Fig. 3 Block-diagram control system for free-frequency pulsed plasma arc welding process

depending on the results of penetration quality real-time measurement during the welding process so that the key hole may be formed at the adequate diameter. **Figure 3** is the block diagram of the control circuit for the free-frequency pulsed plasma arc welding process, which shows the principle of the function. **Figure 4** is the circuit diagram. **Figure 5** shows the relation between pulse current duration and sensor output signal (V_{sos}), which indicates that t_p will vary from minimum value (t_{po}) to infinitely great (∞) when the V_{sos} is varying in the region from the

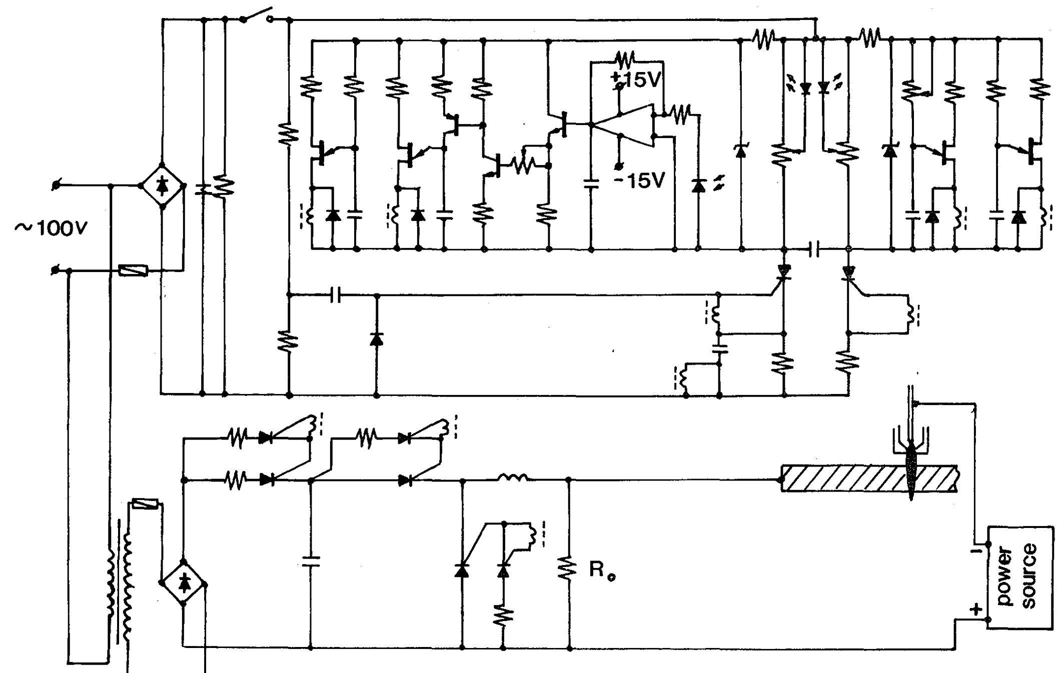

Fig. 4 A typical structure of control circuit

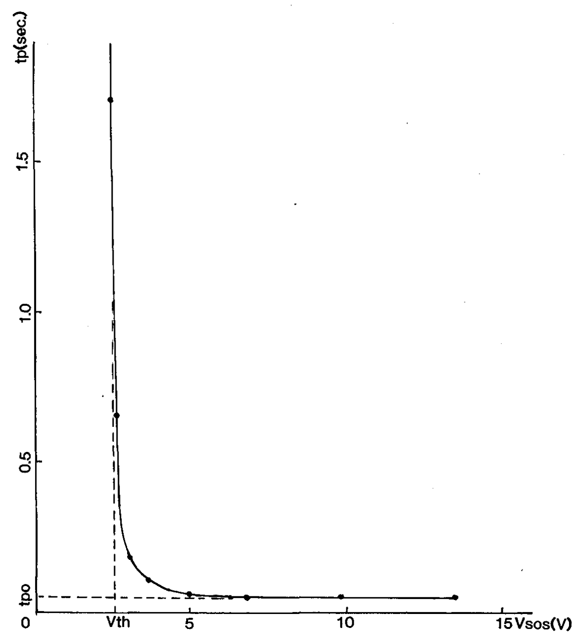

Fig. 5 The relation between t_p & V_{sos}

maximum value (13.5 [v]) to the threshold (V_{th}) and the values of t_{po} and V_{th} can be adjusted by setting the circuit parameters. Once the transforming plasma arc is triggered, the circuit will ensure producing the pulse current (I_p) and only at the time the keyhole occurs and V_{sos} becomes larger than the threshold, the arc current will be turned into its base current. So long as the value of I_p is chosen large enough for a given weldment and other presetting process parameters, the keyhole can be formed in every pulse duration and its diameter can be maintained within optimum value. It is obviously that the value of plasma current I_p, base current I_b can be set by adjusting the power source and the resistor R_o which is connected in serial with set by adjusting the parameter of the control circuit.

