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Investigation on Welding Arc Sound (Report III)†
—Effects of Current Waveforms on TIG Welding Arc Sound —

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Abstract

Investigation has been made on the effects of the rectangular, sawtooth, triangular and sine current waveforms on the welding arc sound of TIG arc, that is a stationary arc on the water cooled copper plate, by means of a transitor control type power source.

The experimental results have indicated that the welding arc sound depends on the current waveform, pulse frequency f_p and pulse amplitude τ_p. The welding arc sound is composed of a fundamental tone which has a frequency spectrum of f_p and its harmonics. An excellent frequency spectrum f_{EX} agrees with f_p in the triangular and sine wave current, but f_{EX} changes to higher harmonic in the rectangular and sawtooth wave current.

The effective sound pressure P_e is shown as a function of f_p and τ_p ($P_e \propto f_p^m \cdot \tau_p^n$), and the useful equations which are possible to estimate the noise level have been obtained.

KEY WORDS: (Acoustics) (Arc Welding) (Process Parameter) (Environment)

1. Introduction

Investigations on improvement of solidification structer, grain size and mechanical properties of the weld joints have been carried out by pulsing the welding current in plasma welding[1], MIG welding[2)-5)]. TIG welding [6)-12)] and covered arc welding process[13]. These methods, which are often called the pulse arc welding, have such advantages as unnecessary of installing a special apparatus to the base metal or the torch side, differing from the magnetic controlling procedure, and admitting the welding of thin plates and different metals of controlling the electric power supply in a wide range. Conversely, it is unavoidable for this method to accompany the occurence of large noise due to use of the current waveform with short times of rising and falling. (In general, rectangular current waveform is used. The use of the other waveforms will be investigated in the future.)

The authors started the study on the assumption that the so-called arc sound generated during the welding will offer new available information on the welding phenomena, and therefore, have investigated sevaral characteristics of arc sound and the relation between the arc sound and the welding situation[14)-15)]. In this paper, the influence of pulsation of the welding current on the arc sound was investigated, and moreover, the influences of pulse frequency and pules amplitude were compared for four types of current waveforms.

2. Experimental Apparatus and Method

The welding electric power source employed in this experiment was a DC transistor control type. In this power source, as the controls of the current and the voltage is made to detect the difference of values between the standard and the output with feedback system, a perfect DC output is, of course, obtained and if the standard value is set by using of a function generator, arbitrary waveforms of the current and the voltage can be obtained. The power source has the response frequency of about 10 KHz, and its responsibity and stability are far better than the conventional type. The subject of this experiment was focussed on a TIG arc occured on the water cooled copper plate. This method rarely involves the consumption of an electrode and the formation of a molten pool, and therefore, it is possible to think that all the arc sound characteristics will be based on the output waveform only. In the experiment, four current waveforms were employed; rectangular ($d=\Delta/T=0.5$) and sawtooth ($d=0$) which were of short rising and the falling time, while triangular ($d=0.25$) and sinnsoidal were of relatively long time. The main conditions of generation of the arc are shown in **Table 1**. The measure and analysis

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of the arc sound were conducted in the same way as the previous reports[14−15].

Table 1 Arcing conditions.

	Rectangular	Sawtooth	Triangular	Sine
Current Waveform	Rectangular	Sawtooth	Triangular	Sine
$d = \Delta/T$	0.5	0	0.25	
Arc Current (A)	I_{av} = 100 (17 V), I_p = 150 (20V), I_b = 50 (14 V); $\tau_p = I_p - I_b = 100$		I_{av} = 100, 150 (17 V), I_p = Var (20V), I_b = Var (14 V); $\tau_p = I_p - I_b$ = 40~460	
Pulse Frequency (Hz)	10, 30, 50, 100, 200, 360, 500, 1000, 2000, 3000			
Arc Length (mm)	5			
Gas Flow Rate (l/min)	15 (Ar gas)			
Electrode Diam. (mm)	4			

3. Experimental Results and Discussions

3.1 Effects of pulse frequency

Figure 1 describes the relation between the sound pressure level of arc sound, SPL, and the pulse frequency, f_p, for each current waveforms. It was shown from this figure that SPL increased in nearly proportional to logarithm f_p with increase of f_p. This tendency of the increase varied with each current wave; the waveform indicating a maximal value of SPL was the rectangular, decreasing sawtooth, triangular, and sine in order. Of these waveforms, the former two indicated a smooth increase of SPL, while the latter two had a tendency of a sharp increase of SPL, i.e., SPL increased by about 4 dB for the former, where as by about 7 dB for the latter when the f_p duplicated. Comparing the rectangular waveform, its value of f_p is usually used in the range of several harts to several hundreds hertz, with the sine in **Fig. 1**, it was found that

