DEVELOPMENT OF DIGITAL DC-ARC WELDING MACHINE

Ngo Manh Dung, Ba Da Park, Yeong Deug Jeong and Sang Bong Kim

School of Mechanical Eng., College of Eng., Pukyong National University,
San 100, Yongdang-Dong, Nam-Gu, Busan, 608-739, Korea
(Tel: +82-51-6201606; Email:sbkim@yahoo.com)

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 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. Because the DDWM is changed from ready mode into the standby mode automatically after 2 minutes interval from this unload start. Then the DDWM is changed into ready mode automatically since it is reused to weld. Mover, 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 and durable test.

Key word: DC-arc welding machine, power switching IGBTs, hot-start function, anti-stuck function, ferrite transformer.

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[1] and a thousands of other manufacturing activities. Furthermore, welding is used in shipbuilding, automobile manufacturing and repair, aerospace applications[2].

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 60Hz 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 suppler 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.

2. PROBLEM STATEMENT

The DC-arc welding machine is shown in Fig.1. An power input 220V-60Hz mains at a power of 5 kW is applied to the device. The arc welding machine should output an arc of 180A maximum at 25V DC. 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 constant during the welding process. Nowadays, there is the conventional inverter DC-arc welding machine. Its scheme is shown in Fig. 2. 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. The PI controller is designed. A PI controller will adjust the $e \rightarrow 0$ as $t \rightarrow \infty$. 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 easily creates and maintains. By adjusting the value of the hot-start volume, the DDWM can increase the initial setting current from 0A to 40A 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.

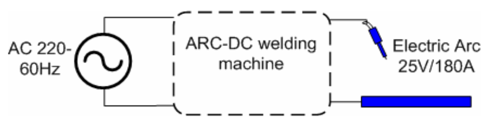

Fig.1 DC-arc welding machine

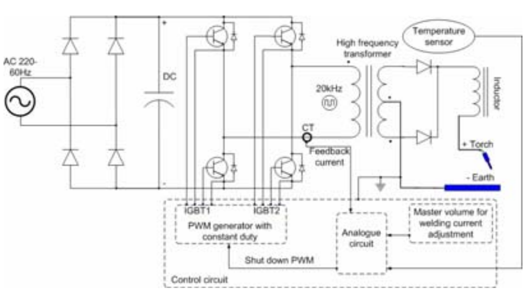

Fig. 2 Scheme of conventional inverter DC-arc welding machine

3. HARDWARE AND SOFTWARE IMPLEMENTATION

3.1 Hardware Design

Three main parts of DDWM were described on Fig. 3. First part is an inverter. It inverts the frequency of the power supply from 60Hz to 20kHz 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. Second part includes a ferrite transformer, a power rectifier and a filter of welding current. The ferrite transformer is shown in Photo 1. Third part is a control circuit which is shown in Photo 2. It includes an isolated 5V-DC and 12V-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.

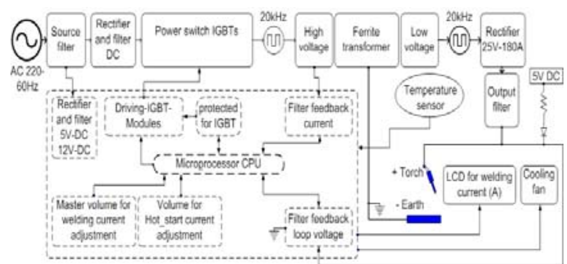

Fig. 3 Main part diagram of the DDWM

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

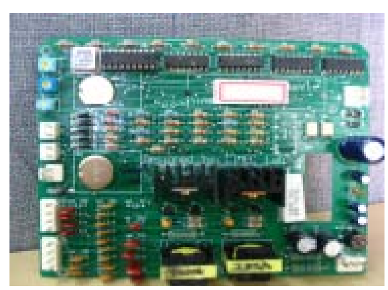

Photo. 2 Control circuit of the DDWM

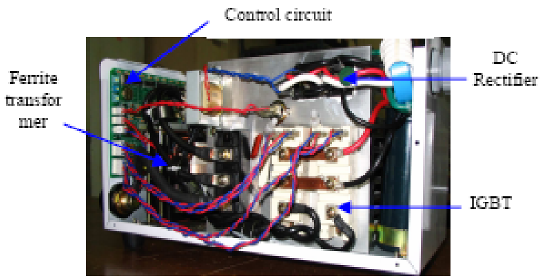

Photo. 3 Developed hardware of the DDWM

Photo. 4 Developed DDWM

3.2 Software Design

The flowcharts of the hot-start function, anti-stuck function and main function of DDWM, are shown in Fig. 6, 7 and 8 respectively.