4. Results of Welding Experiment

A series of on-plate welding experiment have been made on using the control system. Thickness of the specimen (SUS 304) is 6[mm]. No back and tail shield gas is utilized. The main results are as following.

(1) It can be observed that the value of t_p is random varying from every oscillogram record of the plasma arc current or voltage the ripple of weld as shown in **Fig. 6**. cause of change in height of the torch that is caused by thermal distortion of weldment, in every weld frequency varies as shown in **Fig. 7**.

(2) If the value of plasma arc current is adjusted during welding process, the value of t_p will increase as the value of I_p and/or I_b is decreased as shown in **Fig. 8**.

(3) When the presetting value of I_p (I_b) or welding speed (V_w) are changed in certain region, the width and the height of the bottom weld bead are almost definite as shown in **Fig. 9**, but the average value of frequency will increase with increasing the I_p or decreasing the V_w as shown in **Fig. 10**.

However, in case the presetting value of I_p is too large or V_w is too small, the excess-proturberance is apt to occur, in case the presetting value of V_w is too large, the discontinuous penetration weld is apt to occur and in case the presetting value of I_p is too small, the incomplete penetration weld is apt to occur as shown in **Fig. 11**.

The above mentioned results indicate that careful and

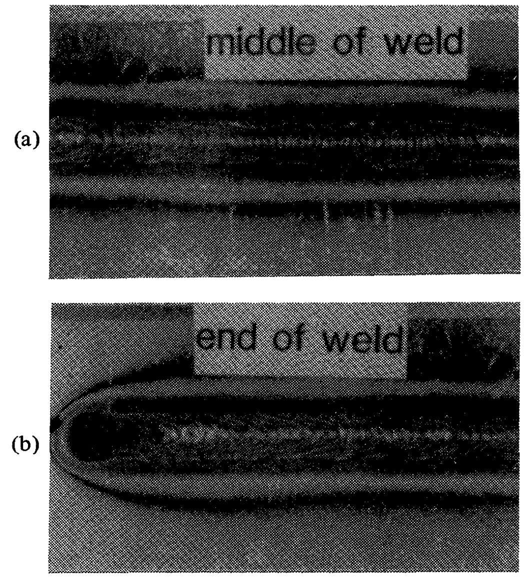

Fig. 6 Typical ripple varying in weldment (V_w = 18 cm/min., I_p/I_b = 180/100A, Q_p = 3 /min) (a) middle (b) end of weld

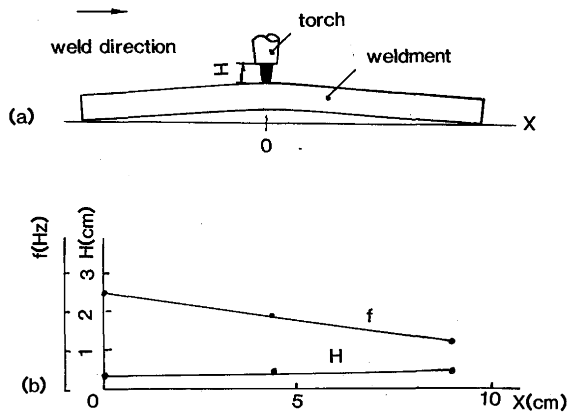

Fig. 7 Thermal distortion of weldment (a) & frequency varying (b)

