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Development of Digital DC-ARC Welding Machine

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KEY WORDS: DC-arc welding machine, Power switching IGBTs, Hot-start function, Anti-stuck function, Ferrite transformer

ABSTRACT: *This paper introduces the results of the development of a new mobile digital DC-arc welding machine (DDWM). A simple PI controller is applied to the DDWM to control the output welding current that is tracking the constant setting current. Furthermore, a hot-start function, an anti-stuck function, a standby mode and an intelligential circuit breaker (ICB) are included in the DDWM. The DDWM increases welding quality and saves more power energy than a conventional welding machine. The DDWM is changed from ready mode into the standby mode, automatically, after 2-minute intervals from this unload start. Then, the DDWM is changed into ready mode, automatically, since it is reused for welding. Moreover, the DDWM increases welding quality, productivity and reduces costs of welding. So, the DDWM can make a considerable contribution to the mobile welding industries. The effectiveness of the DDWM was proven by the experimental results.*

1. Introduction

Welding is the most common way of permanent joining metal parts. In this process, heat is applied to metal pieces, melting and fusing them to form a permanent bond. Because of its strength, welding is used to join beams when constructing buildings, bridges, and other structures, and to join pipes in pipelines, power plants at the construction sites. Also, a large number of mobile welding machine is used in the home appliance discussed by Charles et al. (2000) and a thousands of other manufacturing activities. Furthermore, welding is used in shipbuilding, automobile manufacturing and repair, aerospace discussed applications by Takasaki et al. (2003).

To solve the problem of weight and size of DC-arc welding machine it is necessary to design an inverter which provides much higher frequency than 60 Hz to supply for ferrite transformer. So ferrite transformer of much smaller mass is used to permit the handing of much greater powers output. Furthermore, to reduce a welding noise the operating frequency has to select over the hearing frequency of human ability. The choice of 20 kHz for the DDWM was determined by the above specifications.

The output welding current is controlled by controlling the power supplier for ferrite transformer at high frequency. The power supply for the ferrite transformer is provided by an inverter. So a control circuit and an inverter are developed. The control circuit for driving the power switch IGBTs of the inverter is designed. The inverter has permitted the implementation of these specifications through controlling high power at high frequency.

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2. Problem Statements

The requirements for a good DC-arc welding machine can be explained as the following: Firstly, an output welding current easily achieves the setting welding current at first welding. Secondly, the output welding current of an electric arc must be maintained constantly during the welding process.

The conventional analog welding machine generates the steady PWM for driving IGBT of its inverter and controls the output welding current by switch on or off of the PWM. So it can not regulate well the quality of welding current to track the setting welding current. To solve the above mentioned problem the DDWM is developed.

The DDWM controls the output welding current by controlling the duty cycle of PWM. Based on the error between the values of feedback output welding current and the setting current, a PI controller is designed. The PI controller will adjust the $e \to 0$ as $t \to \infty$. Moreover, by using the hot-start function the output current of DDWM easily achieves the setting current at welding start of state. So the electric arc of DDWM is created and maintained easily . By adjusting the value of the hot-start volume, the DDWM can increase the initial setting current from 0 A to 40 A bigger than the setting welding current at start. Then the initial setting current is decreased to the setting welding current according to exponential curve. Furthermore, the anti-stuck function, standby mode, LCD for welding current and intelligent CB are included in the DDWM.

3. Hardware and Soft ware Implementation

3.1 Hardware Design

The general DC-arc welding machine is shown in Fig. 1. An main power input 220 V-60 Hz at a power of 5 kW is applied to the device. The arc welding machine should output an arc of 180 A maximum at 25 V DC.

The conventional inverter DC-arc welding machine is shown in Fig. 2. The conventional inverter DC-arc welding machine ignores the feedback of the welding voltage and only considers the feedback of the welding current. So the conventional inverter DC-arc welding machine without feedback voltage cannot design anti-stuck function. That is, because the conventional DC-arc welding machine without the feedback voltage cannot detect whether arc is off or on, a well-trained welder is needed for welding a thin gauge steel sheet. In practice, the DC-arc is stable when the output welding voltage has the range from 6 to 36 V DC. When a thin gauge steel sheet is welded with low energy, it means that the output voltage is near the minimum value to create arc. So stuck phenomenon can be easily produced at the welding condition with low energy.