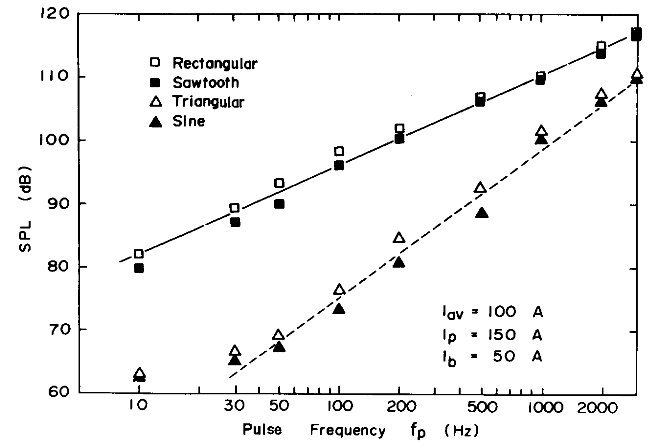

Fig. 1. Effects of pulse frequency fp on sound pressure level SPL.

SPL for the former was higher by ca. 25 dB at f_p = 50Hz and by ca. 20 dB at f_p = 200Hz than that for latter.

Now, if the effective sound pressure of the arc sound is represented by p_e, and the standard value of sound pressure by p_{eo} ($p_{eo} = 2 \times 10^{-4}$ μbar $= 2 \times 10^{-5}$ Pa), as $SPL = 20 \log_{10} p_e/p_{eo}$, then the relation between p_e and f_p is obtained by the method of least square as follows;

in the cases of rectangular and sawtooth waveforms

$$P_e \propto f_p^{0.7} \quad .... \quad (1)$$

in the cases of traingular and sine waveforms

$$P_e \propto f_p^{1.2} \quad .... \quad (2)$$

3.2 Effects of pulse amplitude

The effects of pulse amplitude, τ_p, for each current waveforms on SPL was shown in **Fig. 2**. The value of SPL increased almost proportionally to logarithm τ_p with increaes of τ_p. Like this, SPL was affected by the difference of the current waveform in same manner as in the section of **3.1**. In addition, SPL did not change at constant τ_p value even if the average current, I_{av}, changed, even in the case of I_{av} = 150A or 200A, the relation between SPL and τ_p was almost the same as the results given in **Fig. 2**. (Omitted the figure representing the state). These facts will be of interest in connection with the result that there was little occurrence of arc sound when the perfect DC was employed. The relation between SPL and τ_p was obtained from **Fig. 2** as described below;

for rectangular and sawtooth current waveforms

$$p_e \propto \tau_p^{0.7} \quad .... \quad (3)$$

for triangular and sine current waveforms

$$p_e \propto \tau_p^{1.2} \quad .... \quad (4)$$

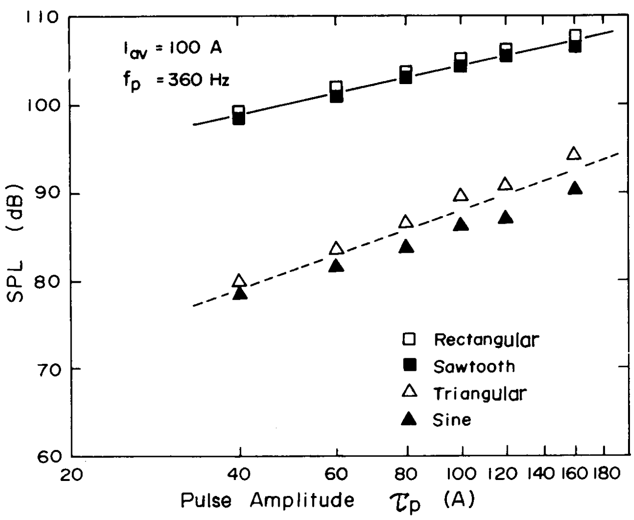

Fig. 2 Effects of pulse amplitude τ_p on sound pressure level SPL.

