

Digitalized Evaluation of Welder Skill by using Cyclogram Characteristics

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Abstract. This paper proposes a new evaluation method for welder skill in Gas Metal Arc Welding (GMAW) process in term of studying the natural hand-movement that affect the signal processing. Weld quality of GMAW generally depends on welder skill to maintain the uniform of hand movement. Therefore, the welder skill is considered as the critical point to maintain the weld quality. Hence, welding current and voltage signal could be an alternative way for monitoring and assessing the skill of welder based on the signal variation of the welding process. This research defines in two stages, first is the physical-simulation using robot welding Fanuc Arc Mate 100iB and monitoring the signal using Cyclogram technique. Second is comparing the Cyclogram characteristic of robot welding and manual welder. By using the data acquired, the characteristic of Cyclogram was analyzed by varying Torch angle change (W1) and Torch-height change (W2) to investigate the signal processing. Furthermore, the data of current and voltage were generated as a quantitative method to determine the size of Cyclogram. The results show that the method capable of differentiating the two beginner welders compare to the robot welding performance based area of Cyclogram characteristic. Finally, the Cyclogram could be a novel tool for monitoring and evaluating the welder skill with high sensitivity to detect hand motion.

1 Introduction

The Gas metal arc welding (GMAW) process is widely used in the industrial welding process. Moreover, the fabrication industry such as pressure vessel and shipbuilding are required very high weld quality because it relates to product safety. Most of GMAW process is done by the manual welder. In Thailand, the welder qualification is determined by following the international standard AWS D1.1 [1] or ASME section IX [2]. For qualifications of the welder skill, many sample tests were collected and then classified the possible imperfections in the welds. The actual evaluation of tests specimens can be examined by either destructive test or non-destructive test. This method was used to monitor and evaluate the welder skill before they were employed for fabrication of the critical component. However, the method to qualify the welder skill is commonly used after welds are completed and it is time-consuming to obtain the welder qualifications results. Furthermore, nowadays the demand to qualify the welder skill like training for novice welder requires faster evaluation method. The evaluation method consists of analyzing and classifying the welder skill.

Implementing signal processing is an alternative way of monitoring the welding skill within a short period. The signal processing method works by tracking the

variation of welding current and voltage recorded in the welding process [3]. Because of the welding power source gives the dynamic changes in current and voltage during the welding process; hence these variations could reflect the welder skill. Due to these variation happens so randomly and rapid so need a tool to examine this situation. Contact to work distance change (CTWD), and inconsistency welding speed have significant impact on the change of welding current and voltage. It can be concluded that welding current and voltage depends on the ability of the welder to maintain a steady hand during welding. Increasing CTWD produces a longer electrode extension, and it also increases electrical resistance which means the welding current will decrease. Therefore, this research has designed a data acquisition system, with a high sampling rate of 5000 per second. In other words, this sampling rate sufficient to record the variations of current and voltage during welder performance in their welding test. Furthermore, arc data also provide variety option for a researcher to monitor the quality of weld by using Statistical process control (SPC) [4]. The signal current and voltage also could become a tool for feedback to the welder to adjust hand-movement during welding in real time by using mean and standard deviation, and control chart [5]. This is the possible way to help the trainee welder to correct their travel angle, arc length, and travel speed properly.