Three main parts of DDWM were described in Fig. 3. The first part is an inverter. It inverts the frequency of the power supply from 60 Hz to 20 kHz to supply the power for a ferrite transformer. This part includes a source filter, a rectifier & filter of DC source and a power switch IGBTs. The DC source is necessary for the proper operation of an arc welding machine. The second part includes a ferrite transformer, a power rectifier and a filter of welding current. The ferrite transformer is shown in Photo. 1. The third part is a control circuit which is shown in Photo. 2. It includes an isolated 5 V DC and 12 V DC, a microprocessor PIC, a driving IGBTs modules, a protected IGBTs for over current, a filter feedback current, a filter feedback loop voltage, a hot-start volume and a master volume which adjusts the setting current. Based on the feedback current and the feedback loop voltage, the output welding current is controlled to track the setting current by controlling the duty cycle of PWM. The developed hardware and the DDWM are shown in Photo. 3 and Photo. 4, respectively. With the hot-function, the anti-stuck function and main function of the DDWM, any one can do welding works in any conditions.

Fig. 1 DC-arc welding machine

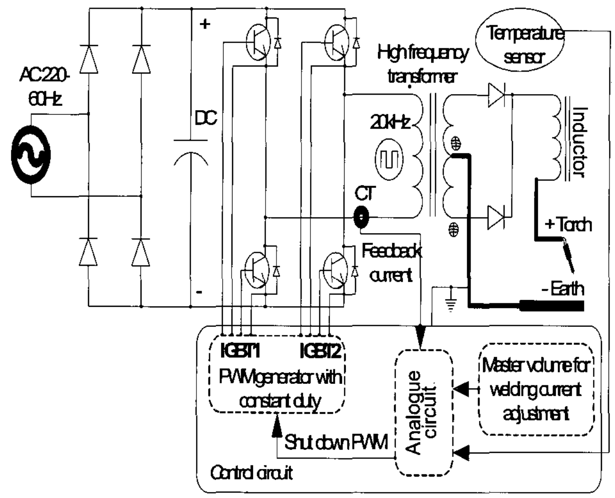

