

# Study on Evaluation Method of Aluminum Alloy Pulse MIG Welding Stability Based on Arc Voltage Probability Density

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## ABSTRACT

Bring forward a new analytical method in order to evaluate the stability of the process of aluminum alloy pulsed MIG welding. The ratio of the first and the second peak in arc voltage signal probability density was selected to evaluate aluminum alloy pulse MIG welding stability. By calculating the arc voltage signal probability density from 80 sets of welding experiments, the ratio of the two peaks in arc voltage probability in every set was captured. And the evaluation system of aluminum alloy pulse MIG welding stability was established. The smaller the ratio of peaks in arc voltage signal probability density is, the better the stability of the welding will be; the bigger the ratio of peaks in arc voltage signal probability density is, the poorer the stability of the welding will be.

**Keywords:** Aluminum Alloy, Pulse MIG, Welding Stability, Probability-Density, Arc Voltage

## 1. Introduction

The process of aluminum alloy pulse MIG welding is characterized by its non-linearity, strong time-varying, strong coupling between the parameters, and so forth [1]. The reason why its process is unstable has not been well explained until now. Because of the lack of the parameter matched stability evaluation indicators, the control of the aluminum alloy pulse MIG welding by changing the welding parameters is very difficult. The fail of matching the parameter will probably lead to the instability in the welding process or even worse. In recent years, many scholars at home and abroad have studied the stability in the welding process: reference [2] put forward an on-line evaluation model of the process stability by use of the statistical analysis and partial least-squares regression. Reference [3] and [4] found that the approximate entropy of the arc signal varied with the change of the parameter. Reference [5] and [6] analyzed the probability density of the corresponding welding current and voltage and finally evaluated the welding stability.

This paper analyzed the probability density distribution of the 80 sets of voltage signal under different welding speed, wire-feeder speed and duty cycle matched parameters.

## 2. Experimental System

The experiment applied DELEX VIRIO MIG-400L welding machine to pure Ar gas shield bead-on-plate welding. The designation of the welding wire was 5356, diameter 1.2 mm. The material of the workpiece was aluminum50581-H321 with the thick of 6mm. The torch was fixed during welding. And its distance between the workpiece was unchanging. The workpiece moved on the worktable. The initial wire extension was 15 mm. Data acquisition card PCL812PG was applied to the welding and its frequency was 1 kHz. The current sensor was CSM400FA/100 mA. The time between the arc igniting and ending was not less than 45 s. Video acquisition captured the condition of the arc and molten pool to judge the stability of the welding. **Figure 1** was the experimental system.

Because of the finding that the duty cycle of the pulse current, the wire-feeder speed and welding speed impact the welding stability greatly, the experiment combined the duty cycle, the wire-feeder speed and the welding speed to weld. The base value of the welding current was 25 A, the peak value 180 A, pulse frequency 40 Hz, welding voltage 18 V, and shielding airflow 18 L/min.

Because the aluminum alloy pulse MIG welding was

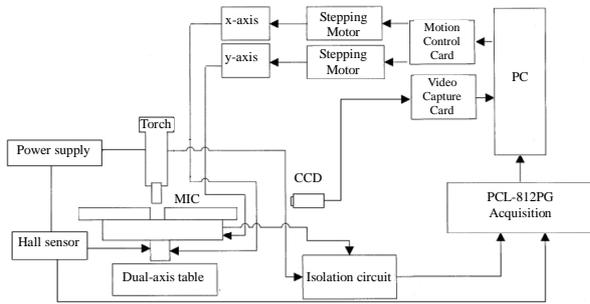


Figure 1. Experimental system.

very strict to its parameter matching, the welding parameters in **Table 1** were fixed through the welding experiments. These parameters could be combined randomly. The maximum and minimum of single parameter was the upper and lower limits of the matching.  $5 \times 4 \times 4$  sets of welding experiments were conducted and 80 sets of arc voltage signals were acquired.

### 3. Voltage Signal Probability Distribution Analysis

With regard to time array  $x(t)$ , when amplitude falls on the range  $(x, x + \Delta x)$ , the total time is  $T_x = \sum_{i=1}^k \Delta t$ .

