International Journal of Pure and Applied Mathematics
Volume 117 No. 20 2017, 437-447
ISSN: 1311-8080 (printed version); ISSN: 1314-3395 (on-line version)
url: http://www.ijpam.eu
Special Issue

Hardware Implemented Arcing Period Evaluation Method for ARC Welding Monitoring Systems

[1]Jeenmo Yang, [2]Yongseok Sim and [3]Jeongtak Ryu
[1]School of Electronic and Electrical Engineering,
Daegu University,
Gyeongsan, South Korea.
jmyang@ daegu.ac.kr
[2]School of Electronic and Electrical Engineering,
Daegu University,
Gyeongsan, South Korea.
yssim@daegu.ac.kr
[3]School of Electronic and Electrical Engineering,
Daegu University,
Gyeongsan, South Korea.
jryu@daegu.ac.kr

Abstract

Welding monitoring systems measure welding parameters (current, voltage, and gas flow rate), and evaluate the quality of final welded beads in real time. In determining the quality of beads, finding the welding start and stop time for each bead is very important. This paper designed a circuit, which measures welding voltage and arc current, and proposed a hardwired evaluation method in determining arc start and stop time by using the measured welding voltage and arc current. The proposed method functions well under a retrial of welding setup, and evaluated accurate arc period. From experiments, the method evaluated at the accuracy of more than 90% for voltage and more than 98% for current against voltage and current command from the welding machine used.

1. Introduction

Gas metal arc welding (GMAW) is widely used in industry because of its high metal deposition rate, flexibility and low cost [1]. It is attractive for high-productivity manufacturing applications and is well suited to automatic or robotic welding [1, 2].

Welding, depending on processes, has profound impact on final product's quality, productivity, and production cost. The welding involves metal heating, melting, fusioning, clotting and cooling at a narrow area within a short time. Any malfunction in welding process can cause various defects in welded spots, and threaten the quality and durability of products because of the defects [3].

Due to developments in IT technology, there are increasing demands for systems capable of performing in real time in the industry [4-5]. Nowadays welding quality monitoring systems that predict defects on welded spots in real-time has become an essential tool for a working operator to decide the quality of welding process, rather than check the quality after finishing a whole welding process. In order to evaluate the quality of welded beads in real-time, the characteristics of the processed welding operation should be analyzed. To do the analysis, process parameters for welding processes should be determined. According to recent research results, the parameters are welding current, arc voltage, arc light, welding sound, welding temperature, and gas flow-rate[6-9].In previous studies, we analyzed welding conditions and beads qualities by using welding voltage and current signals processed in real time [10-13].

Figure 1(a) shows arc voltage and welding current waveform while welding, where field noise is filtered out. Setup time(T_s) is the time interval between wire feeding and arc generation after starting a welding process, depicted in Figure 2. During the setup time, welding machines generate a predefined high voltage, and the setup period varies between welding trials. Welding period (T_w) is the time interval between start and finish of welding, and arc period(T_a) is the time between arcing. In real-time monitoring systems, the accuracy of measured arc period(T_a),during which a bead is formed, is very important in measuring average arc voltage and welding current, which in turn are used in evaluating the quality of welding.

So far, the monitoring systems has been using two different methods in detecting arc start and stop time, used to measure arc period. One is using teaching commands(arc ON/OFF signal from teaching pendant of welding robot) which is transferred through triggering signal of external digital I/O of the robot. The other method is to generate a trigger signal when the arc current reaches a predefined level(I_{ref}), and is processed by software.

Teaching command method[14], shown in Figure 1(b) and denoted as 'case 1', produces welding period(T_w) that is not the arc period, because it uses arc ON/OFF command from teaching pendant. Since setup time(T_s) is included in the welding period(T_w), the arc period(T_a) is determined by extracting a predefined fixed setup-time value at the welding start/stop time of the welding period(T_w), in monitoring systems. Even when there was several retrial of arc setup, this method does not have any way of changing the setup time but to use the predefined fixed value.