Fig. 2 Scheme of conventional inverter DC-arc welding machine

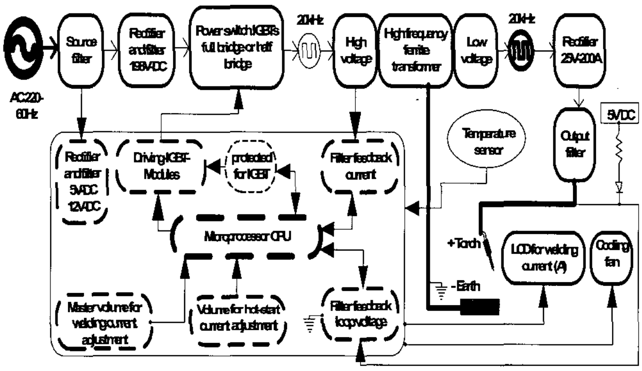

Fig. 3 Main part diagram of the DDWM

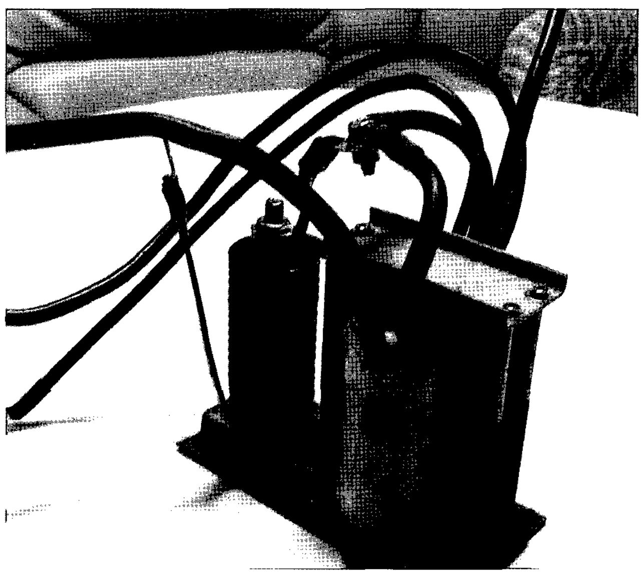

Photo. 1 The Ferrite transformer and the output filter coil of the DDWM

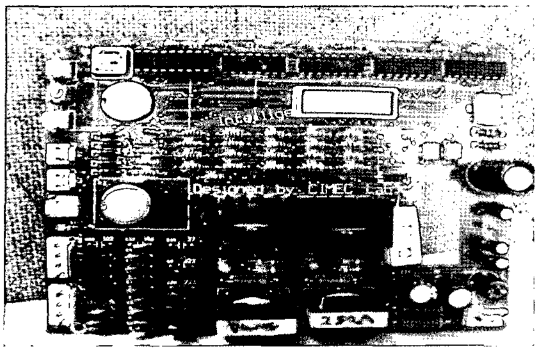

Photo. 2 Control circuit of the DDWM

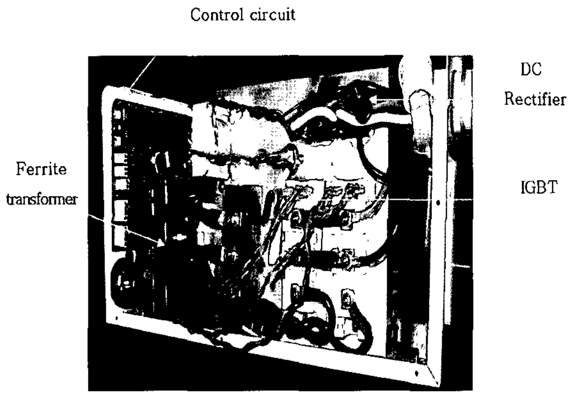

Photo. 3 Developed hardware of the DDWM

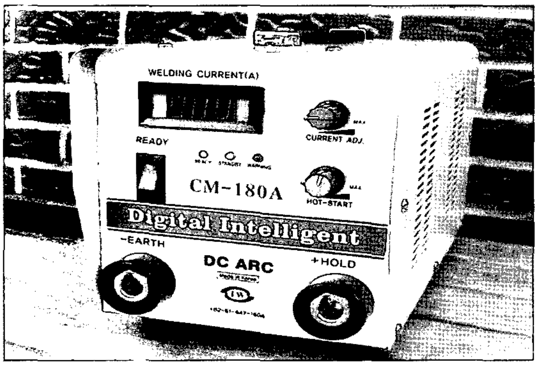

Photo. 4 Developed DDWM

3.2 Software Design

Table 1 shows relationship of welding state and welding voltage based on technical data of Fronius International GmbH.

The flowcharts of the hot-start function, anti-stuck and main function of DDWM are shown in Fig. 6~Fig. 8, respectively.

In the start of welding, this hot-start function of the developed DDWM generates output current 0~40 A higher than setting welding current depending on the value of hot-start volume(%). So the developed DDWM generates arc more easier than traditional welding machine. Anti-stuck function makes welding voltage high and sets to normal welding voltage as soon as output welding voltage reaches 6 V of minimum voltage as shown in Table 1.

Table 1 Relationship of welding state and welding voltage

State	Voltage [V]
Normal welding	7~35
Stuck(V_{min})	Under 6
Arc disappear(V_{max})	Over 36