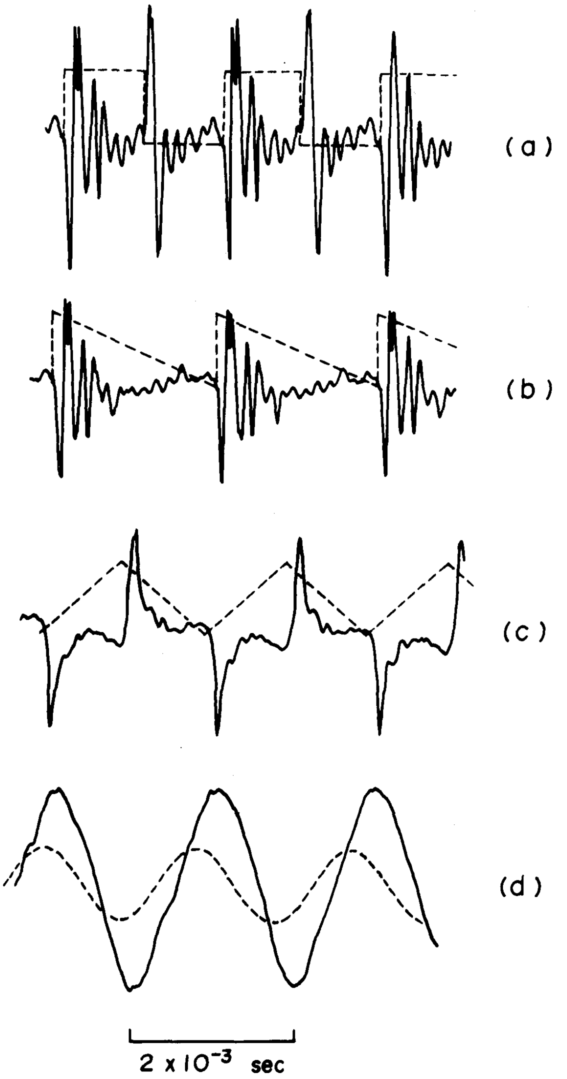

Fig. 3 Typical sound waveforms in various current waveforms (f_p = 500Hz, τ_p = 100A).
(a): Rectangular, (b): Sawtooth, (c): Triangular, (d): Sine

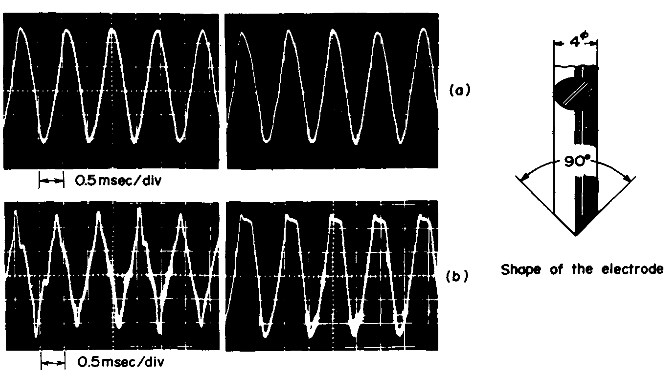

Fig. 4 Variations of sound waveform with change of electrode shape (Sine current, f_p = 500Hz, τ_p = 100A).
(a): Normal sound waveforms,
(b): Deformed sound waveforms

3.3 Arc sound pressure waveform

Figure 3 indicates typical sound waveforms obtained at the conditions of f_p = 500Hz and τ_p = 100A (I_{av}=100A), including the current waveform as a model (dotted line). The sound pressure waveform had a characteristic shape depending on the current wave and changed periodically corresponding to f_p.

In both the rectangular (a) and sawtooth wave current (b), there could be observed the occurrence of the sound wave with large amplitude where the current changed from the base current, I_b, to peak current, I_p, or from I_p to I_b. These sound pressure waveforms are similar to that observed at the conditions of short circuiting transfer in CO_2 arc welding, and both waveforms contained of strong components of higher harmonics. On the other hand, the components of sound pressure waveform in triangular(c) or sine(d) wave current were weaker than in (a) as well as (b). Particularly in (d), the sound pressure waveform could be considered to be almost wave. What is more, the time lag between the sound pressure waveform and the current waveform would be caused by the observation point of the sound being 12cm away from the point of arc occurence.

In general, the sound pressure, p, is approximately expressed as the following equation in the low frequency range of ka>1 (k : wave length constant. a : radius of sound source); $p \propto A\omega^2$ [16], where A is the amplitude of sound pressure, and ω is the angular frequency. For this, the difference of SPL come out as differences among current waveforms in **Fig. 1** and **Fig. 2** was thought to be influenced by the strength of the higher harmonics components.