When observation time tends to infinity, array  $T/T_x$  is the probability of case  $[x < x(t) < x + \Delta x]$ , which can be written as  $P[x < x(t) < x + \Delta x] = \lim_{T \rightarrow \infty} T_x/T$  the probability density function can be defined as:

$$P_x = \lim_{\Delta x \rightarrow 0} \frac{P[x < x(t) \leq x + \Delta x]}{\Delta x} \tag{1}$$

$$= \lim_{\Delta x \rightarrow 0} \frac{1}{\Delta x} \left[ \lim_{T \rightarrow \infty} \left( \frac{T_x}{T} \right) \right] = \lim_{\Delta x \rightarrow 0} \left( \frac{1}{T_{\Delta x}} \sum_{i=1}^k \Delta t_i \right)$$

Probability density function  $p(x)$  constantly equals to real-value non-negative function. The data must be standardized before analyze its probability density. Every variable minus the mean and then divided by its standard deviation, supposing the collected good-running data matrix is  $X \in R^{n \times p}$ , each column corresponds to a variable

Table 1 .Welding parameters.

Welding speed cm/min	Wire feed speed m/min	Duty cycle %
11	6	50
15	6.5	44
20	7	40
25	7.3	37.5
31		

and each line corresponds to a sample. Standardized the  $X$  as follows:

$$X_s = [X - (11 \dots 1)^T P] \text{diag} \left( \frac{1}{s_1}, \frac{1}{s_2}, \dots, \frac{1}{s_p} \right) \tag{2}$$

$P$ —the mean of variable  $X$ ,

$$P = \left[ \frac{1}{s_1}, \frac{1}{s_2}, \dots, \frac{1}{s_p} \right], S$$
—the standard deviation of the variable,  $S = [s_1, s_2, \dots, s_p]$ .

Then, normalize the standardized data. Finally, calculate and analyze the probability density.

Analyze the probability density of 4 sets of voltage signal selecting from 80 sets of welding experiments arranging from good to bad. Every set of voltage signal cut from the 10<sup>th</sup> second and 30000 points were captured, namely 30 seconds. The results are shown in **Figure 2**.

According to **Figure 2**, two peak values were found in each set of probability density distribution figure and the distance between the two peaks increase. In order to get the accurate variation of the two peaks from 4 sets of experiments, the ratio of the first peak and the second peak was selected to reflect the variation of the distance between the two peaks. The variation of the ratio was shown in **Figure 3**.

The ratio of the two voltage probability density peaks gradually increase in the four sets of experiments. After comparing the corresponding weld bead, it was found that the ratio of peaks was small when the weld bead shaping was good, and the opposite was big. The second set and the fourth set were shown in **Figure 4**. Obviously, the weld bead of the second set was better than that of the fourth. And the ratio of peaks of the second set was smaller than that of the fourth. Therefore, the ratio of the two peaks in voltage probability can be applied to evaluate the stability of aluminum alloy MIG welding.

### 4. Evaluation System of Welding Stability

According to the result above, 80 sets of welding voltage signal was calculated for probability density. By making use of the ratio of the two peaks in each set of voltage signal probability density, the evaluation system of aluminum alloy pulse MIG welding stability was established. The result is shown in **Figures 5-7**. What is shown in **Figures 5-7** is the fluctuation of the ratio of peaks in arc voltage signal probability density under different parameter. The figure well reflects the aluminum alloy pulse MIG welding stability under different welding speed, wire feed speed and duty cycle. In aluminum alloy pulse MIG welding, the smaller the ratio of peaks in arc voltage signal probability density is, the better the stability

