Development of a Blowhole Detection System for Robotic MAG Welding*

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Multi-layered pulse MAG welding by robots is used for large structures. The sensing technology for the detection of defects is crucial towards improving the productivity and quality of robotic welding. The authors have developed a system that detects welding defects (blowholes) by utilizing welding current and voltage waveform data. By processing the measurement data, it is possible to detect welding defects with a probability of 95% or better. The developed defect detection system has been introduced in the company's robotic welding systems.

Key Words: Robot welding, Pulse welding, Defect detection, Welding current and voltage waveform

1. Introduction

Automatic multi-layered MAG welding is used for large structures1). To perform proper welding with lower spatter, pulse MAG welding may be used2). Because multi-layered welds are formed successively in automatic robotic welding, blowholes caused by poor shielding or defects due to contamination during the welding process will lead to a significant loss of time, since inspections and repairs have to be made after the completion of all welding operations.

As a method of detecting welding defects during automatic robotic welding, Iwai3) and Hamamoto et al4) show a method of photographing weld parts with cameras for image processing. Nishimura et al5) show a method of comparing current / voltage waveforms with reference waveforms during welding. In the former case, since a camera is attached to the tip of the torch, interference and welding direction problems are occurred. In the latter case, because the method needs comparing with a reference waveform using a threshold, it is difficult to apply to a pulse MAG welding which described later.

Over detection occur in the existing defect detection system. Therefore, it is difficult to apply to the multi layered welding for the robot to stop frequently. The reduction of repair time was targeted in developing a system that can detect blowholes during the layered welding process.

2. Blowhole detection method

2.1 Pulse MAG welding

Figure 1 shows waveforms of I-V characteristics of a pulse MAG welding power supply unit for proper welding condition. In pulse MAG welding, the peak and base values appear with a certain cyclicity in the current and voltage waveforms. The peaks and bases in these waveforms are synchronized with each other and, if the welding was performed properly, the peak and base current and voltage values appear periodically. For this reason, if the current and/or voltage deviate from the proper pattern due to a disturbance in the welding for some reason, as shown in Fig. 2, it is possible to detect them as abnormal values.

![Fig.1 Current/Voltage waveforms in pulse MAG welding (Proper values)](image1)

![Fig.2 Current/Voltage waveforms in pulse MAG welding (Abnormal values)](image2)

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2.2 Frequency distribution of the current and voltage

Since the current and voltage change synchronously on a pulse MAG power supply unit, the frequency distribution of the current and voltage was checked first. Figure 3 and 4 show the frequency distribution of the current, voltage and frequency on the X, Y and Z axes, respectively. Both welding conditions are welding current 220A, arc voltage 26V, travel speed 30cm/min. Figure 3 shows the frequency distribution at no wind and Figure 4 shows the frequency distribution at 4m/s wind, both were measured by condition of measuring time 1 second and measuring rate 10 kHz. Wind blows from the rear side of the welding direction and wind speed is measured at the center of the weld line.

It can be seen that the peak and base values of the current and voltage are concentrated at the pulses in proper welding. On the other hand, frequency other than the base and peak increase because of disturbed wave form when the blowhole are generated. Therefore, current and voltage distribution data of a certain cyclicity are analyzed statistically and the parameters are determined to detect blowholes.

2.3 Blowhole detection algorithm

2.3.1 Area division of current/voltage distribution charts

Figure 5 shows the two dimensional current and voltage distribution chart. It is possible to draw a straight line \( L \) through the most frequently observed values for the bases \( (M_b) \) and peaks \( (M_p) \) of the current and voltage, respectively. It is also possible to draw straight line \( L_s \) which is the same slope as \( L \) and parallel moved from \( L \) to the voltage axis direction \( V_2 (=V_4) \). After setting \( V_1 \) to the voltage axis direction and \( I_1, I_2 \) to the current axis direction from \( M_b \), \( V_3, I_3 \), and \( I_4 \) can be set from \( M_p \) similar to \( M_b \). By using the \( L_s \) and the setting value \( I_1~I_4, V_1~V_4 \), the current and voltage distribution charts can be divided into six areas as shown in Figure 5. Area division is carried out at every distribution of current voltage at a certain cycle.

2.3.2 Calculation of characteristic quantities

In development method, the following 9 characteristic quantities were determined for the purpose of blowhole detection. Each characteristic quantity was calculated to determine if it exceeded the threshold and the presence of blowholes was determined by evaluating them as a whole.