Trigger signal method [14], also shown in Figure 1(b) and denoted as 'case 2', recognizes one bead as two beads when a protrude signal, shown in Figure 1(a), is presented in the welding current signal. To prevent this problem, monitoring systems use hold time (T_h) as shown in Figure 1(b), which is a preset time done by software, that should be maintained after a variation of welding current. In this method, when the time interval between beads is shorter than the hold time, the monitoring systems recognize the two beads as a one, as in Case 2 of Figure 1(b).

In welding monitoring systems that evaluate welding quality in real-time by measuring arc voltage, welding current, and gas flow rate, dependable estimation of arc start and stop time for each bead is the most important factor for an accurate evaluation of average arc voltage and welding current. This paper, therefore, designed a circuit for measuring arc voltage and welding current, which is to be used for real-time welding quality monitoring systems, and proposed a hard-wired evaluation method that measures arc period more accurately and reliably. Also it proposes an alternative to the problems of the above two methods, which is being used most widely in the industry.

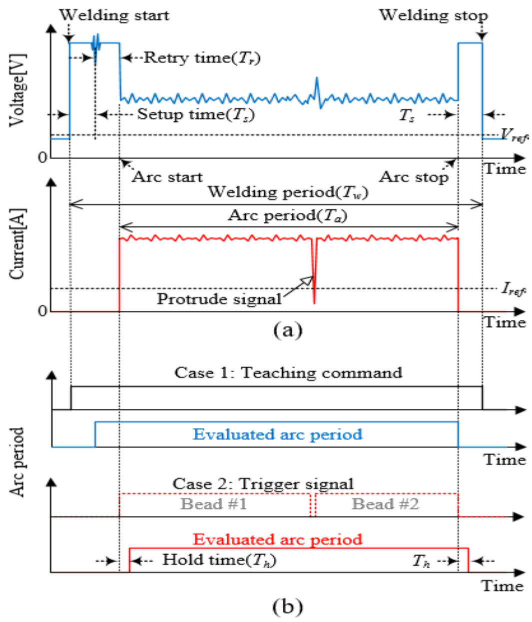

Figure1 (a): An arc Voltage and Welding Current of a Welding Process. (b) ARC Period Evaluation of Existing Methods.

2. ARC Period Detection Method

In order to initiate a welding, the welding machine generates a high voltage (usually 50~70[V]) during the setup time after initial resting status with low voltage, shown in Figure 2. The high voltage status is maintained until the welding rod touches the parent material. The arc voltage, the voltage after the touching, is sustained according to the arc voltage setting of the machine (usually 10~30[V]), during normal welding process. The welding current is the electrical current that flows from the rod to the parent material while arcing, and it is usually in the range of 80[A] to 500[A].

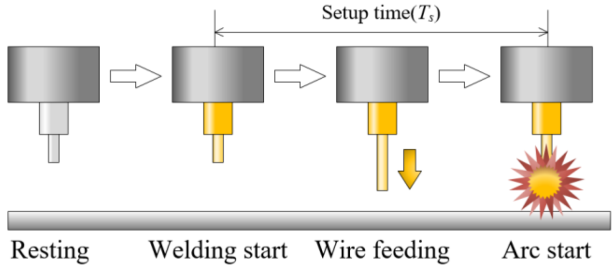

Figure 2: Arc Start with Setup Time

For arc period detection, the teaching command method uses arc voltage waveform where teaching command is closely related. The trigger signal method uses welding current information to determine the arc period. In this paper, however, arc voltage and welding current information are used in complementary manner to improve the robustness of arc period evaluation.

Figure 3 shows the block diagram of the proposed detection method, where Arcing Detection Circuit is included besides usual signal conditioning circuit for arc voltage and welding current measurement. The function of Arcing Detection Circuit is to implement the state diagram of Figure 4, and help to increase the robustness of arc period evaluation.