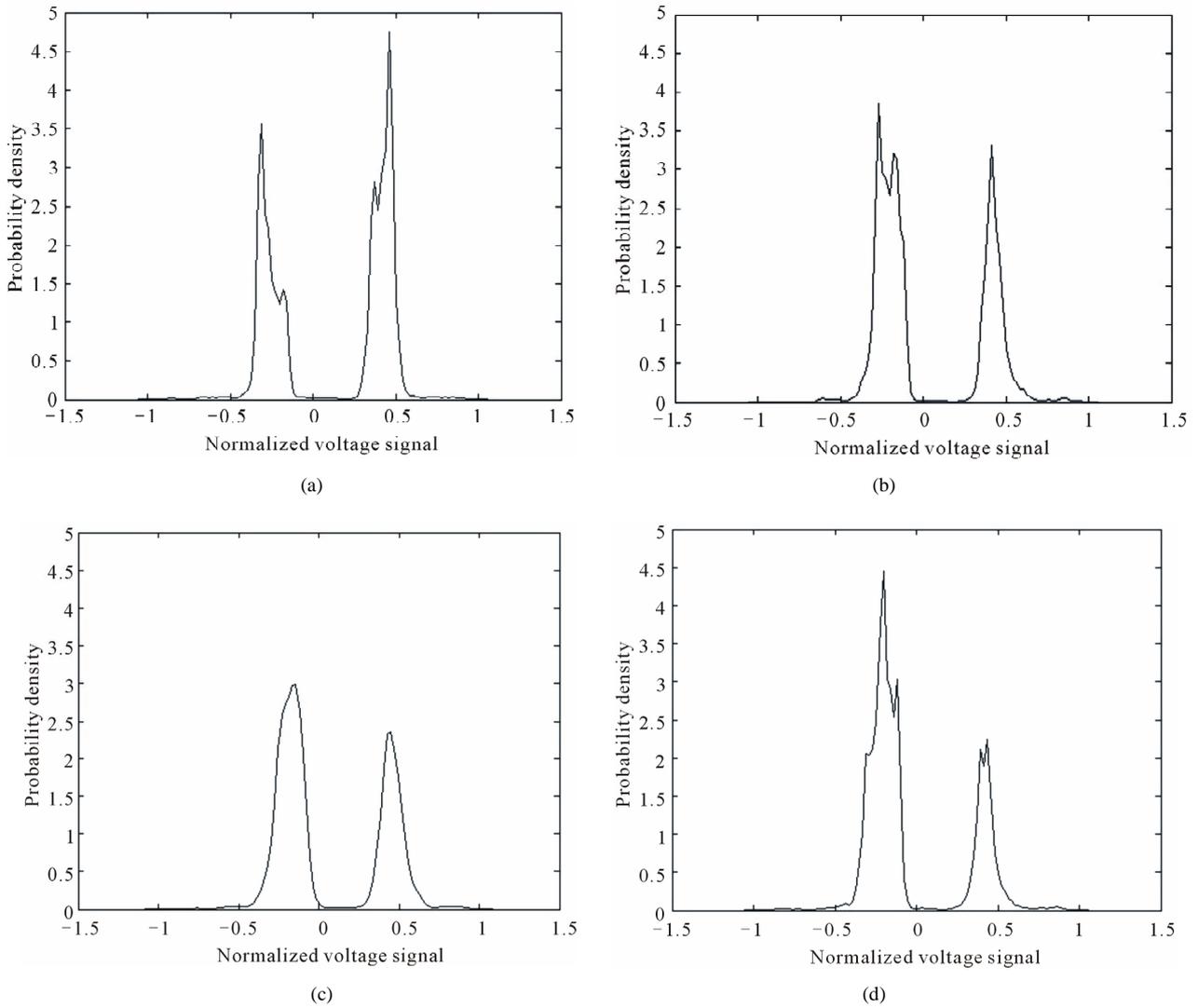


Figure 2. Probability density of voltage. (a) NO.1; (b) NO.2; (c) NO.3; (d) NO.4.

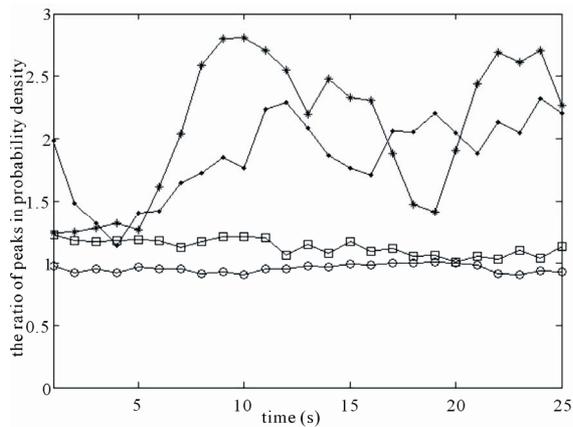


Figure 3. Changes in the ratio of peaks in probability density.