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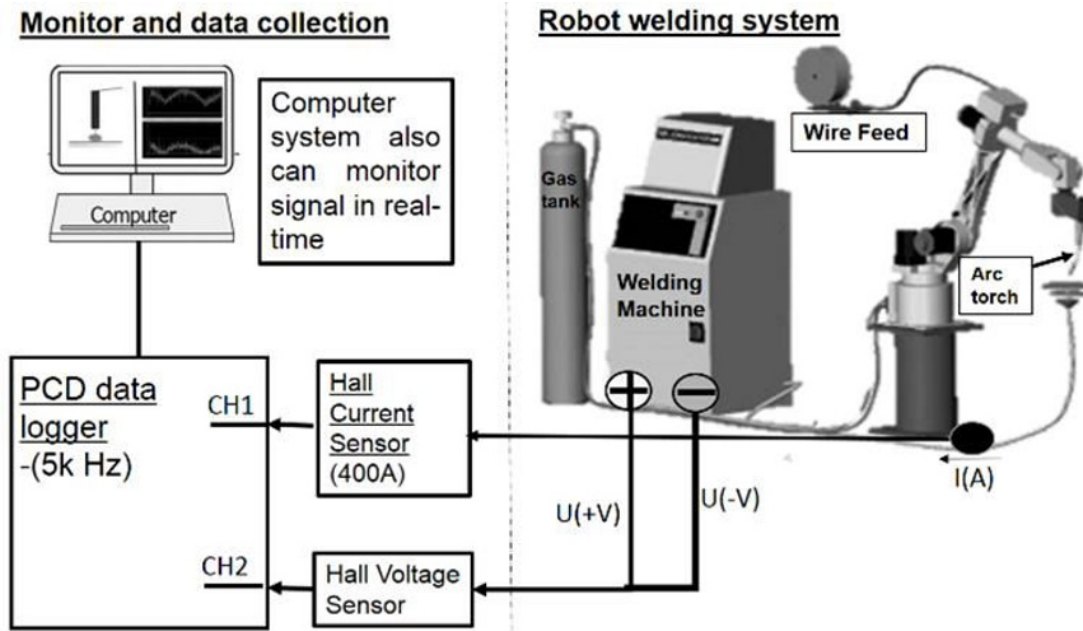


Fig. 1. Schematic for setup the collecting data voltage and current signal from robot welding

Therefore, it can reduce the training duration and improve the welder performance.

Zhang [6] has used current and voltage for monitoring in real time that reflect the welding process. For testing and optimizing the arc welding data, statistical tools were utilized by another research such as probability density distribution (PDD) [7, 8]. PDD is the construct of the percentage of the total data collection for each experiment in discrete number. Moreover, the probability distribution also uses for studying about the welding current intensity with three different gases (CO₂, Ar/CO₂, and TIME mixture) with low current intensity 100A and high current intensity 430A welding parameter [9]. The arc stability of PDD analysis was applied for determining the arc stability of welding voltage underwater [10]. Besides, PDD also selected to evaluate the trainee welder performance based on the proportion of arc voltage and also could be used to rank the welder skill by comparing with the ranking from Self-Organizing Maps (SOM) technique, artificial neural network [3].

The signal Cyclogram was used to monitor the arc stability; because of Cyclogram are the combination between welding current and voltage with ignoring the time axis. Historically, Cyclogram was introduced in biomechanical for movement of the human body; little research has been studied about motion analysis of human gait [11, 12]. Meanwhile, in the welding industry, Cyclogram was used to represent the arc stability of the current and voltage in the metal transfer. This method can be more sensitive to observe the size of the region of the short-circuit area, arc extinction area and arc burning area. Moreover, it can reflect the arc stability, and it is critical for the quality of the weld pool. However, analyzing the fluctuation of welding current and voltage in the time domain is not sufficient to represent the arc stability for qualifying the welder skill. Hence, Cyclogram technique could use for fast monitoring and

evaluating the welder skill. Although some papers have been studied on Cyclogram characteristic in metal transfer for observing the arc stability, Cyclogram has not been applied for monitoring and evaluating the welding skill. Therefore, this paper will study on the characteristic of Cyclogram which constructed by the signal current and voltage from the welding machine. Robot welding was used to create the simulation of hand-movement since it can be programmed precisely. The specific of the hand-motion pattern was created from robot simulation, and then Cyclogram shapes were investigated based on experimental results. Finally, the Cyclogram characteristic is used to distinguish the performance of the robot welding and manual welder.

2 Experiment Setup

This study involved two steps to describe about a new concept of signal analysis in Cyclogram characteristic. The first step is the simulation of the natural hand-fluctuation by using robot welding in GMAW process to observe the fluctuation signal in current and voltage. The following step is analyzing the fluctuation signal characteristic to create a pattern of Cyclogram. Then, implementing the data from the robot was compared with the actual welder. The parameter for 12 experiments by varying wave amplitude and frequency the robot is shown in Table 1. As shown in Figure 2, torch angle (W1) represents in wave amplitude that starts from number 1 to 6, and it refers to the weaving technique style (Zigzag technique). And the Torch Height change based on the number of frequency change from 1 to 6 that represents how often the CTWD change. Both conditions of varying torch angle and torch height could affect the current and voltage signal and generate the characteristic of Cyclogram that relate to the physical simulation of torch movement.