Arcing Detection Circuit generates arc period signal(T_a), using the two welding parameter(arc voltage and welding current) and $\bar{s}$ signal, which is used as an input to Switching Circuit(NPN transistor). The arc period T_a is logical 'OR' of the two comparator outputs, which are the result of comparison V_{OUT} with V_{ref} and I_{OUT} with I_{ref}. $\bar{s}$ signal is used to let V_{OUT} to go zero forcibly when I_{OUT} is less than I_{ref}, this can be happened during setup time(T_s) and retry time(T_r) as well as initial start-up period. When $\bar{S}=1\,(\text{high})$, Switching Circuit pulls down V_{OUT} to go zero. When $\bar{S}=0\,(\text{low})$, Switching Circuit becomes OFF state and the input signal is passed over to the output, meaning the output of the previous stage becomes V_{OUT}. While arcing action continues, V_{OUT} and I_{OUT} must have values that are larger than the reference values(V_{ref} and I_{ref}), and the output of 'OR' gate(T_a signal) should go to logical '1' state. The logical 'OR' ensures to produce proper T_a signal even when one of the arcing signal(V_{OUT} and I_{OUT}) falls below the reference signal(V_{ref} and I_{ref}) by accident, which can be happen due to noises in the floor.

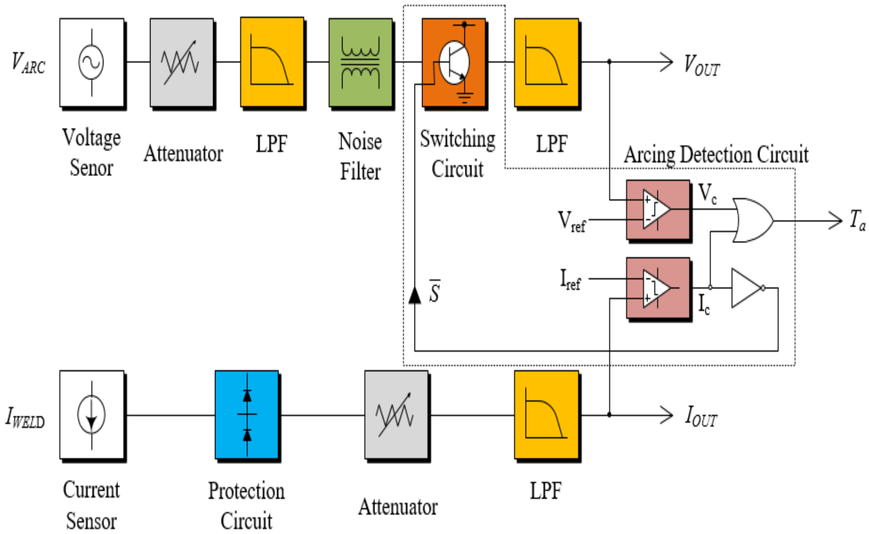

Figure 3: Proposed Signal Processing Circuit for Arc Period Detection.

Figure 4 shows state transition diagram of Arc Detection Circuit, where the circuit operates between two states (Idling and Welding state). The detection circuit starts with Idling state, and remains the state while welding current is low(I_C=0). The detection circuit goes to Welding state when welding current goes high(I_C=1). In Welding state, two abnormal conditions might happen due to field noise in the working place, V_C=0 while I_C=1 and I_C=0 whileV_C=1. But, since these two conditions are kind of happening that cannot occur in normal condition, the state should not be changed, remains in Welding state. This counterplan in Arc Detection Circuit increases the robustness of arc period detection algorithm.