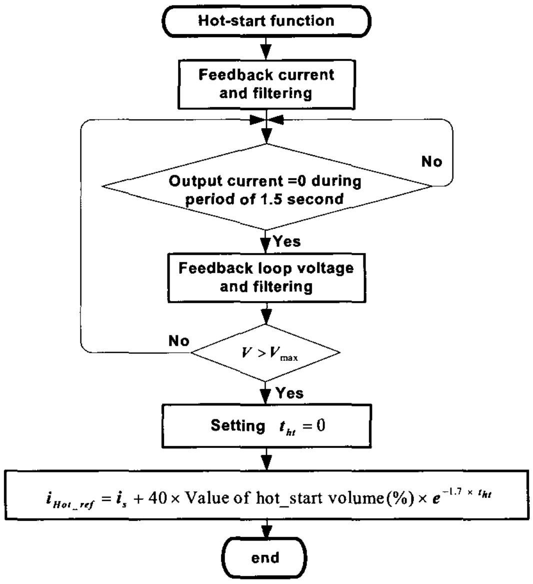

Fig. 6 Flowchart of the hot-start function

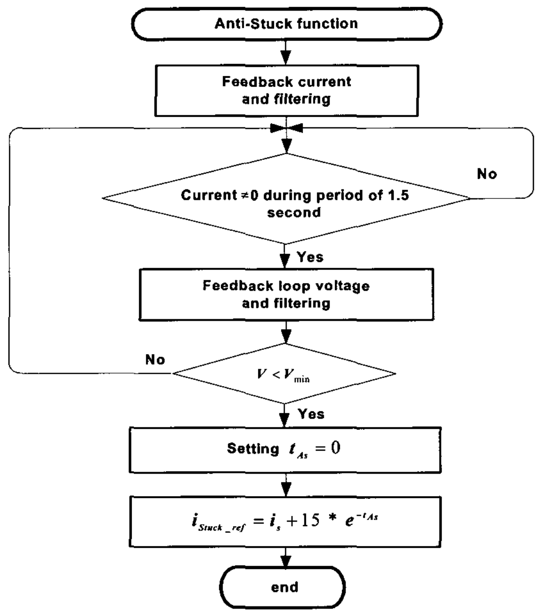

Fig. 7 Flowchart of the anti-stuck function

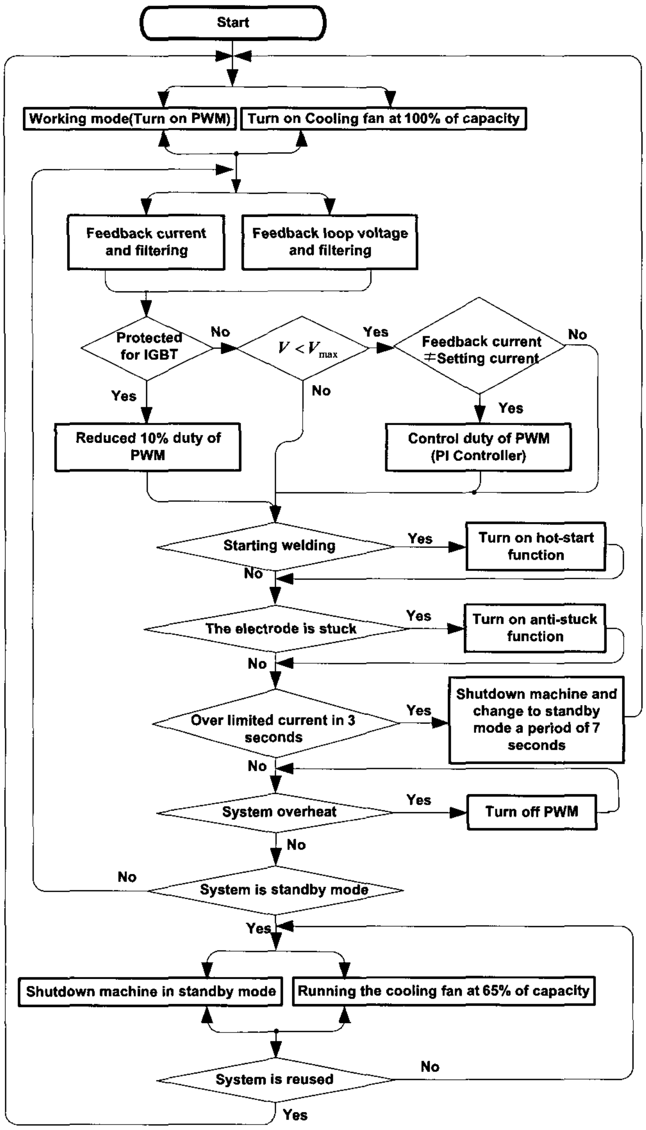

Fig. 8 Flowchart of main function of DDWM

In Fig. 6~Fig. 7, i_{Hot_ref} is reference welding current in hot-start function i_s is setting current, t_{ht} is time during hot-start function, i_{stuck_ref} is reference welding current in anti-stuck function and t_{As} is time during anti-stuck function.

