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Arc Energy Characteristics Analysis of AC Square Wave Submerged Arc Welding using WVD

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Abstract

In process of AC square wave submerged arc welding, electric signal waveform determines the arc energy characteristics in the time and frequency domain, which also reflects the arc stability of welding process and quality indirectly. Using Wigner-Ville distribution (WVD), time frequency analysis is conducted to the current signal of AC square wave submerged arc welding. The Pseudo Wigner-Ville and smoothed Wigner-Ville distribution are discussed separately to suppress the cross-term interference. The numerical results indicate that the Choi-Williams kernel function has much superiority for time frequency analysis of the submerged arc welding electric signal. It can effectively suppress cross-term and eliminate noise in the Wigner-Ville distribution of welding electric signal, as well as owing the ability to portray the local feature of arc energy in AC square wave submerged arc welding.

Keywords: AC square wave submerged arc welding; Arc energy characteristics; WVD; Choi-williams kernel

Introduction

The AC square wave submerged arc welding is suitable for the ring seam welding, multi-arc welding and other special occasions because of the advantages of quick speed of crossing arc zero, non-magnetic blow and high welding deposition rate [1,2]. In the actual welding process, the arc space and the electrode surface temperature change versus time during the alternating positive and negative polarity of arc [3,4], the arc resistance is not constant and changes as the arc current changes, and the welding power supply source easily interfered by the electric characteristic and the external factors. The presence of such phenomenon results in the irregular distortion of the actual outputting arc current and voltage waveform, especially in the process of high-speed and high current arc welding, which has direct influence on the arc stability and welding formation quality, and also reflects the arc characteristic information in the time domain and frequency domain. It is one of the effective ways to achieve detection of the arc stability and welding quality by the way of arc signal analysis and arc information extraction [5-7].

Submerged arc welding process is a complex and dynamic process of interaction of multiple factors. The actual monitoring of electrical arc current and voltage are non-stationary signals. Wigner-Ville time-frequency distribution (WVD) is a basic and most widely used time-frequency distribution.WVD is secondary time-frequency distribution that can obtain the instantaneous energy, frequency and power spectral density of signal, which is a powerful tool for analysis of non-stationary and time-varying signal. WVD is a two-dimensional joint function as a time-frequency energy density function in two-dimensional plane. WVD is given by the Heisenberg uncertainty principle when time-bandwidth product reaches the lower bound, which greatly improves the feature extraction accuracy of the welding arc signal with characteristics of high energy accumulation and good time-frequency resolution [8,9]. Based on WVD, arc electrical signals of the submerged arc welding process are analyzed, and the electrical energy distribution characteristics in time-frequency plane are obtained to assess the arc stability and welding quality. It is directive significance for the study of the arc stability and the welding seam formation in AC square wave submerged arc welding process.

Secondary Time-Frequency Analysis

WVD satisfies most of the mathematical properties, which is the most basic and applied time-frequency distribution. The Fourier transform of the signal $x(t)$ is $X(j\Omega)$, and then the signal $x(t)$ is defined as Wigner

$$W_x(t,\Omega)=\int_{-\infty}^{\infty}x(t+\tau/2)x^*(t-\tau/2)e^{-j\Omega\tau}d\tau \tag{1}$$

W_x is Wigner-Ville distribution of signal $x(t)$. WVD can be understood as a spectrum corresponding to each time based on this time as the center, which conducts the Fourier transform to the results from the signal multiplied by the right and left of all parts. The advantage of the WVD is the good focusing ability of time-frequency.