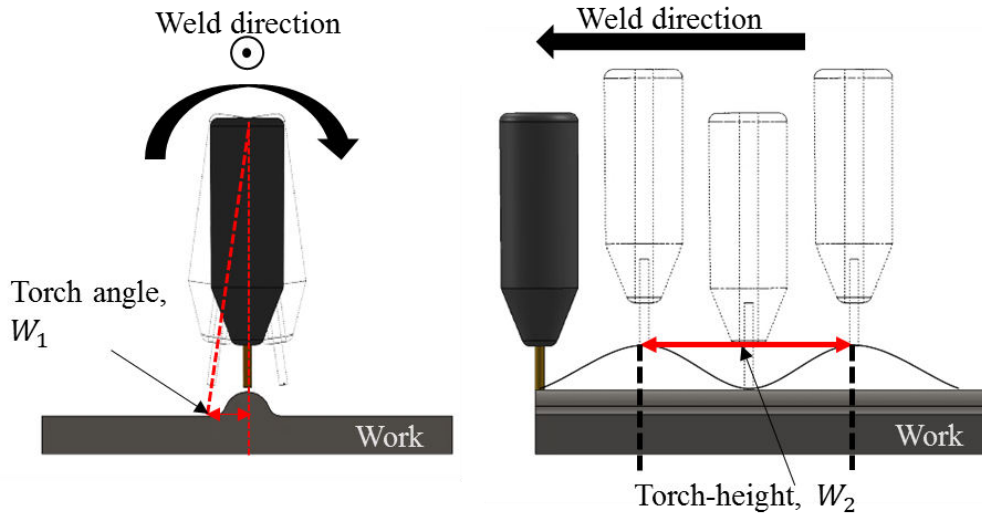


Fig. 2. Torch angle (W_1) and CTWD (W_2) from robot by fix the velocity

Table 1. Experiment by varying the wave amplitude and wave frequency.

Condition variable	Experiment number	Amplitude		Frequency	
		Number of Amp	Torch angle change (mm)	Number of Freq	Frequency (Hz)
Stable	1	0	0	0	0
	2	1	4.25	1	1.43
Amplitude	3	2	4.5	1	1.43
	4	3	5	1	1.43
	5	4	5.25	1	1.43
	6	5	5.75	1	1.43
	7	6	6.35	1	1.43
Frequency	8	1	4.25	2	1.71
	9	1	4.25	3	2.00
	10	1	4.25	4	2.29
	11	1	4.25	5	2.57
	12	1	4.25	6	2.86

2.1 Simulate hand-fluctuation using robot welding

A series of the experiment carried out on robot welding machine model FANUC Arc Mate 100iB which can move in six axes, reachability 1437mm and the fastest move about 2000mm/s as shown in Figure 1. Then the robot is used to simulate the hand-fluctuation signal by varying to the condition of wave frequency and wave amplitude in robot welding — the parameter for assign for experiment setup following Table 2 [13]. There are three different weld beads-on-plate duration 20s, which the first plate defines a steady arc welding, the second experiment performs the unstable of arc welding that using a robot to simulate the hand-motion of the human. Furthermore, data of the robot will take to compare with the welder.

Table 2. Parameter for welding experiment

GMAW process	
Thickness of Material	9 mm
Welding current (A)	170
Arc voltage (V)	21
Travel Speed (cm/min)	30
Extension Length (mm)	20
Wire feed YM26 diameter (mm)	1.2
Gas flow 100% CO ₂ (L/min)	15

2.2 Data acquisition

For recording the Digital signal processor (DSP) platform of current and voltage, a PCD data logger (model PCD-320A) was used to reach a higher sampling rate 5000hz per second. It has four channels and A.C to D.C coupling. The signal of welding voltage and current are syncing to the computer by using software DCS100A, and then we see on PC monitor in real-time during a welding process. Furthermore, signal data will automatically save in CSV format file. Using hall current sensor is possible to measure up to 400A DC. For a contactless measurement with the clamp ring, this device uses a hall effect to measure the axial magnetic field generated in the wire by current flowing through it. This clamp also provides electrical and physical isolation with an excellent dynamic response for the voltage measurement which was customized by using a shunt resistor to minimize the value of a voltage, and it is suitable for our PCD data logger.