As shown in **Fig. 3**, the sound pressure waveform exhibited the characteristics shape corresponding to the waveform of the current. However, the sound pressure waveform is warped by the change of electrode shape during the occurrence of arc. **Figure 4 (a)** and **(b)** showed the examples of normal waveforms and deformed waveforms respectively. SPL increases slightly when the deformed waveform appears, and the change can be easily discerned even by the hearing.

3.4 Frequency characteristics of arc sound

Examples of the frequency spectrum of the arc sound analysed by using a constant ratio band width analyser (Type 3301, Denshi-Sokuki) are shown in **Fig. 5(a)** to **(d)**. The main spectrum of the arc sound is the fundamental spectrum of f_p and its higher harmonics such as 2 f_p, 3 f_p,

... n f_p in every case of the current waveforms, and contains the components of higher harmonic over 10 f_p except the sine wave current. Thus, in case of the current wave with the pulse frequency of f_p, the arc sound will be composed of the fundamental tone which has the frequency spectrum of f_p and its harmonics.

Figure 6 shows the analytical examples of the signal waveform from the function generator, while are obtained in like manner. These results could be regarded as being about equal to the result of the current or the voltage waveform. It is found from the figure that the rectangular and triangular waves contains the spectrum components of f_p and its odd harmonic, while the sawtooth wave has the components of f_p, 2 f_p, 3 f_p and so on. It should be clear that the sine wave comprises from only spectrum of f_p, although the figure is omitted. Moreover, the results that the frequency analysis are represented as a continious spectrum shown in Fig. 5 and Fig. 6 is because of the effects of the filter-type analyser. It is obvious from the Fourier expansion that the case of **Fig. 6**, the results should be shown as the line spectrum theoretically.

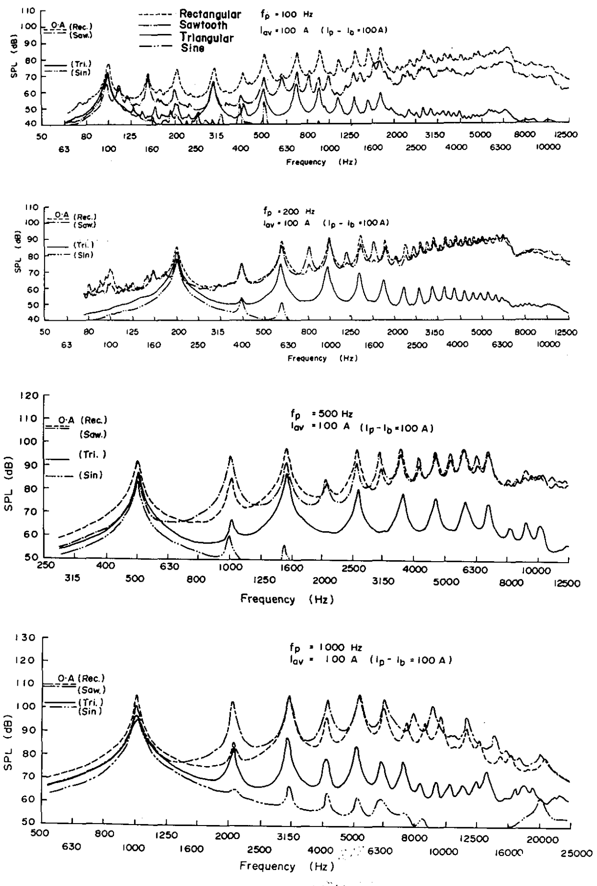

Fig. 5 Frequency spectrum of arc sound.
(a): f_p = 100Hz, (b): f_p = 200Hz, (c): f_p = 500Hz, (d): f_p = 1000Hz

Here, the spectrum which has a maximal value of peak among the frequency spectrum was defined as the excellent frequency spectrum, f_{EX} and the relation was investigated between f_{EX} and f_p. As shown in **Fig. 6**, f_{EX} is consistent with f_p for the signal waveforms from the function generator, where the line connecting the each peaks become a simple declining curve. On the contrary, it was found in case of the arc sound that f_{EX} did not necessarily agree with f_p as shown in **Fig. 7**, and the connecting line is a complicated curve with maximum or minimum.

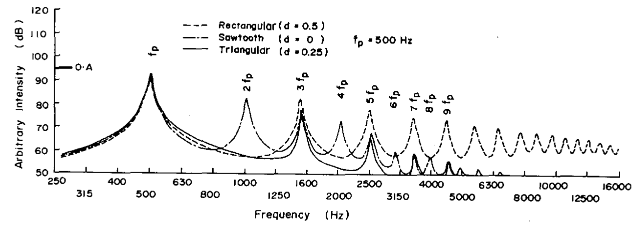

Fig. 6 Frequency spectrum of output signal from function generator (f_p = 500Hz).