Since the arc electric signal of submerged arc welding is a multi-component signal, it has a serious cross-term on WVD time-frequency analysis. So it is necessary to take effective measures to eliminate the interference of cross-terms. The suppression of cross-terms can effectively by adding kernel function. The common adding kernel functions of Wigner-Ville distribution as below:

Pseudo Wigner-Ville Distribution

The oscillation characteristics of the cross-terms can be eliminated by the smoothing of WVD, that is, a smooth window function is added in time domain, and then the pseudo Wigner-Ville distribution is obtained:

$$PW_x(t,\Omega)=\int_{-\infty}^{+\infty}h(\tau)x\left(t+\frac{\tau}{2}\right)x^*\left(t-\frac{\tau}{2}\right)e^{-j\Omega\tau}d\tau \tag{2}$$

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Where $h(\tau)$ is a window function, the windowing function in the time domain is shorter, the smoothing effect on frequency domain is more obvious, the eliminating effect of the cross-term is also better. However, the elimination of the cross-term may result in the reduction of resolution, that is, the smoothing of Pseudo Wigner-Ville in the frequency direction may make the frequency resolution of the signal worse.

Smoothed WVD

In general, let $G(t, \Omega)$ be a time-frequency distribution of a window function, then the smoothed WVD is defined by convolution of $G(t, \Omega)$ and $W_x(t, \Omega)$ in both t and Ω, marking $SW_x(t, \Omega)$:

$$SW_x(t,\Omega) = \frac{1}{2\pi}\iint W_x(u,\xi)G(t-u,\Omega-\xi)\,du\,d\xi \qquad (3)$$

Where the effect of $G(t, \Omega)$ on $W_x(t, \Omega)$ depends on the shape of $G(t, \Omega)$. In fact, the left part of (3) is one of the general forms of the Cohen class. The time-frequency distribution of Cohen class has high time-frequency resolution, but it is difficult to eliminate the cross-term. Ref [9] used Choi-Williams distribution (CWD) to describe the time frequency energy distribution of arc signal of CO_2 welding, which has effectively suppressed the cross-term interference.

Figure 1 is an arc current signal x(t) of AC square wave submerged arc welding by experiment, the specific welding parameters and experimental phenomena is shown in Table 1. It can be seen from the Figure 1, the current waveform is an irregular square wave of 50 Hz alternating positive and negative, which contains interference signals of other frequency components in each waveform peaks and valleys and impacts at the crossing zero position. The sampling frequency is 2.5 kHz, 2500 number signals are selected to be calculated and analyzed.

The WVD of the signal is shown in Figure 2. It can be seen from Figure 2, the energy distribution of the signal is mainly concentrated in the contour of 50 Hz, and there contain other frequency contour lines of mutations and interference components, which is fully consistent with current outputting parameters of the actual AC square wave submerged arc welding process. It shows the WVD can effectively extract the current signal characteristics of submerged arc welding. However, the cross-terms are easily mixed with the principal and other items, which disturb the interpretation of WVD. So, the cross-terms are easily seemed as the studying object for the interpretation of arc energy information.

Experiment number	Currents (A)	Voltage (V)	Speed (m/min)	Frequency (Hz)	Duty ratio	Welding cases
1	630	40	0.6	50	0.5	No short-circuit and breaking arc, arc stability, good welding formation

Table 1: Welding parameters and experimental phenomena.

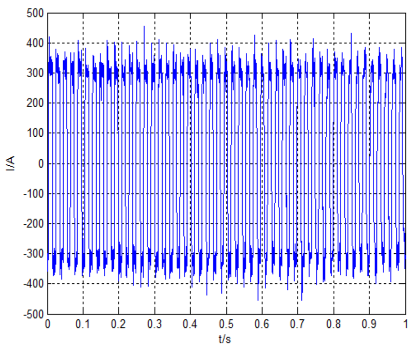

Figure 1: The collected current signal.

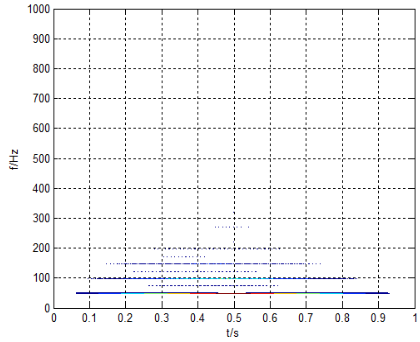

Figure 2: WVD of current signal.