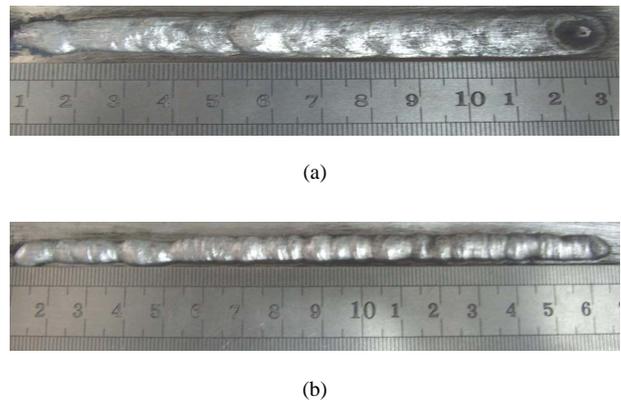


Figure 4. The weld of different parameters. (a) NO.1; (b) NO.4.

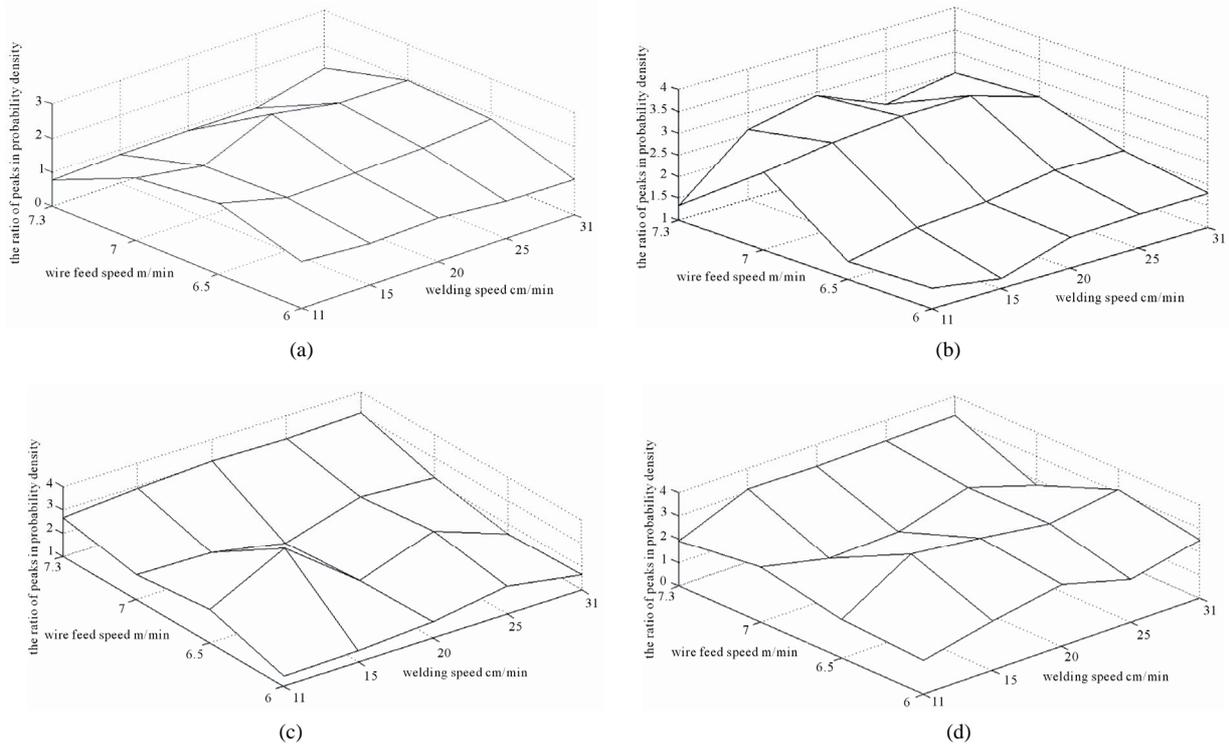


Figure 5. The match of welding and wire feed speeds on different duty cycle. (a) duty cycle 50%, (b) duty cycle 44%, (c) duty cycle 40%, (d) duty cycle 37.5%.