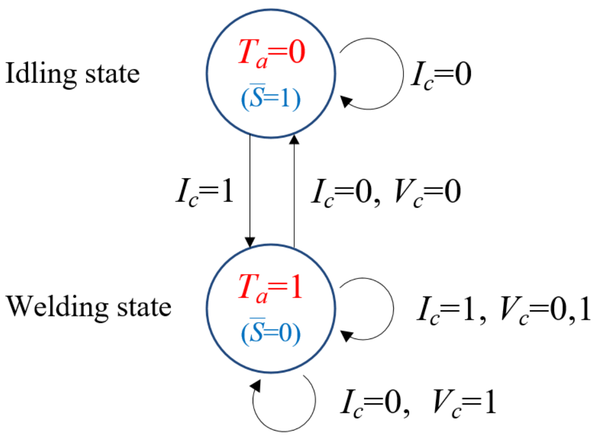

Figure 4: State Transition of Arc Detection Circuit

3. Experiments

In order to evaluate the operations of the proposed arc period detection method, the circuit shown in Figure 3 is implemented and tested for a real-world welding signal. The circuit operates at the rated voltage of DC5[V], and it can handle maximum arc voltage of 100 V_{rms} and welding current of 500 A_{rms}.

Arc voltage(V_{ARC}) and welding current(I_{WELD}) signal, generated from voltage and current sensors of welding machine, are scaled downappropriately and have voltages between 0~5V at the outputs of the low-pass filters(LPF). The filters remove welding noise presented in V_{ARC} and I_{WELD} signal, the cutoff frequency of each filter is 25 [Hz]. The comparators are implemented using OPA2244, and Switching Circuitis using NSS60201LT1G (NPN transistor) due to its low saturation voltage($V_{CE(sat)}$).

Figure5 shows arc voltage(V_{ARC}) and welding current(I_{WELD}) signal from P-350 welding machine of DAIHEN, which is in a welding robot MH-6 of YASKWA. Thesignals are oscilloscope outputs when welding is done for two beads at atime interval of 1 second, under the welding setup condition of arc voltage 18[V] and welding current 180[A]. From the signal, one can see that there was a welding retrial after a setup time in the second bead.

Figure 6(a) shows arc voltage(V_{MON}) and welding current(I_{MON}) which are mathematically scaled-up in monitoring system to compensate thescaled-down done in the attenuators of the proposed detection circuit. Figure 6(b) shows the arc period signal(T_a) when the above signals are processed by using Teaching Command method, discussed in Section I. In the figure, welding period T_w, which stems from ON/OFF teaching command of welding robot, and arc period $T_a$for each bead are shown. The arc period signal T_a is evaluated by extracting a predefinedsetup time(200 [msec]) from the welding period signal T_w.Since there is a retrial in the second bead, the time spent for the second setup is about two times that of the predefined setup time(200 msec). This means that the arc period evaluated by this method becomesnot accurate at all. As a result, evaluated welding parameters such as average arc voltage, current, and gas flow-rate become unreliable.

Figure 7(a) shows arc voltage(V_{OUT}) and welding current(I_{OUT}) when the arc voltage(V_{ARC}) and welding current(I_{WELD}) signal of Figure 5 is process by using the proposed method, shown in Figure 3. The resulting arc period $T_a$signal detected by the method is shown in Figure 7(b). Every setup time shown in Figure 5 is omitted in the output signal(V_{OUT},I_{OUT}, andT_a). The waveform of T_a signal shows that the proposed circuit detects arc period properly even when there was one retrial during the setup of second bead.

To test the robustness of the proposed method, an artificial protrude is fabricated inI_{WELD}signal of Figure 5, shown in Figure 8, and the signal is fed into SPICE simulation of the proposed circuit shown in Figure 3. Even for this case, the evaluated arc period signal is all the same.