1. Distribution in the base area
2. Distribution in the rising/falling area
3. Distribution in the peak area
4. Frequency in the peak area
5. Frequency in the short-circuit area on the base side
6. Frequency in the short-circuit area in rising/falling
7. Frequency in the short-circuit area on the peak side
8. The highest frequency in the peak area
9. Standard deviation of the power spectrum of current waveform FFT
3. Blowhole detection system

3.1 System configuration

Figure 6 shows the configuration of the blowhole detection system. The rate of measurement is 10 kHz and the system supports single and tandem welding. If a judgment was made that there is a defect, signals to stop the robot and indicate a warning will be sent to the control panel of the welding robot. This system makes it possible to detect blowholes early in the welding process and reduce the time required for repair.

3.2 Blowhole detection process

The process for detecting blowholes consists generally of the three processes of preparation, calculation of characteristic quantities, and judgment of blowhole presence as shown in Figure 7.

In the preparation process, current and voltage data obtained from the data logger are converted into CSV format. After eliminating data in the periods 5 seconds after the start and 10 seconds before the end of welding, data are grouped at intervals of one second. Next, the characteristic quantities are calculated for the obtained data every second. After generating frequency distribution charts for the current and voltage, the charts are divided into six areas using straight lines that pass through the highest peak and base values and settings. The selected 9 characteristic quantities are calculated for the six areas and recorded in a data file on the computer. These processes are repeated for the entire length of the weld beads.

Finally, the presence of blowholes is determined. The judgment is made by checking if each characteristic quantity calculated every second exceeds the threshold. If there were a certain number of characteristic quantities exceeding the thresholds and such a condition lasted more than a certain time, it is concluded that there are blowholes.

It is also possible to add a weight to each characteristic quantity used for judgment. Since the thresholds for characteristic quantities need to be adjusted to the current, they are modified automatically according to the cyclic frequency of welding current waveform. Should a conclusion be made that there are blowholes, the welding robot stops before the next pass. At the same time, the warning lamp up to inform the operator that blowholes have been detected. The current and voltage frequency distributions are displayed on the monitor screen in real-time during welding. The points at which blowholes are considered present are also displayed in such a way that the actual points on the weld bead are identified as shown in Figure 8.
3.3 Blowhole detection effect

In order to confirm the effect of developed blowhole detection system, welding experiments were conducted under the condition to generate blowholes intentionally. The experiments simulated shielding gas scattered by the wind.

Welding experiments with varying wind speeds under the conditions shown in Table 1 were conducted to investigate the occurrence of blowholes. After welding, outside and inside of weld bead were visually inspected to confirm presence of blowholes. Figure 9 shows inside of weld bead. There was no blowhole when the wind speed was 1 m/s or less, and blowholes occurred when the wind speed was 3 m/s or more. At a wind speed of 2 m/s, there were both cases where blowholes occurred and cases where blowholes were not generated.

Figure 10 shows the example of judgement result of blowhole detection by using characteristic quantities under the welding conditions of Table 2. It can be seen that the points at which blowholes show good agreement with actual blowhole positions.

Detection rate of blowholes which are generated under various welding condition is more than 95%. Developed detection system can be applied to multi-layered fillet welding and groove welding as shown in Figure 11.

| No. | Welding current | Arc voltage | Traveling speed | Wind speed | Result |
|-----|----------------|-------------|-----------------|------------|--------|
| 1   | 220A           | 26V         | 30cm/min        | 0m/s       | -      |
| 2   |                |             |                 | 1m/s       | -      |
| 3   |                |             |                 | 2m/s       | -      |
| 4   |                |             |                 | 2m/s       | Blowhole |
| 5   |                |             |                 | 3m/s       | Blowhole |
| 6   |                |             |                 | 4m/s       | Blowhole |
| 7   |                |             |                 | 5m/s       | Blowhole |

Table 2 Welding experiment condition

- **Welding current**: 300A
- **Arc voltage**: 30V
- **Travel speed**: 30cm/min
- **Shielding gas**: Ar80%-CO220%
- **Gas flow rate**: 30l/min
- **Wind speed**: 2m/s

![Fig. 9 Confirmation result of blowhole inside weld bead](image)

![Fig. 10 Judgement result of blowhole detection](image)

![Fig. 11 Types of welding parts to apply the developed system](image)
4. Conclusions

A system has been developed to detect blowholes in robotic MAG layered welding using current and voltage waveforms during the welding process. It has been found that the presence of blowholes can be determined by dividing the current/voltage distribution chart of pulse MAG welding into six areas and calculating characteristic quantities in each area. In an experiment to generate blowholes with a cross-wind, a defect detecting rate of 95% or better was achieved.

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