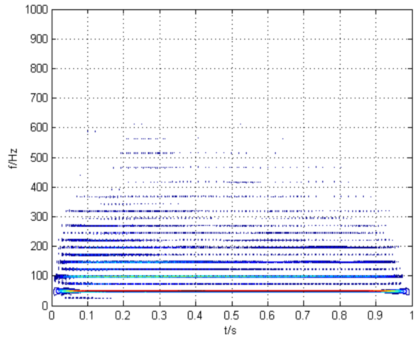

Figure 3: Pseudo Wigner-Ville distribution.

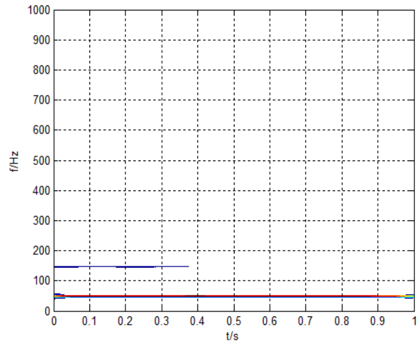

Figure 4: Smoothed Wigner-Ville distribution.

According to the above method of cross-terms suppression, the pseudo Wigner-Ville distribution and smoothed Wigner-Ville distribution are used to reduce the cross-term interference. Two steps are generally taken to eliminate different frequency components, the first step is calculation of the analytical signal instead of actual signal, and the second step is to suppress cross-term interference by time-frequency analysis of pseudo Wigner-Ville distribution and smoothed Wigner-Ville distribution. The calculation results are shown in Figure 3 and Figure 4.

Figure 3 is Pseudo Wigner-Ville distribution, Figure 4 is smoothed Wigner-Ville distribution. It can be seem form Figures 3 and 4 that the main component of 50 Hz can seen in the Wigner-Ville distribution with other interference components and cross-term interference. Since these cross-terms fluctuate along the time axis, therefore it is difficult

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to distinguish the characteristics of welding arc energy distribution. The pseudo Wigner-Ville distribution has eliminated the cross-terms at a certain degree. The smoothed Wigner-Ville distribution has greatly reduced the influence of the cross-terms due to the time domain smooth.

It can be further seen from the Figures 3 and 4, the pseudo Wigner-Ville distribution and smoothed Wigner-Ville distribution can suppress the cross-terms effect at a certain degree, improve the application effect of the WVD, and can clearly distinguish the energy distribution characteristics of the main current waveform, but it cannot observe the local features of impact crossing zero and mutations of AC square wave current waveform, that is, it cannot effectively portray local features of arc energy of AC square wave submerged arc welding.

The signal of Figure 1 is still considered as the studying object, taking two steps to suppress the cross-term interference and eliminate the noise signal of different frequency components. The first step is to calculate the analytical signal instead of actual signal; the second step is taking the Choi-Williams kernel as time-frequency analysis [9]. The time frequency results of the signal by WVD with Choi-Williams kernel is shown in Figure 5.

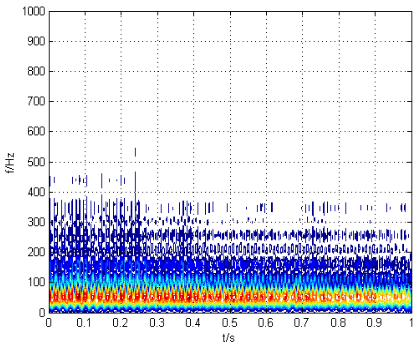

Figure 5: WVD by Choi-Williams kernel.