3.3 Feedback Controller Design

Let u be an control signal input, P_w is a duty of PWM (%) and i_{out} is an output welding current (A). In our particular case we desire to find the relationship between them and then design PI controller which controls the current output so as to track the setting current.

u : Control signal,

i_{ref} : Reference welding current,

i_{out} : Output welding current of machine,

u_i, e_i : Control signal at i^{th} sampling time and the control error at i^{th} , respectively,

t_d : Sampling time,

T_i : Integral time of the controller,

K_p : Proportional gain of the controller,

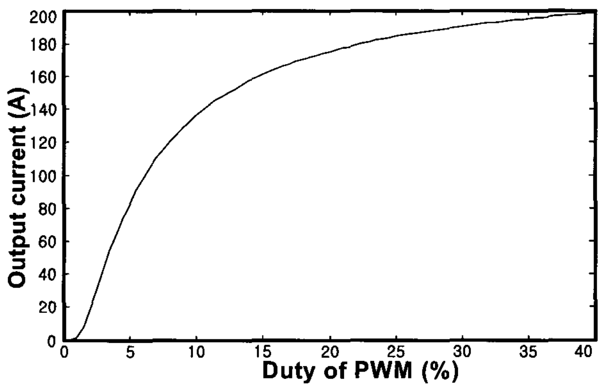

Fig. 9 Relationship between current output and duty cycle switching of IGBTs

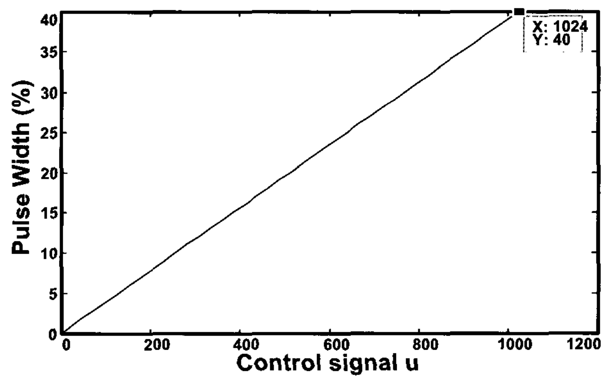

Fig. 10 Relationship between duty cycle switching of IGBTs and control input

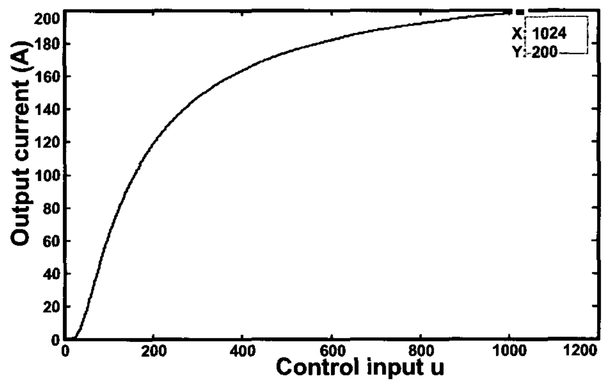

Fig. 11 Relationship between current output and control input

K_I : Integral gain of the controller,

P_w : Duty of PWM (%), $0 < P_w < 0.4$, proposed by Chae et al. (1999)