Data acquired for welding experiment was plotted by using raw data both current and voltage were shown in Figure 3. However, data of current and voltage were plotted in the time domain in 1-second duration. On the other hand, Cyclogram plot from a function of voltage and current welding signal already using the filter method, and it is the better choice for studying about arc stability. To obtain desirable quality in welds requires

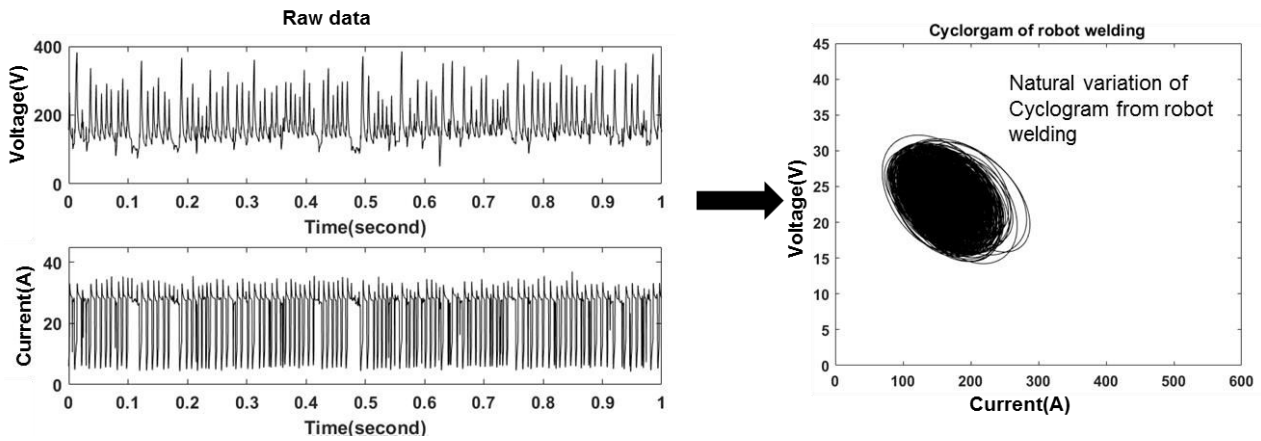


Fig. 3. Raw data of welding current and voltage then using butter smooth filter for plotting Cyclogram

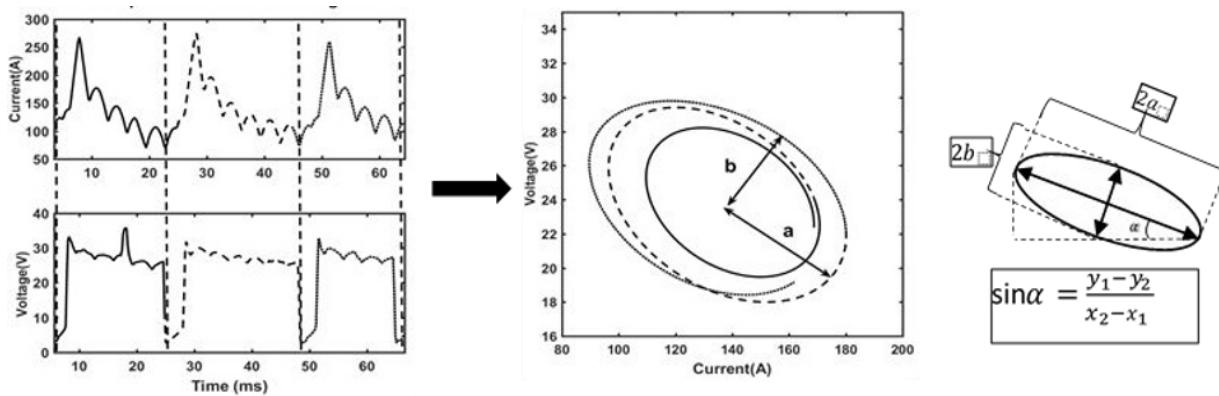


Fig. 4. Construction Cyclogram from current and voltage in 60 milliseconds and ellipse size of major axis and minor axis

many works, which can be achieved by monitoring and controlling the process parameters that affect the weld quality in real time [14]. The fluctuation in physical movement of arc welding caused by vary CTWD could impact the value of the voltage and current. In the experiment, robot welding was used to simulate the hand-fluctuation that will perform unitability of arc welding like increase the CTWD and the angle of arc torch. The simulate employed the defaults wave option from FANUC Arc robot welding, and it is possible to compare the steady signal of welding current and voltage.

