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Full Length Article

Output characteristic and arc length control of pulsed gas metal arc welding process

Qiang Wang*, Bojin Qi, Baoqiang Cong, Mingxuan Yang

School of Mechanical Engineering and Automation, Beihang University, Beijing, 100191, China

A R T I C L E I N F O

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A B S T R A C T

A pulsed gas metal arc welding (P-GMAW) power source is produced with a stepped output characteristic. The steeped output characteristic control circuit is designed based on peak current-mode control and one cycle control methods An adaptive arc length control method is put forward and introduced based on a digital signal controller (DSC). Bead-on-plate experiments are carried out on mild steel to investigate the influences of output characteristics on the stability of P-GMAW process in an open-loop arc length control condition.Results show that stepped characteristic at background duration has the advantage of decreasing arc extinguishments and short-circuits phenomena, and the welding process is more stable without spatters than constant current or constant voltage characteristic. Welding with adaptive arc length control strategy, the dynamic behavior of arc working point and arc length is described, resulting in an identical arc length at the end of background time for each pulse period. One-drop-per-pulse transfer mode is obtained by carefully selecting pulse parameters with a droplet radius approximately equal to that of the electrode. Arc lengths are measured with different threshold voltages and background currents. The mathematical model of threshold voltage with respect to arc length and welding current is established through multiple linear regression analysis method. Welding with a step wire-feed speed and a step CTWD, the adaptive arc length control strategy shows strong disturbance resisting ability.

1. Introduction

Pulsed gas metal arc welding (P-GMAW) is one of the most frequently used welding technologies in industrial areas. It will obtain a pulsed spray transfer mode under the condition that the mean welding current is lower than the critical current for spray transfer, which extends the rang of welding current [1]. Meanwhile, the advantages of low spatters, low heat input, high efficiency and good penetrability lead to the wide application of P-GMAW process in manufacturing industry [2–5].

It is usually set to be either constant current (CC) characteristic or constant voltage (CV) characteristic during peak duration and background duration for P-GMAW process. To obtain stable welding process, the output characteristic of each pulse period must be properly controlled, especially during background duration when welding current is low. Under the condition of CV mode at background time, the arc voltage is stable but the welding current is fluctuant. Once the welding current is too small to maintain arc burning, the arc is likely to extinguish. Under the condition of CC mode, on the other hand, the arc current is constant while arc voltage is varied. The electrode wire will stick to the molten pool when arc length is too short, causing numerous spatters [6,11]. To solve these problems, a stepped output characteristic is invented [7,8], wherein the power source operates at the "∟" characteristic during background time to keep the arc stable and avoid short-circuiting. During the peak time, however, the power source works at the "¬" characteristic to keep a uniform drop transfer and avoid burning-back. Currently, comparisons of different output characteristics, especially during background time, are less reported yet.

P-GMAW process usually utilizes an I–I type power source wherein CC characteristic is adopted at both background and peak time. Under this circumstance, the arc length varies in real time with high fluctuation for the weakness of inherent arc self-regulating ability. Hence, it is a significant issue to keep a stable arc length during P-GMAW process, and various efforts have been made. Synergic control is regarded as an one-knob control method wherein the power supply and the wire feeder are directly linked in such a way that mean current is determined by wire feed rate to ensure stable arc [9]. Welding parameters automatically match with the given wire-feeding rate. This control method can only be operated in the fixed ranges of mean current as large mean current might produce multiple droplet detachments per pulse.

* Corresponding author.
E-mail address: qiangwang@buaa.edu.cn (Q. Wang).

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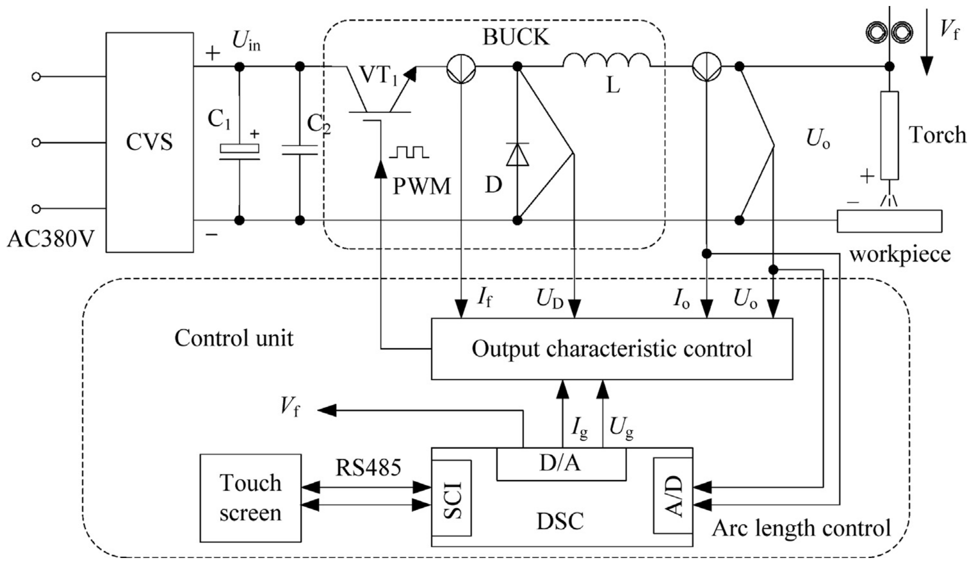

Fig. 1. Schematic diagram of P-GMAW power source.