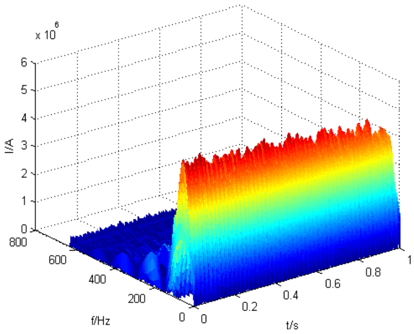

Figure 6: Three-dimensional WVD by Choi-Williams kernel.

Figure 7: AC square wave SAW experiment and testing platform.

Experiment sequence	Currents (A)	Voltage (V)	Welding speed (m/min)	Frequency (Hz)	Duty ratio	Welding conditions
1	630	40	1.2	50	0.5	Breaking arc, arc instability, poor welding formation
2	630	40	1.2	80	0.5	No short-circuit and breaking arc, arc stability, good welding formation
3	630	40	1.2	100	0.5	No short-circuit and breaking arc, arc stability, good welding formation

Table 2: Welding parameters and results.

Comparing Figure 5 with Figure 6, using the Choi-Williams kernel as time frequency analysis, it effectively suppresses the cross-term influences of the main component and other interference components. Although the noise interference is not completely eliminated, the influence of the noise to WVD can be negligible. The energy distribution of arc signal retains the components of impact and mutation, which means a valid portrayed capacity of local features for AC square wave submerged arc welding.

From the above calculation analysis, WVD can effectively extract the characteristics of the welding arc signal, which can provide an intuitive and accurate criterion for the arc stability and welding quality. The Choi-Williams kernel based WVD analysis can effectively suppress cross interference term, eliminate the influence of noise to the welding arc electrical signal, and highlight the local characteristics of arc energy.

Experiential Results and Analysis

The measurement instruments for arc current and voltage signals of AC square wave submerged arc welding are consists of the Hall sensor, Ethernet data acquisition, industrial computer and other parts, and the experimental platform is shown in Figure 7. The collected welding current, voltage signal are transported to industrial control computer by cable transmission. The collected signal are analyzed and processed by Matlab. Experiments are done by alternating current square wave submerged arc welding machine MZE1000. The material of work piece is low carbon steel Q235 with slab thickness of 20 mm, the welding wire trademark is H08A with diameter of 4.0 mm, and welding flux is HJ431. Under the conditions of the different welding parameters such as voltage, current and welding speed, the welding experiment of submerged arc welding is carried out, and the current and voltage signals are acquired corresponding with the welding parameters. Welding parameters and testing phenomena are shown in Table 2. The Choi-Williams kernel based WVD is adopted to analyze the welding current signals in Table 2, the welding current signals and corresponding results of time-frequency distribution are shown in Figures 8-10.

The current waveform and WVD distribution of experiment sequence 3 (Figure 10).

It can be seen from Figures 8-10, the joint distribution of the amplitude of the welding current signal on the time and frequency plane can be clearly observed. The energy of each group signal mainly concentrates on the 50 Hz, 80 Hz and 100 Hz, with some other irregular frequency components fluctuating along the time axis. The irregular frequency components are actual outputting current waveform distortion of the welding power source with random distribution. The current waveform distortion and the size range directly affect the distribution of arc energy, and then affect the welding formation.