2.3 Construction of Cyclogram

Cyclogram was constructed by welding current and voltage which could demonstrate the dynamic characteristic of the welding process. Figure 4 shows the welding voltage and current in 60 milliseconds which has three arc pulse. These three pulses plotted as the voltage function and welding current, and it generates the Cyclogram have a similar shape to an ellipse. The raw data of welding current and voltage were using smoothing method to reduce the noise signal. The signal was applied the Butterworth filter with cut off frequency 50hz, which can construct the better shape of Cyclogram than using moving average. By using this filter, the Cyclogram consider nearly complete the cycle or similar to the ellipse shape.

Analyzing the Cyclogram characteristic can determine the arc stability. As shown in Figure 4, the $2a$ represents the major axis length of ellipse, while the $2b$ represents the minor axis length of an ellipse. Value a describe about the deviation of the current value in the x-axis, and value b describe about the deviation of the voltage in the y-axis. Therefore, the Cyclogram characteristic can be used for monitoring the arc stability.

3 Results

The result shows two groups of Cyclogram: the first group is stable arc welding and the second group is unstable of arc welding by increasing the number amplitude which relates to the torch angle from 4.25mm to 6.35mm. And increasing the wave frequency refers to sequence change of CTWD (torch-height) from 1.43hz to 2.86hz Table 1. Moreover, the size of Cyclogram also grows larger when the number of amplitude and frequency were increased. To determine the size of Cyclogram the ellipse fitting method was used to become a quantitative method. As shown nn Figure 5, the red circle is the ellipse fit to cover the data of Cyclogram in statically of 95 confidential intervals. The area of the ellipse in arbitrary formula obtained:

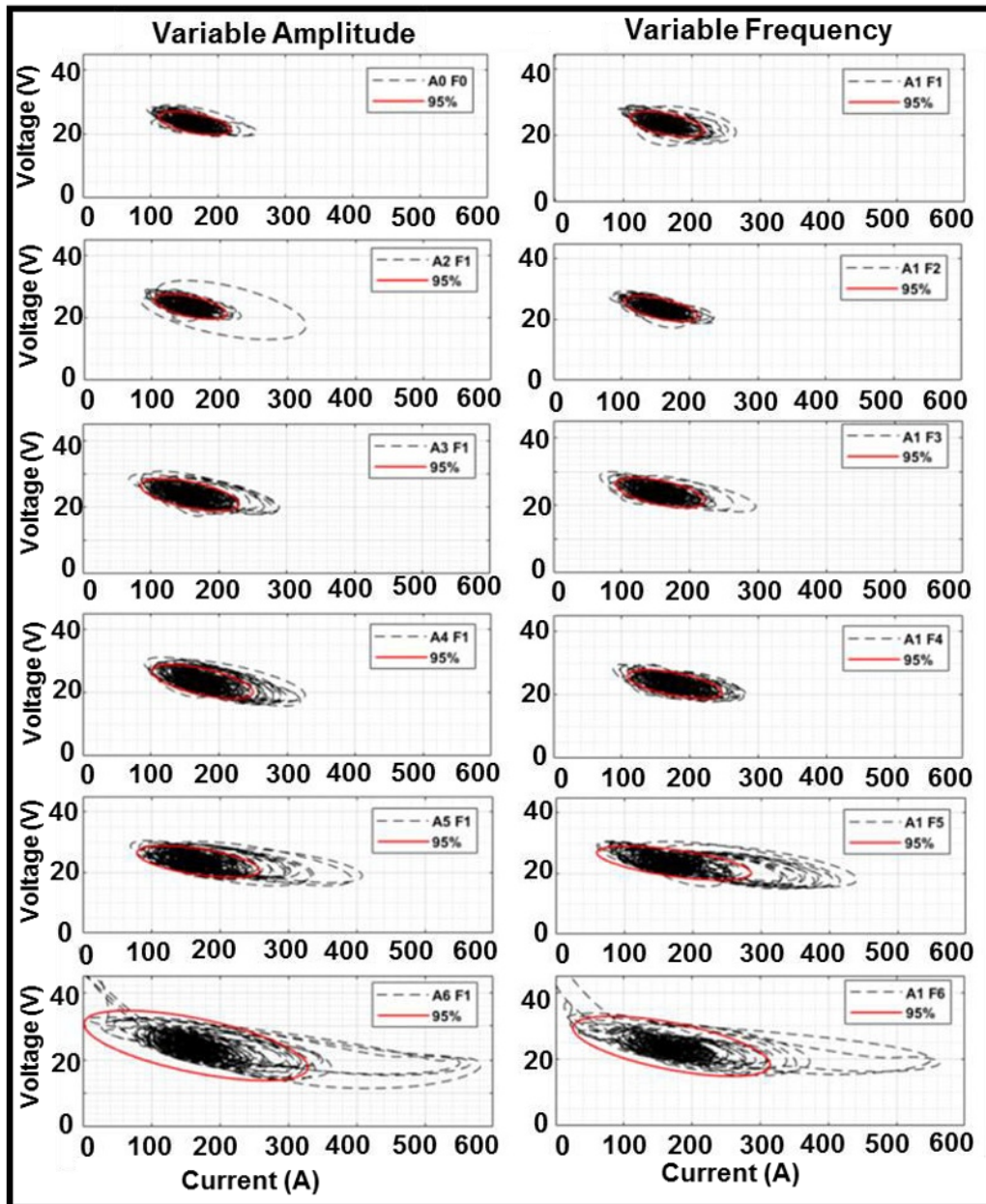


Fig. 5 Cyclogram with varying the amplitude (torch angle) and the frequency (Torch-height) during welding

$$\text{Area} = ab\pi \quad (1)$$

- a is semi major axis of ellipse (current variation)
 - b is semi minor axis of ellipse (voltage variation)
- Equations should be centered and should be numbered with the number on the right-hand side.

Cyclogram is created from the current and voltage combination, and this technique is utilized to determine the arc stability during the welding process. The x-axis represents the current, and the y-axis represents voltage. When the number of amplitude and frequency increased, the characteristic of Cyclogram shows larger size. As shown in Figure 5, the 12 cyclograms were plotted by varying the value of amplitude and frequency that represent the fluctuation of torch angle and CTWD change.

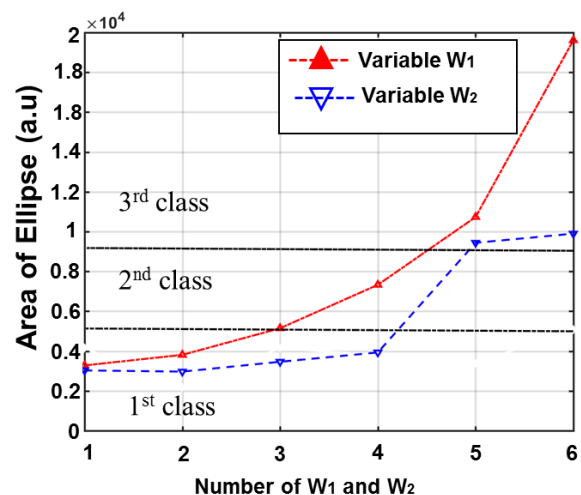


Fig. 6. Area of ellipse by varying amplitude (W1) and frequency (W2)