Wire-feeding arc voltage control achieves the control by modifying wire-feed rate. If the arc length increases, wire-feeding rate is increased to maintain constant arc length. This method is currently not popular due to poor stability and comparatively slower response rate of wire feeders [10]. Frequency arc voltage control achieves the control by modifying pulse frequency, which in turn modifies mean welding current [11]. This mode basically restores the arc length by adjusting the background time, which is easily implemented by a digital controller. Y M Zhang designed an arc light sensor and developed a closed-loop arc length control system by analyzing arc spectral information [12,13]. Thomsen described a feedback linearization based arc length controller by cancelling the nonlinearities with a nonlinear state feedback control part [14]. Adaptive control tries to restore the arc length to set reference voltage by automatically modifying the burn off rate [15]. The waveform produced by this type of control method has constant peak duration, peak current and base current. Only variable pulse parameter is base current duration which is decided by the given wire feed speed. This method is easy to realize and saves time for trial and error, but, so far, no detailed mathematical control model has been given yet.

In this paper, a set of P-GMAW power source is designed. Stepped output characteristic is achieved through peak current-mode control and one cycle control methods. Adaptive arc length control strategy is employed to maintain the arc length. The primary objective of this paper is to investigate the influence of output characteristics on the stability of P-GMAW process during background current duration, and to give a detailed mathematical model for better understanding the dynamic arc behavior of adaptive arc length control strategy.

2. Methods

2.1. Circuit arrangement and stepped output characteristic of the P-GMAW power source

The schematic diagram of the designed P-GMAW power source is illustrated in Fig. 1, wherein the main circuit comprises a constant voltage source (CVS) and a BUCK converter, and the control unit includes an output characteristic control circuit, a 32bits digital signal controller (DSC) and a touch screen which serves as a human-machine interface (HMI). The output voltage of the CVS is about 80 V. The power switch VT_1 operates at a fixed switch frequency of 20 kHz whose duty cycle is decided by the output characteristic control circuit according to the values of desired current I_g and desired voltage U_g. The signals I_f, U_D, I_o and U_o, representing current that flows at VT_1, voltage across the ends of freewheel diode D, output current and output voltage, respectively, are transmitted to the output characteristic control circuit to control the output characteristic of the P-GMAW power source. The DSC plays a core role in the control unit for arc length control algorithm. I_o and U_o are acquired and converted to digital signals by the DSC through an A/D converter module to record welding parameters as well as to be used for arc length control algorithm. The signals I_g, U_g and V_f, standing for desired current, desired voltage and wire feed speed, respectively, are given by the DSC through a D/A converter module. Additionally, the touch screen communicates with the DSC through a serial communication interface (SCI) module following the principle of RS485.

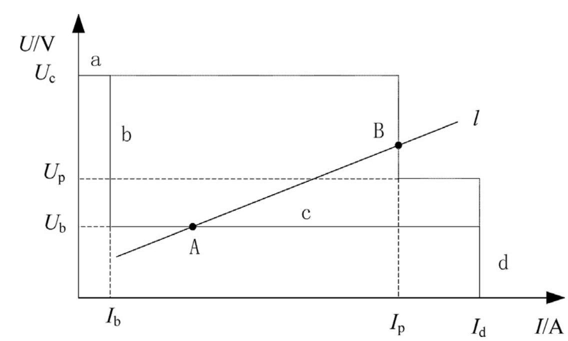

Fig. 2. Sketch of stepped output characteristic.

The sketch of stepped output characteristic is shown in Fig. 2, where lines a–d represent open-circuit characteristic, constant current (CC) characteristic, constant voltage (CV) characteristic and short-circuit characteristic, respectively. The open circuit voltage and short circuit current are U_c and I_d respectively. According to stepped output characteristic, welding arc load works at different characteristic curves when the set parameters are changed. Take a certain arc length of l for example, during background current, the steady working point (point A) is in CV characteristic at the condition of $U_g = U_b$ and $I_g = I_b$. During peak current duration, however, the steady working point (point B) presents in CC characteristic at the condition of $U_g = U_p$ and $I_g = I_p$. Similarly, diverse output charac-