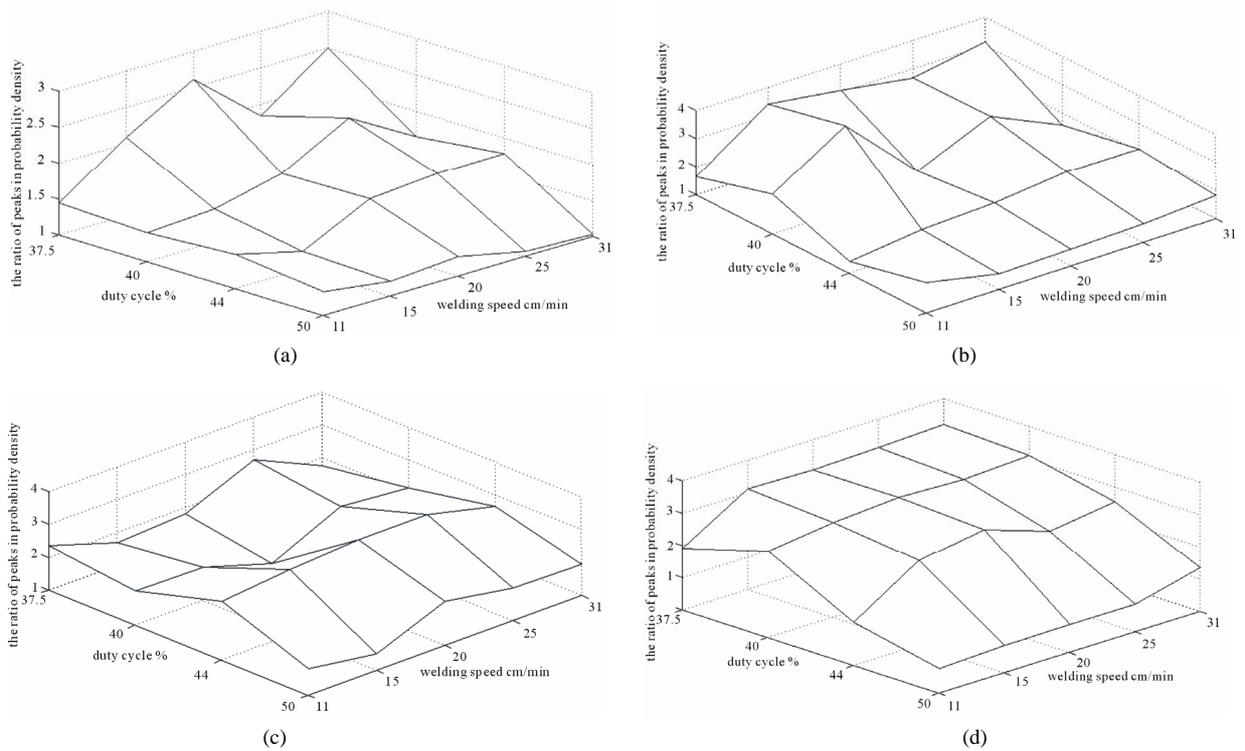


Figure 6. The match of welding speeds and duty cycle on different wire feed speeds. (a) wire feed speed 6 m/min; (b) wire feed speed 6.5 m/min; (c) wire feed speed 7 m/min; (d) wire feed speed 7.3 m/min.

