Developments of real-time monitoring method of welding†

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KEY WORDS: (Digital signal analysis) (Arc voltage) (Welding current) (In-process-monitoring) (Gas shield arc welding)

1. Introduction

Nowadays, demands for the welding process reliability and on-line welding quality controllability and prediction are higher than ever before. For this reason, it has become more and more important to develop efficient methods for evaluating welding quality. Advances in sensor and computer-related techniques have allowed a wide range of computer-based sensing techniques to be brought to use in monitoring welding quality, including the behavior of the arc column, the molten pool and droplet transfer [1-6]. Additionally, traditional nondestructive testing methods are also currently widely used for the credible examination of weld beads. However, methods such as those mentioned above have the disadvantage of high cost, low efficiency and cannot be used for in-situ detection.

The present paper deals with the development of a real-time monitoring equipment to evaluate welding quality in gas shielded arc welding by electrical sensing. Welding current and arc voltage acquired easily from the welding process. And the hardware used for the proposed system is relatively simple, which should contribute to increasing the efficiency and decreasing costs. A novel algorithm is presented to analyze data with methods of signal processing and computer statistics in real time. On the basis of this algorithm, a new piece of equipment is developed.

2. A developed algorithm

Example scatter plots of transformed data calculated from blocks of 0.5 second sampled voltage and current data, as shown in **Fig. 1**. The data shown in Fig.1 are obtained by normalizing the reference data. It can be seen that the data from a reference weld Fig.1(a) are located near the center. However, the distributions of data shown in Fig.1(b) deviate from the point of origin and incline to the right.

The analysis method of the proposed system is based on Mahalanobis distance (MD). The calculation of MD is described in the field of statistics. To elucidate MD, a conceptual diagram of MD is shown in **Fig. 2**. Points A and B are located on the same circle and the Euclidean distances of two points are equal. However, point B is far from the data distribution. Therefore, the shape of the data is considered; this is where MD shows superiority to the Euclidean distance. With this concept, a set of points pitched at an equal distance is turning circles into ellipses. Consequently, MD of point A is small and point B is large. For this study, how large the compared values of MD are is an indicator of whether a welding fault has occurred, with a large distance indicating a fault.

Figure 3 shows distributions of MD calculated from Fig.1(a) and (b). According to quality control, the threshold is commonly set to $\mu \pm 3\sigma$ (μ:mean, σ :standard deviation). That is to say, if results are within the range of $\mu \pm 3\sigma$, the results are good. If not, the results are bad. MD values are always greater than zero. In this study, MD locating at the range from zero to $\mu+3\sigma$ of the reference MD (the dotted line shown in Fig. 3) are defined as “good”. Conversely, data beyond the range are considered “bad”. Consequently, MD on the left-hand side of the line is good, and on the right-hand side is bad. It is clear, then, that welding quality can be quantified as per the formula shown below,

$$\text{Quality } (\%) = (n/N)^* \, 100$$

Where n is the number of data on the left-hand side of the dotted line, and N is the total number of the data obtained in one second. (As described below, in this study, the total number of data accumulated in one second is about 4000.)

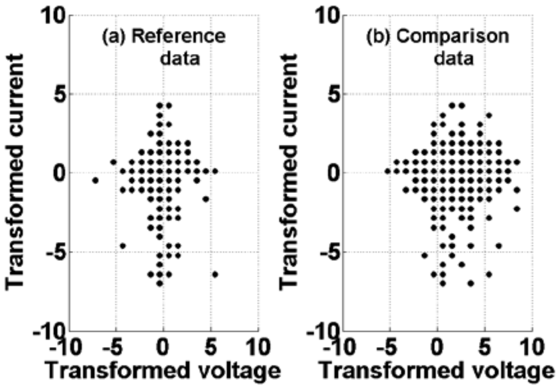

Fig. 1 Example scatter plots of transformed data calculated from blocks of 0.5 second sampled voltage and current data (a) reference and (b) comparison.

† Received on 30 September 2010
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Transactions of JWRI is published by Joining and Welding Research Institute, Osaka University, Ibaraki, Osaka 567-0047, Japan

According to the theory above, a new piece of equipment has been developed. The developed system has the capability to detect and quantify welding quality in real time.

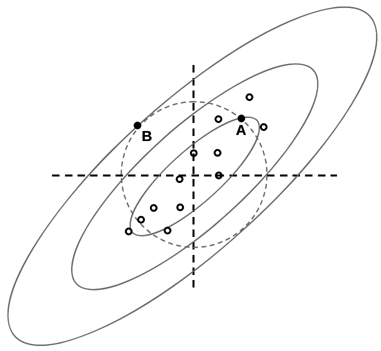

Fig. 2 Conceptual diagram of Mahalanobis distance.