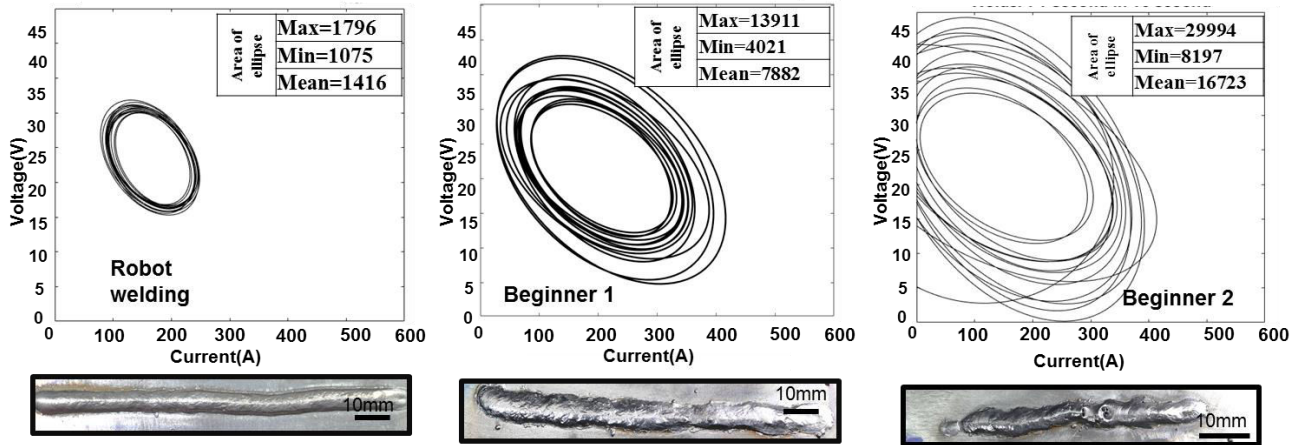


Fig. 7. Comparison of the repeatability of the ellipse area in 16 seconds between Robot welding data and two beginner welder data

Due to increasing the number amplitude (torch angle change) and frequency (CTWD change), the size of Cyclogram also increase significantly following hand-movement simulation.

Figure 6 shows the data of ellipse area that cover the Cyclogram is raising from 0.3×10^4 to nearly 2×10^4 a.u. (Arbitrary Unit) approximately, when the value amplitude change from 1 to 6. When the frequency is varied from 1.43 to 2.86 time per second, the ellipse area increased from 0.3×10^4 to 0.9×10^4 a.u. The weld quality is classified in three class based on the visual inspection, and weld weight and height. The first class defines as the stable arc welding from robot welder. The second class has the weld bead occur some defect. The third class defines the defect from wave fluctuation easy to recognize. By this data of ellipse size, it could become the tool to classify the welder skill by observing the deviation of the ellipse area.

4 Evaluation welder performance

The outcome of the Cyclograms could represent the fluctuations of the signal from the welding current and voltage, which is the faster and well demonstrate the arc stability of the welding process. As shown in Figure 7, it is the comparison of robot welding with two beginner welders by using the ellipse fit method. The one second signal of the Cyclogram will create one ellipse circle, and we will compare with data in 16 seconds. Results show that the robot welding performs very well to maintain the arc stability and the appearance of weld pool is also uniformly shape. The 16 circles of an ellipse fit almost repeated in the same area which has the average of ellipse area 1416 a.u. The robot stays in the first class that got the ellipse area lower than 5000 a.u (Figure 6). On the other hand, beginner welder 1 got the ellipse area in average 7882 a.u which stays in the second class. Finally, the beginner welder 2 reach the highest mean of ellipse area with 16723 a.u and the welder stays in the third class the poorest weld quality.

Furthermore, this study could recognize the pattern of stable arc from Cyclogram that generates the value of ellipse fit. The experiments from robot welding got the

lowest ellipse area because ellipse fit in one second is repeatable to the same area, and it indicates the stability of arc during welding. However, when the ellipse fit does not repeat in the same area, it represents the unstable of welding current and voltage causing the larger size of Cyclogram. The numerical data from ellipse fit could become a new aspect tool for monitoring the welder skill or evaluate their performance base on the characteristic of Cyclogram change.

5 Conclusion

The present study has utilized the robot welding to simulate the hand-fluctuation for evaluating signal welding current and voltage). It is possible that the data acquired from welding current and voltage to with only sampling rate 5000 to monitoring the arc stability. In the experiment, the Cyclograms not only able to monitor the overall signal of welding, but also could demonstrate the fluctuation of arc welding in a particular time of welding process by analysis on the repeatability of ellipse fit in each second. Hence, the Cyclogram could recognize the pattern of weld quality based on numerical data from the ellipse area. Therefore, Cyclogram can become a novel tool for monitoring the performance of welder, and also possible to classify the skill of the welder based on their ability to maintain the arc stability. In future, the data acquired from a different group of welder skilled (Expert welders, Intermediate welders, and beginner welders) will be studied and classified the pattern of welder data from ellipse area.

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