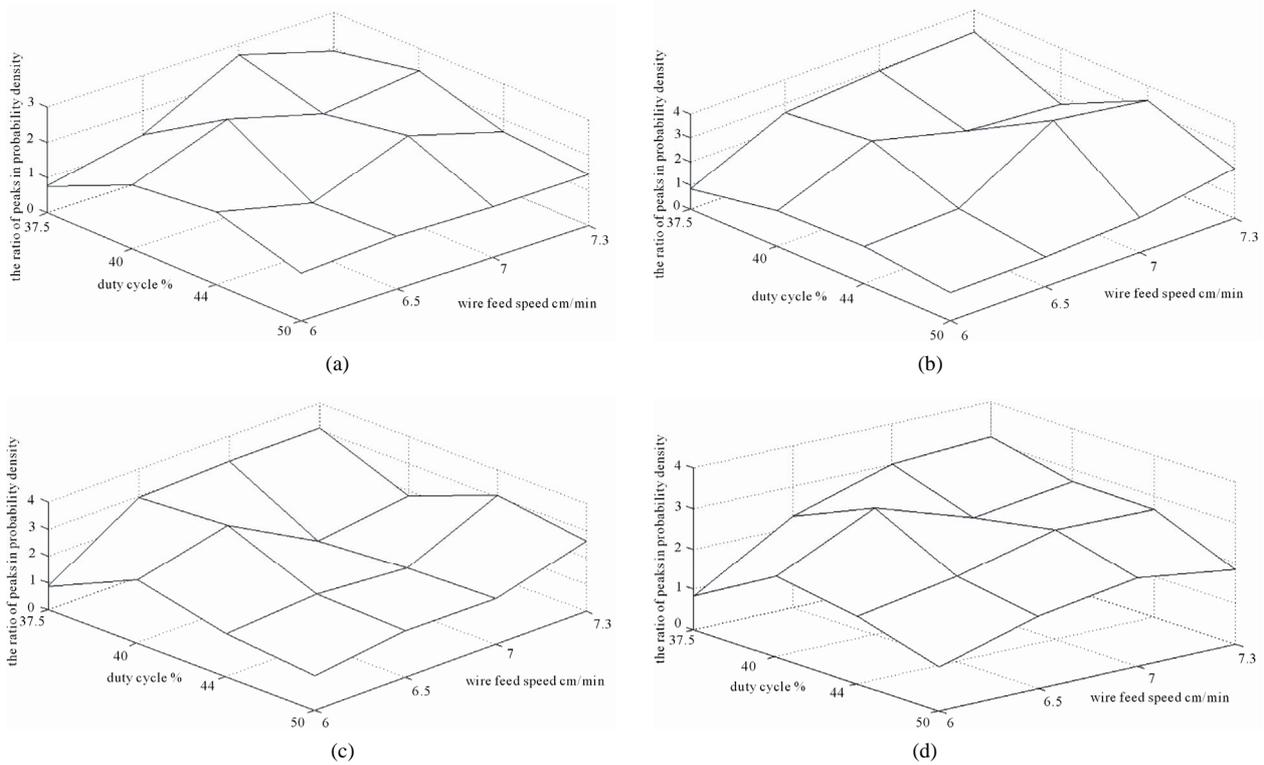


Figure 7. The match of wire feed speeds and duty cycle on different welding speeds. (a) welding speed 11 cm/min; (b) welding speed 15 cm/min; (c) welding speed 20 cm/min; (d) welding speed 25 cm/min.

Table 2. The ratio of peaks in voltage probability density and weld forming under different welding parameters.

Number	Wire feed speed m/min	Duty cycle %	Welding speed cm/min	Ratio of peaks in probability density	Stability	Welding forming
1	6	50	11	1.3333	Stable	Good
2	6	44	15	1.24	Stable	Good
3	6	37.5	20	2.6111	Unstable	Bad
4	6.5	44	25	2.1	Unstable	Bad
5	6.5	40	15	4	Unstable	Bad
6	6.5	37.5	20	3.0625	Unstable	Bad
7	7	44	11	2.7778	Unstable	Bad
8	7	40	25	2.35	Unstable	Bad
9	7.3	50	20	0.8649	Stable	Good

of the welding will be. The opposite is the instability of the welding.

Table 2 shows the ratio of peaks in voltage probability density and weld forming under different welding parameters, through which the ratio of peaks in arc voltage signal probability density and the welding stability can be compared more objectively.

## 5. Conclusions

1) By analyzing the ratio of peaks in arc voltage signal probability density and comparing the welding bead, the ratio of peaks in aluminum alloy pulse MIG welding arc voltage signal probability density is suitable to be applied to evaluate the welding stability.

2) According to the fluctuation condition of the ratio of peaks in arc voltage signal probability density, the evaluation system of aluminum alloy pulse MIG welding stability is established. The smaller the ratio of peaks in arc voltage signal probability density is, the better the stability of the welding will be; the bigger the ratio of peaks in arc voltage signal probability density is, the poorer the stability of the welding will be.

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