The relationship between P_w and i_{out} for the used IGBT module SKM75GB063D is as follows

$$i_{out} = 225e^{\left(-\frac{5}{P_w}\right)} \tag{1}$$

The relationship between P_w and u based on the microprocessor PIC (Fig. 10) can be expressed as follows

$$u = 25.6P_w \tag{2}$$

$$P_w = \frac{1}{25.6}u \tag{3}$$

So that, relationship between i_{out} and u can be expressed as follows

$$i_{out} = 225e^{-128/u} \tag{4}$$

The tracking error of the system is given by:

$$e = i_{ref} - i_{out} \tag{5}$$

The proposed PI controller can be described as follows:

$$u = K_p e + K_I\left(\frac{1}{T_i}\int_0^{T_i} edt\right) \tag{6}$$

In the discrete time signal the control signal in PI controller can be calculated from:

$$u_i = K_p e_i + D(i) \tag{7}$$

where

$$D(i) = D(i-1) + \frac{K_I * Sampling\ time}{2}(e_{i-1} + e_i)$$

By choosing $K_p = 2.5$ and $K_I = 5$, the tracking error of the system $e \to 0$ as $t \to \infty$.

4. Experimental Results and Discussions

Figure 12 shows the setting current and output current of the traditional welding machine. It takes about two seconds for the output current to track the setting current 140 A. So it is difficult to generate arc.

For the developed DDWM, the output welding current is set at 140 A and the value of hot-start volume is set to 60%. An electrode welding rod (ϕ3.6 mm) is used. The reference current at first, the output welding current, the control signal and the tracking error in hot-start function are shown in Fig. 13~Fig. 15, respectively. In Fig. 13, the proposed controller makes the output welding current track the reference current very well and the output current rapidly achieves the reference current at first welding because of the hot-start function and then the output current reaches the setting current. That is, in the start of welding, this hot-start function of the developed DDWM generates output current 0~40 A higher than the setting welding current. So the developed DDWM generates arc more easier than traditional welding machine. The control signal is an input signal to get output current tracking reference current in hot-start function and is shown in Fig. 14. Figure 15 showing the tracking error converges to zero when $t \geq 3$ seconds and remained around zero. Photo. 5 shows the welding result of the DDWM. Photo. 6 shows PWM of DDWM at $u \approx 260$ with 20 KHz of frequency.

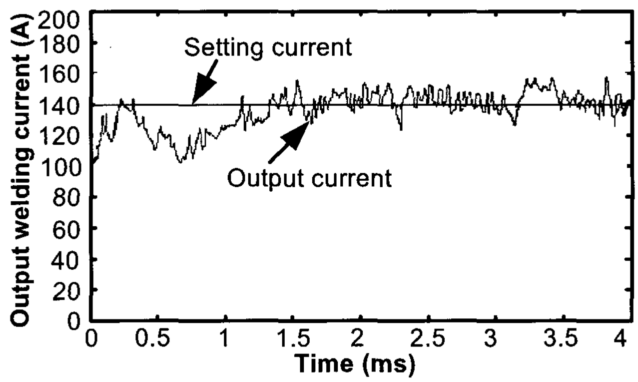

Fig. 12 Setting current and output current of the traditional welding machine

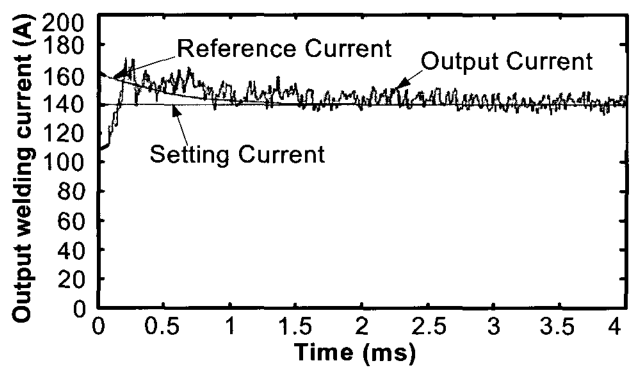

Fig. 13 Reference current, setting current and output current in hot-start function