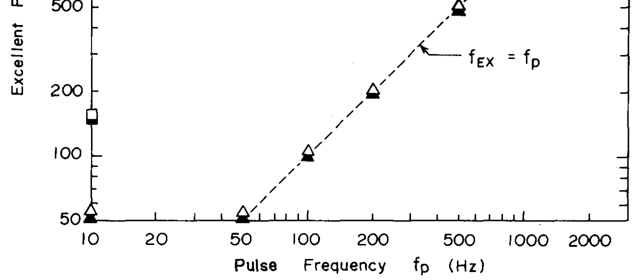

Fig. 7 Relation between pulse frequency f_p and excellent frequency spectrum f_{EX} (τ_p = 100A).

The total level of the sound pressure, L_T, is related to the band level. L_1, L

The total level of the sound pressure, L_T, is related to the band level. L_1, L_2, ... L_n, as follows;

$$L_T = 10 \log_{10} (\log_{10}^{-1} L_1/10 + \log_{10}^{-1} L_2/10 + \dots + \log_{10}^{-1} L_n/10)$$

Therefore, in the triangular and sine wave currents in which the value of f_{EX} and f_p agree well, SPL is greatly affected by f_p itself, while in the rectangular and sawtooth wave currents, SPL is preferably dependent upon the harmonics.

3.5 Noisiness of the arc sound

In regard to the noisiness of the arc sound, a pertial investigation was carried out in the previous paper[15]. There are many regulations on the noise established from the standpoint of conservation of the hearing. The permissible limit of value of American Conference of Govermental Industrial Hygiensts (ACGIH) is 85 dB(A) on the noise level for continuous noise exposure of 8 hours per day, 90dB(A) for 4 hours per day and 100 dB(A) for 1 hour per day respectively, and the noise exposure over 115 dB (A) is prohibited. Although the noise level and the sound pressure level are different substantially, the both are almost equal in the value as for the sound having the higher harmonics component like the arc sound[15].

Now, taking the case of τ_p = 100A given in **Fig. 1** when $f_p \fallingdotseq$ 30Hz in rectangular and sawtooth wave current, and $f_p \fallingdotseq$ 300Hz in triangular and sine wave current, the permisible limit of value of 85 dB(A) is attained respectively, and the value of 115 dB(A) is reached at about 2000Hz in the case of former. In some cases, the arc sound should be examined from standpoint of the conservation of the hearing as above and particular attention should be paid to high pulse frequency and large pulse amplitude conditions.

Based on the experimental results showed in section of **3.1** and **3.2** the following relation is obtained between p_e, f_p and τ_p.

$$p_e \propto f_p{}^m \cdot \tau_p{}^n \quad \text{-------------} \quad (5)$$

where m and n are constants settled by the waveform of the current.

If the equation (5) is written in terms of the sound pressure level by using the data given in **Fig. 1** and **Fig. 2**, SPL is expressed by the following equations (6), (7).

for the rectangular and sawtooth wave current

$$SPL = 14 \log_{10} (f_p \cdot \tau_p) + 40 \pm 2 \quad dB \text{ ---- } (6)$$

for the triangular and sine wave current

$$SPL = 24 \log_{10} (f_p \cdot \tau_p) - 20 \pm 3 \quad dB \text{ --- } (7)$$

These ecperimental equations are available practically in estimating the noisiness of the arc sound.

4. Conclusions

The influence of pulsation of the welding current on the arc sound was investigated on four types of the current waveforms. The results are summarized as follows;

1) The main factors determing the sound pressure, p_e, are the current waveform, pulse frequency, f_p, and pulse amplitude, τ_p, there exists a quantitative relation between these fectors; $p_e \propto f_p{}^m \cdot \tau_p{}^n$ i.e., and therefore at the contant f_p and τ_p, SPL becomes the largest for the rectangular wave current, decreasing sawtooth, triangular and sine wave current in order.
2) The sound pressure waveform depends on the current wareform, but it is warped by the change of electrode shape during the occurrence of arc.
3) The arc sound is composed of a fundamental tone which has a frequency spectrum of f_p and its harmonics, the excellent frequency spectrum, f_{EX}, is consistent with f_p for the triangular and sine wave current, but f_{EX} changes to higher harmonic for the rectangular and sawtooth wave current.
4) The available experimental equations which are possible to estimate the noise level are obtained.

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