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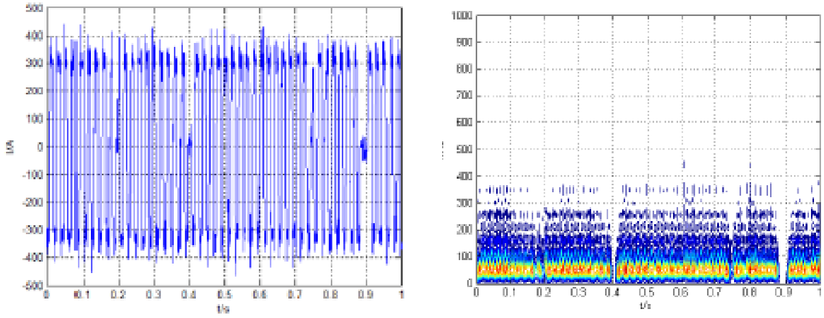
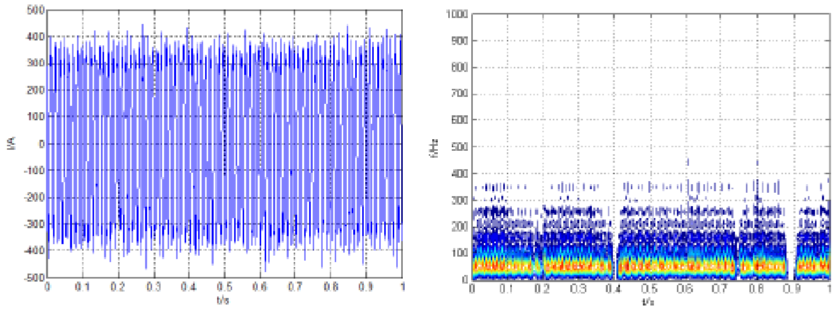


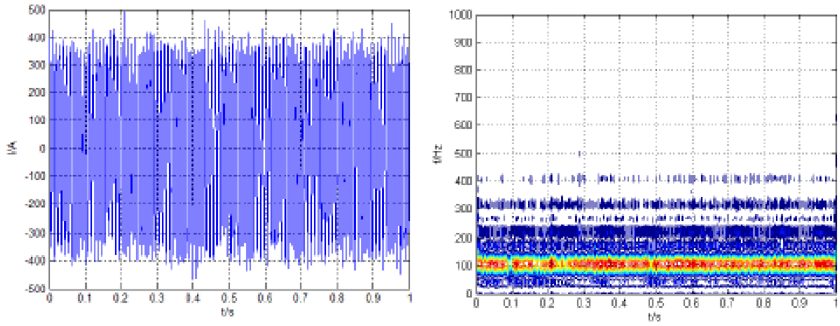
(a) Current signal (b) Time-frequency distribution of WVD

Figure 8: The current waveform and WVD of the experiment sequence 1.



(a) Current signal (b) Time-frequency distribution of WVD

Figure 9: The current waveform and WVD distribution of experiment sequence 2.



(a) Current signal (b) Time-frequency distribution of WVD

Figure 10: The current waveform and WVD distribution of experiment sequence 3.

Figures 8b, 9b and 10b are the time-frequency spectrum calculated by welding current signal under the same duty ratio and different frequencies. The three group signals of time-frequency spectrum of the main frequency components are 50 Hz, 80 Hz and 100 Hz. The amplitude of the current signal is not much difference in frequency domain, the difference among the three group signals are the temporal change in the energy. The arc energy is different versus time seen from the three groups of time-frequency distribution. The energy of the unit time is changed frequently and relatively concentrated as an increasing of frequency.

It can be seen from Figures 9 and 10, the time and frequency contour of arc energy distribution is regular alternation in stable arc burning condition. Figure 8 is the current waveform and time frequency distribution at the condition of breaking arc at a time due to some factors. The arc energy reduces suddenly, which is abnormal phenomena in the process of welding and interferes the arc stability and arc energy distribution. At end of the broking arc, the arc continue burning steadily, the arc energy distribution becomes regular in time and frequency contour.

Conclusion

Time frequency analysis of WVD is conducted to the current signal of AC square wave submerged arc welding. The Pseudo Wigner-Ville and smoothed Wigner-Ville distribution are discussed separately to suppress the cross-term interference. The Choi-Williams kernel function based WVD can effectively suppress cross-term and highlight local characteristics of arc energy, which provides an intuitive, accurate criterion for assessment of welding arc stability and welding quality. By applying WVD to the arc current signals collected under different working conditions, the WVD is indicated as a direct, effective and practical time frequency exaction method for arc energy characteristic.

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