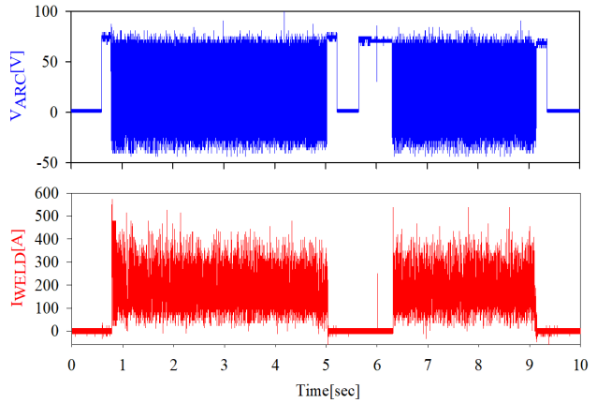

Figure 5: Arc Voltage and Weldingcurrent Waveform used for the Experiments

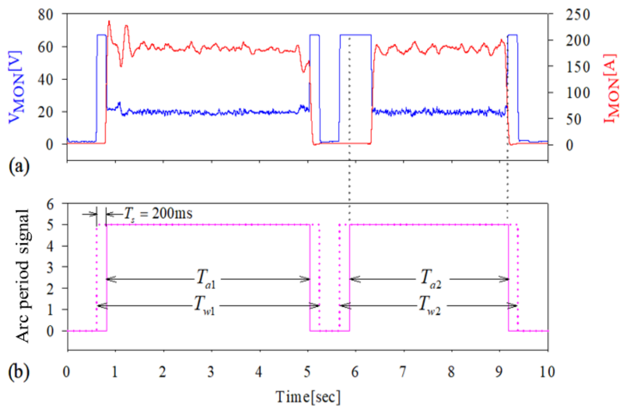

Figure 6: Arc Period Evaluation using Teaching Command Method. (a) arc Voltage and Welding current (b) Evaluated arc Period

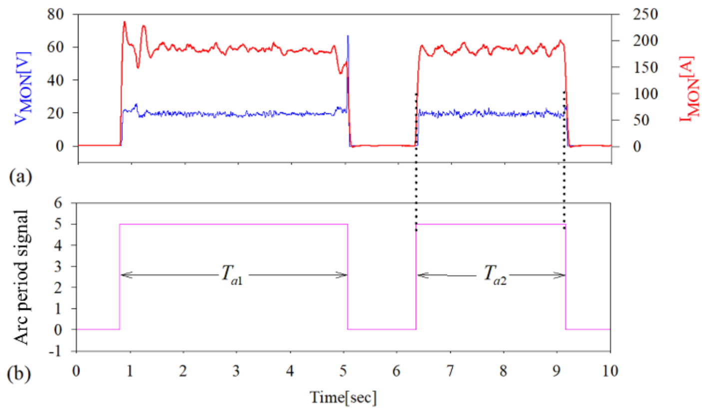

Figure 7: Arc Period Evaluation using Method.(a) arc Voltage and Welding Current (b) Evaluated arc Period.

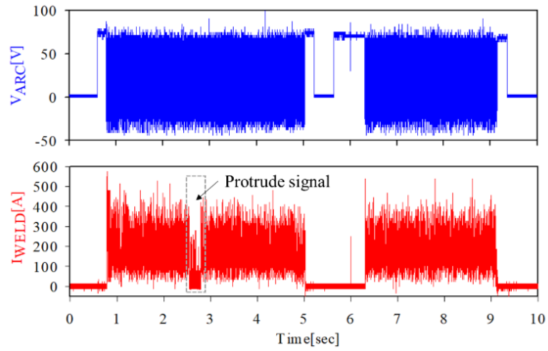

Figure 8: Arc Voltage and Welding Current Waveform used for Simulations

Table 1: Comparisons of Evaluated Average Voltage and Current

Parameter / Method	Average output	
	Voltage[V] (error)	Current[A] (error)
Teaching Command	26.6 (47.8%)	155.2 (13.8%)
Proposed	19.5 (8.30%)	181.9 (1.05%)

The average voltage and current forarc period $T_{a2}$of each evaluation method, Teaching Command and Proposed method, is shown in Table 1.The welding machine setup value was 18 [V] and 180 [A].The percent error is calculated from Equation 1.

$$\text{error} = \frac{\text{welder input} - \text{average output}}{\text{welder input}} \times 100\ [\%] \quad (1)$$

In Teaching Command method, arc period having several welding retrials tend to have more error in average voltage and currentevaluation. This tendency becomes more severe when the arc period is small. The table shows that any 'Good' welded bead might be classified as 'Not Good' if not a proper evaluation method is used. For the proposed method, however, the error is about 8.3% (voltage) and 1.05%(current), which is accurate enough for welding workers to decide the welding quality quite dependably.