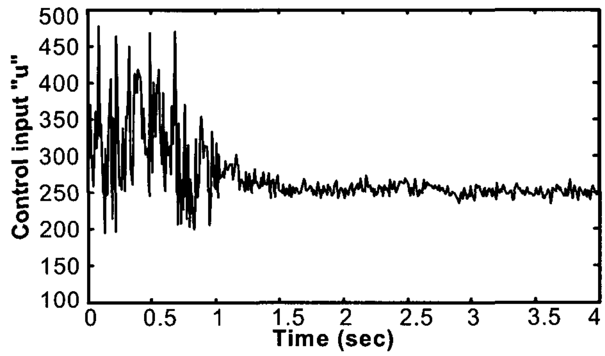

Fig. 14 Control signal, u

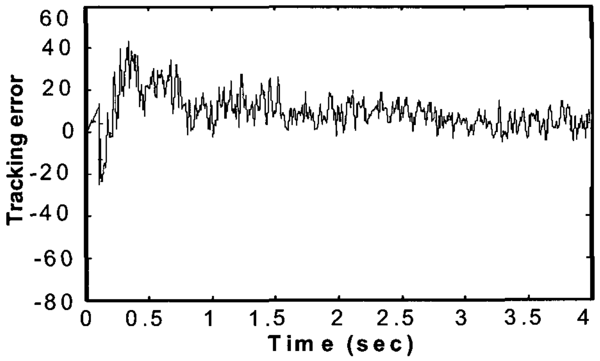

Fig. 15 Tracking error, e

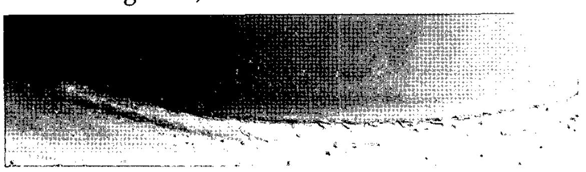

Photo. 5 Welding results of DDWM

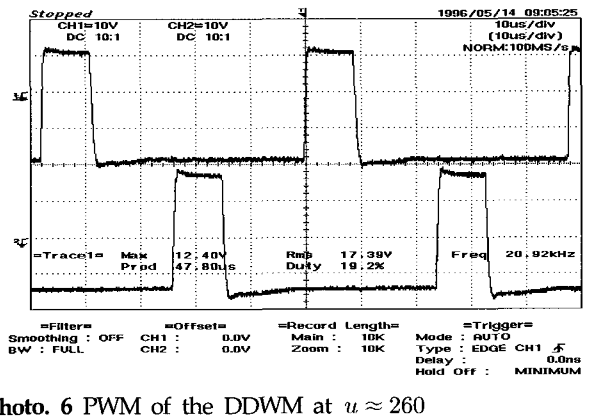

Photo. 6 PWM of the DDWM at $u \approx 260$

Figure 16 shows the anti-stuck function of the developed DDWM. The output voltage is recovered into the normal welding voltage by anti-stuck function as soon as output voltage reaches 6 V of minimum voltage as shown in Table 1. So the developed DDWM can remove stuck phenomenon and keep the normal welding automatically.

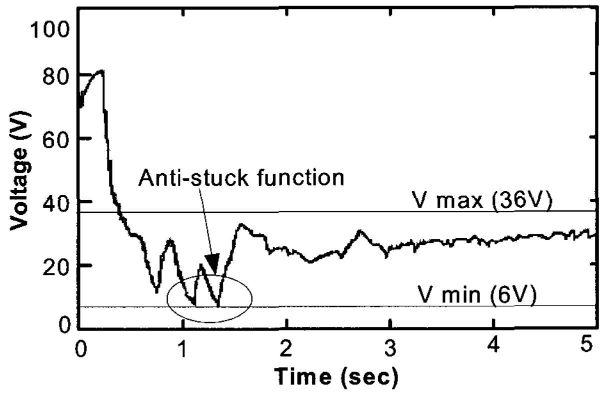

Fig. 16 Anti-stuck function

5. Conclusions

This paper introduces the results of the development of a new mobile digital DC-arc welding machine. The DDWM with small size and light weight produces a maximum 180 A output welding current at 25 V DC. A simple PI controller is applied to the DDWM to control the output welding current tracking the constant setting current and furthermore, a hot-start function and an anti-stuck function are included in the DDWM. The DDWM increases welding quality, productivity and reduces costs of welding. So, the DDWM can have a great of contribution to the mobile welding industries. The effectiveness of the DDWM was proven by the experimental results.

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