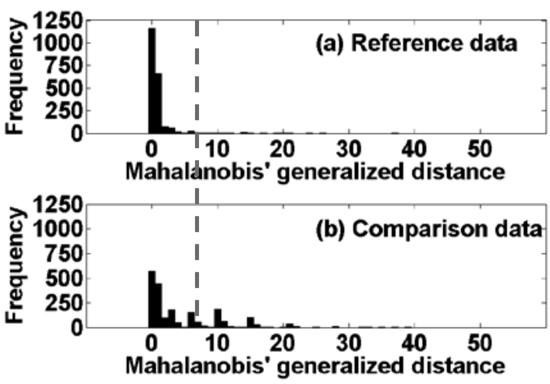

Fig. 3 Distributions of Mahalanobis distance calculated from Fig.1 (a) and (b).

3. Results and discussion

In order to verify the usefulness and application of the developed algorithm, TIG welding experiment was performed. The welding conditions are given in **Table 1**.The welding torch was fixed on a fixture, which made the torch stationary. The specimen was fixed on a trolley controlled by a speed controller that was able to change the welding speed artificially. In this case, the stability of welding was guaranteed. The test weld was made diagonally across the butt line as shown in **Fig. 4**.

Figure 5 shows the average voltage and quality for the test weld. Considering arc voltage and welding current are unstable after the welding start, the reference was selected 4.5 to 5 second data. The sampling rate was about 4000. Quality was calculated every 0.5 second from 5.5 second after start.

Table 1 TIG welding conditions

Specimen dimensions (SUS304)	**0mm×200mm×3mr**
Welding current	**100A**
Welding speed	**5mm/sec**
Arc length	**2mm**
Cathode angle	**60°**
Shielding gas flow rate(Ar)	**0.25L/sec**
Back shielding gas flow rate (Ar)	**0.125L/sec**

The change of the average voltage is not confirmed, but the welding quality changes on the butt line. This developed algorithm is considered to be of benefit for the fault that is difficult to detect by monitoring only average voltage.

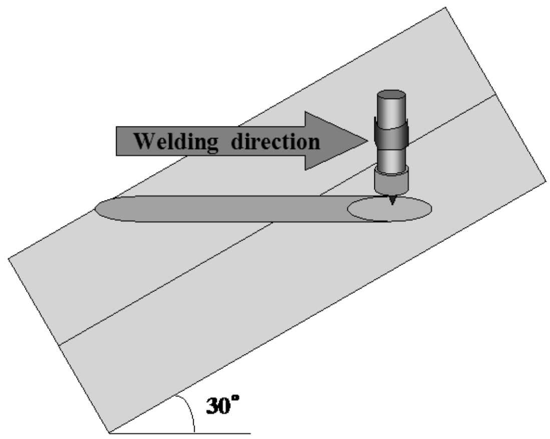

Fig. 4 Test arrangement with weld diagonally crossing the butt line.

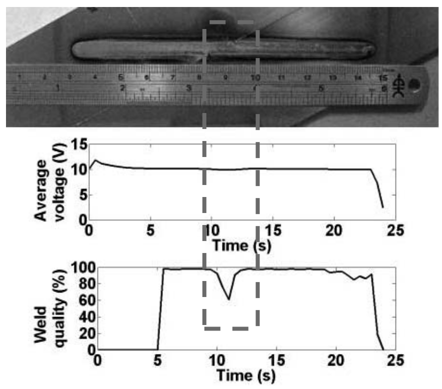

Fig. 5 The weld average voltage and quality for test weld.

4. Conclusions

This study investigated the application of a newly developed piece of equipment for gas shield arc welding fault detection. MD was used to intuitively quantify and qualify welding quality in real time. The method had been developed to be of practical for real time computation and to be applicable to quality monitoring and fault detection in an industrial production environment.

The proposed algorithm employed the concepts of MD to describe a good quality welding to be used as a reference with which to control other welding. First, a reference was defined; from this, MD, mean μ and standard deviation σ values were calculated. Then, values of MD obtained from the reference welding current and arc voltage data. And values located in the range from zero to $\mu+3\sigma$ of the reference MD were regarded as good. Last, the number of values of MD obtained from comparison welds found to belong to the reference set was calculated, in order to quantify welding quality.

TIG welding experiment was conducted by welding diagonally crossing the butt line in order to verify the sensitivity and feasibility of the algorithm. The results demonstrated that this algorithm was capable of quantifying and qualifying the welding faults.

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