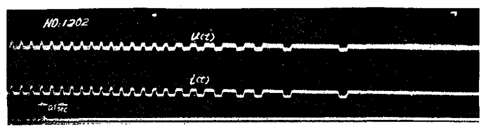

Fig. 8 Oscillogram for indicating relation between I_p & t_p

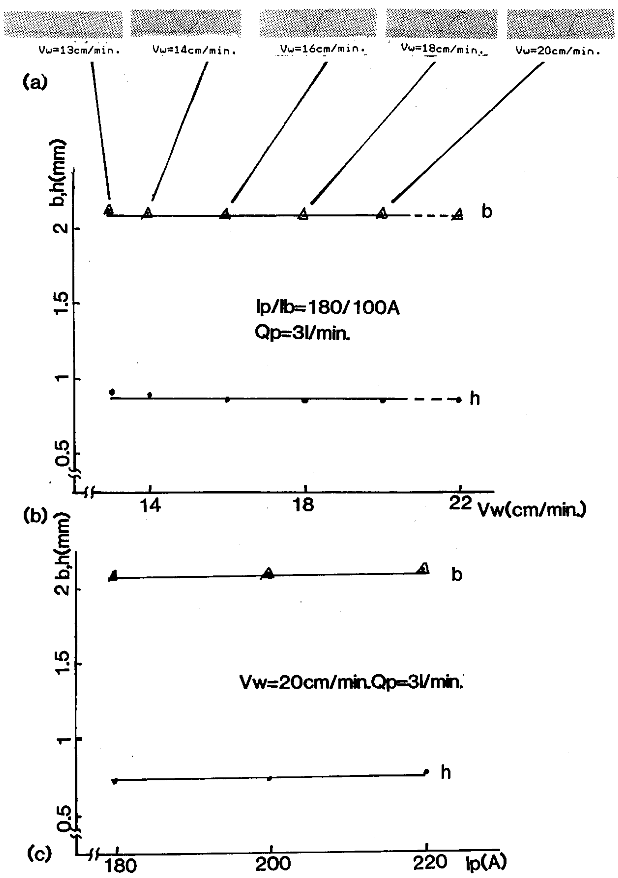

Fig. 9 Typical weld cross-section (a) & width & height of back weld made of different V_w(b) or I_p/I_b(c)

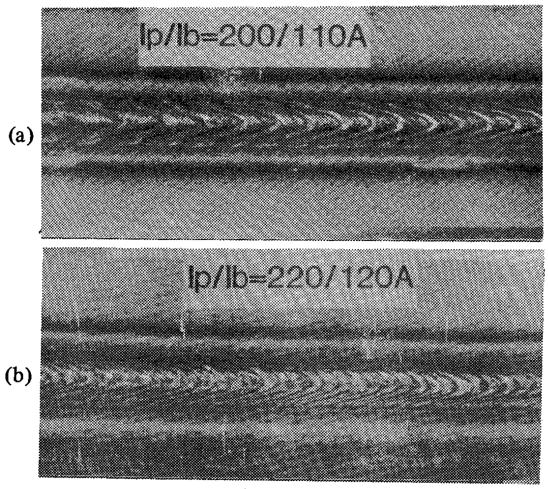

Fig. 10 Typical ripple of weld made of different I_p/I_a, but same other parameters (V_w = 23 cm/min. Q_p = 3 l/min.)

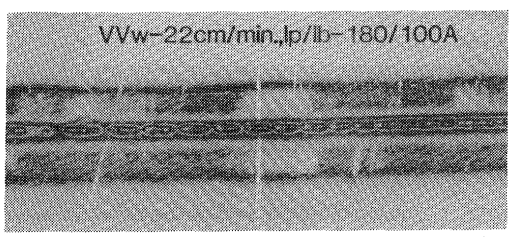

Fig. 11 Typical discontinuous penetration weld

adequate parameter setting is still important in order to use the adaptive control potential of the system fully.

5. Discussion on Adaptive Control Potential

It is obvious that the adaptive control potential of the system will depend on the increse of the average current and the input heat in case the value of t_p is extended under the disturbance condition. The average current can be calculated as following if the pulsed wave is assumed a rectangular wave for the control system shown in Fig. 4.

$$I_R = \frac{I_p t_p + I_b t_b}{t_p + t_b} \tag{1}$$

, where t_p is a variable and other parameters are constant, preset, so

$$\frac{dI_a}{dt_p} = \left(\frac{1}{t_p + t_b}\right)^2 (I_p - I_b) t_b dt_p \tag{2}$$

and

$$\left.\frac{dI_a}{dt_p}\right|_{max} = \left(\frac{1}{t_{p0} + t_b}\right)^2 (I_p - I_b) t_b dt_p$$
$$= f_0^2 \Delta I t_b dt_p \tag{3}$$

, where $f_0 = 1/(t_{po} + t_b)$ is a inherent frequency which depends on the parameter of control circuit. Increase of heat input per unit weld length can be written as following.

$$\left.\frac{dt_a}{dt_p}\right|_{max} = \frac{dI_a V_a}{V_w} \tag{4}$$

From eqs. (3) – (4), the following analysis can be presented.

(1) Decreasing t_{p0} or t_b, especially t_{p0}, the adaptive control potential will be increased:
(2) Increasing ΔI, the adaptive control potential will be increased:
(3) Increasing V_w, the adaptive control potential will be decreased:

It is said that t_{p0} should be chosen as small as possible, ΔI should be chosen as large as possible and t_b and V_w should be chosen in adequate value in order to use the adaptive control potential fully.

6. Conclusion

This report is summarized as

(1) A self adaptive penetration control system for pulsed plasma arc welding is presented in the paper, in which penetration quality is measured by a PSD sensor system and pulsed current duration is adjusted

depending on the results of penetration quality real-time detection.

(2) Welding experiment and theoretical analysis indicate that the system can ensure uniform penetration quality under the disturbing condition.

(3) In order to promote the development of the adaptive control potential of the system, it is still necessary to set the process parameters in adequate value.

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