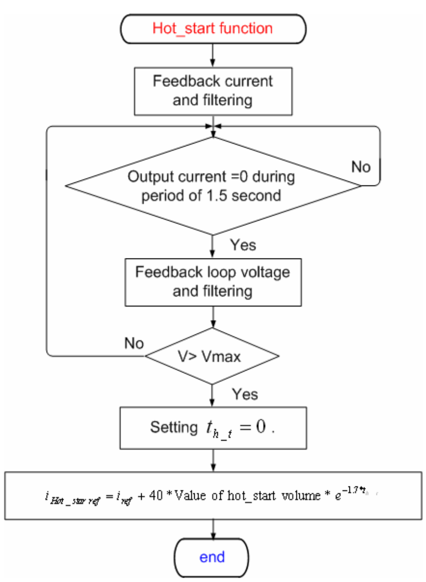

Fig. 6 Flowchart of the hot-start function

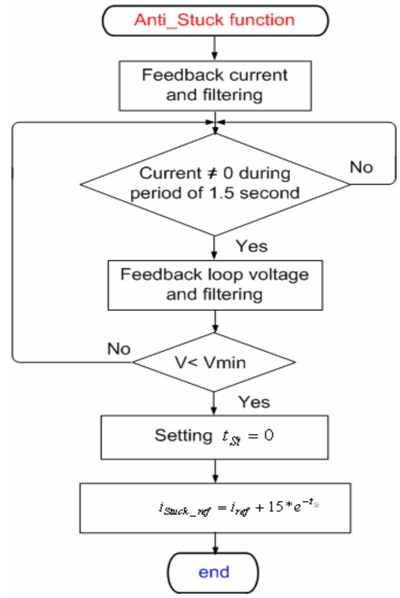

Fig. 7 Flowchart of the anti-stuck function

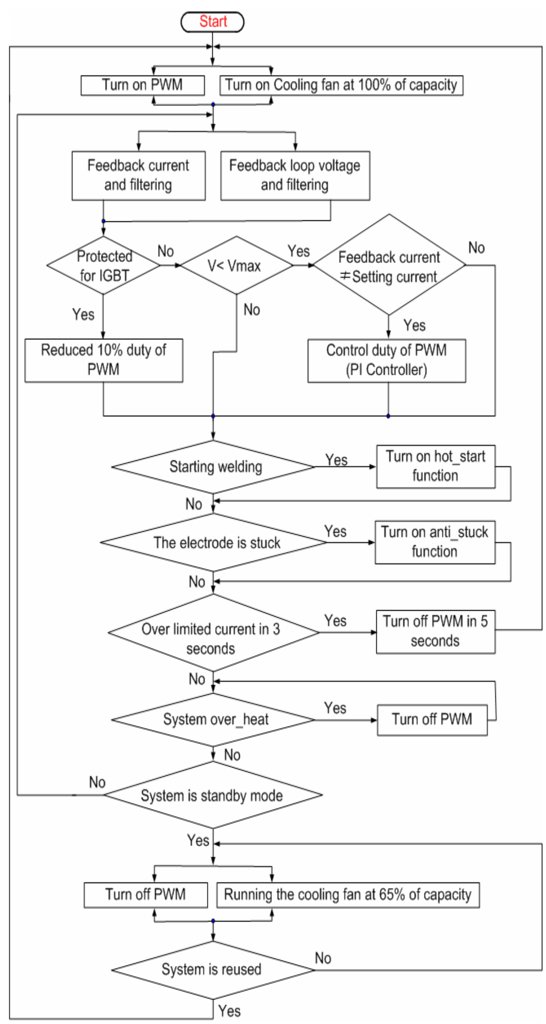

Fig. 8 Flowchart main function of DDWM

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 : The control signal,

i_{ref} : The reference welding current,

i_{out} : The output welding current of machine,

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

t_d : The sampling time,

T_i : The integral time of the controller,

K_p : The proportional gain of the controller,

K_I : The integral gain of the controller,

P_w : The duty of PWM (%), $0 \le P_w \le 0.4$, [4]

We have the relationship between P_w and i_{out} for the used IGBT module SKM75GB063D, as follows

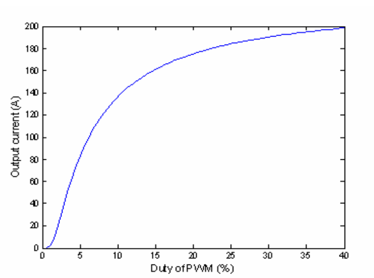

Fig. 9 Relationship between current output and duty cycle switching of IGBTs

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

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

$$u = 25.6P_w \quad (2)$$

$$P_w = \frac{1}{25.6}u \quad (3)$$

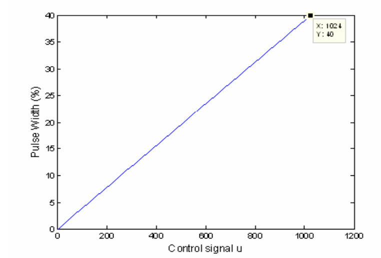

Fig. 10 relationship between duty cycle switching of IGBTs and control input

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

$$i_{out} = 225e^{(-128/u)} \quad (4)$$

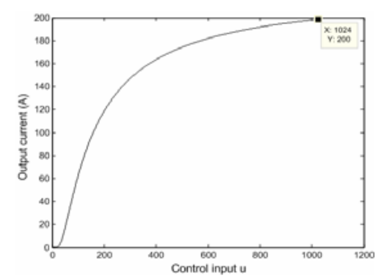

Fig. 11 Relationship between current output and control input

The error of the controller is given by:

$$e = i_{ref} - i_{out} \quad (5)$$

The proposed PI controller can be described as follows:

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

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

$$u_i = K_p e_i + D(i) \quad (7)$$

where

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

By trial and error method we find $K_p = 2.5$ and $K_I = 5$ the system is stable. It means the control error of the system $e \to 0$ as $t \to \infty$.

4. EXPERIMENTAL RESULTS

The output welding current is set at 140A. and the value of hot-start volume is set 60%. An electrode welding rod 3.6 mm diameter is used. The DDWM is durable test in one and haft hour. The setting current at first, the output welding current, the control signal and the tracking error are shown in Fig. 12, 13, 14 and 15 respectively. In Fig. 14, the output welding current rapidly achieves the setting current at first welding because of the hot-start function. The setting current using hot-start function is shown in Fig. 12. By hot-start function the electric arc is easily made and maintained at first. The current output tracks the setting welding current very well. The Fig. 14 showing the error is converted to zero when $t \ge 3$ seconds and remained around. The photo 5 shows the welding result of the DDWM.

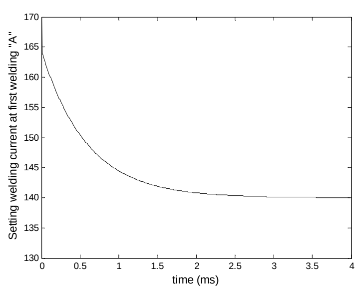

Fig. 12 Setting welding current at first welding

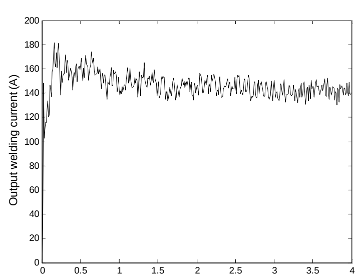

Fig. 13 Output welding current

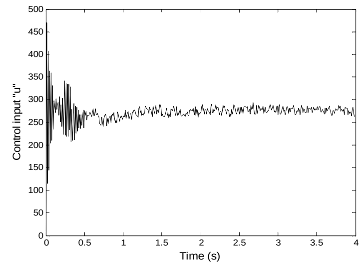

Fig. 14 Control signal u

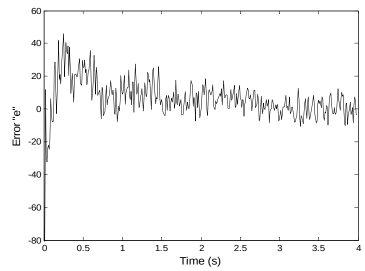

Fig. 15 Tracking error e

Photo. 5 Welding results of DDWM

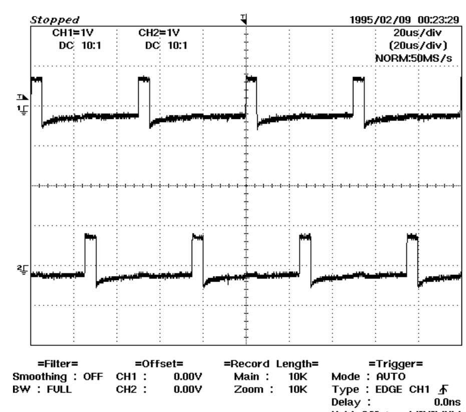

Photo. 6 PWM of the DDWM at $u \approx 260$

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 180A output welding current at 25V 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 and durable test.

REFERENCES

1. J.P. Charles, A. Khoury, A. Hoffmann, New Design Method for Controlling Power Stages Based on IGBT Switching Ferrite Transformers: Applied to an 8kW Small Size Light Weight Electric Welding Machine, Electronics, Circuits and Systems, 2000. ICECS 2000. The 7th IEEE International Conference on Volume 2, 17-20 Dec. 2000 pp. 802 - 804

2. Y. Takasaki, T. Sonoda, S. Fujii, Development of a portable spot-welding machine, Magnetics Conference, 2003. INTERMAG 2003. IEEE International April 2003 pp. HB-06

3. Maouad, Doctorare Thesis, Metz University, France, 1999, Caracterisation des degradations des IGBTs en milieu industriel, pp. 113-153.

4. Y.M. Chae, J.S. Gho, H.S. Mok, and , W.S. Shin, A new instantaneous output current control method for inverter arc welding machine, Power Electronics Specialists Conference, 1999. PESC 99. 30th Annual IEEE Volume 1 July 1999, pp. 521- 526.