4. Conclusions

Welding monitoring systemsare widely used in welding industry to evaluate the quality of final welded beads in real time. To evaluate the welding quality reliably, accurate measurement of arc period is very important. This paper proposesa simple hard-wired accurate method for the arc period measurement as well as circuits for signal conditioning of arc voltage and current. From experiments, the arc start and stop signal(T_a) was shown to be accurate and error-free even under anextra welding retrial and severe noise condition.The proposed technique shows91%(voltage) and 99%(current) accuracy when average voltage and current are evaluated using the measured arc period.This method can be implemented using cheap hardware parts, other than software implementing complex algorithm or teaching command requiring extra hardware modulesfor interfacing. The proposed method can be used in real-time monitoring systems which require fast and accurate parameter measurements.

Reference

[1] Adolfsson S., Bahrami A., Bolmsjö G., Claesson I., On-line quality monitoring in short-circuit gas metal arc welding, Welding Journal-New York (1999), 78, 59.

[2] Wu C.S., Jia C.B., Statistical characteristic for detecting weld penetration defects in gas-metal arc welding, Proc. Inst. Mech. Eng. B: J. Eng. Manufac., 2006.

[3] Hwang D.S., Cho M.H., Development and Application of Real-time weld Quality Monitoring System, Journal of Korean Welding and Joining Society 30 (1) (2012), 44-50.

[4] Kristine Bernadette Barrameda, Sang Hoon Lee, Su-Yeon Kim, IoT and Ontology-Based Modeling for Real-Time Rainfall and Water Level Monitoring and Warning System, Journal of Industrial Information Technology and Application 1 (1) (2017), 6-11.

[5] Myoung-Kyu Sohn, Sang-Heon Lee, Byunghun Hwang, Hyunduk Kim, Hyunsoek Cho, Real-Time Hand Detection from a Single Depth Image by Per-Pixel Classification, Journal of Industrial InformationTechnology and Application 1 (2) (2017), 19-23.

[6] Adam G., Siewert T.A., Sensing of GMAW droplet transfer modes, Welding Journal 70 (4) (1990), 90-99.

[7] Wang W., Liu S., Jones J.E., Flux cored arc welding: Arc signals processing and metal transfer characterization, Journal of Welding 74 (11) (1995), 369-377.

[8] Wu C.S., Gao J.Q., Hu J.K., Real-time sensing and monitoring in robotic gas metal arc welding, Measurement Science and Technology 18 (1) (2007), 303-310.

[9] Moonyoung Chung, Shunghoon Ko, Hyeongsoon Moon, Jinwoo Choi, A Study on Measuring System of submerged Arc welding for Panel Butt Joint in Shipyard, 13th International Conference on Control, Automation and Systems (2013), 1623-1627.

[10] Donghwoon Kwon, Yongseok Sim, Jeongtak Ryu, Development of real-time GMAW welding monitoring system using welding voltage and current signal processing, Journal of Industrial Information Technology and Application (in press) (2013).

[11] Ryu J.T., A study on the effect of welding wire diameter on the welding quality detection, Journal of the Korea Industrial

Information Systems Research (in Korean) 21 (2) (2016), 295-44.

[12] Hong W.H., Ryu J.T., A study on the welding current and voltage signal processing method for the quality evaluation of robotic GMAW, Journal of the Korea Industrial Information Systems Research (in Korean) 19 (6) (2014) 25-31.

[13] Hong W.H., Sim Y.S., Ryu J.T., Moon B.H., Park S.H., The Welding Voltage and Current Error Detection Using a Moving Average Filter, The International Conference on Industrial Information Systems, Chiang Mai, Thailand (2014), 63-65.

[14] Welbee Inverter P-350 User's Manual.