Investigation on Welding Arc Sound (Report II)†
– Evaluation by Hearing Acuity and Some Characteristics of Arc Sound –

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Abstract

Steps of discernment and evaluation by hearing acuity of welding arc sound are systematically discribed along with results and, continued from the preceding report, several characteristics including noisy characteristics of the arc sound are reviewed.

The hearing acuity shows good discerning function; Thus, translating form of droplet and stability of the arc can be discerned by the arc sound; however, in cases of high current arc welding, pulsed arc welding or the like, hearing protective device against noise of the arc sound is sometimes required. Further, among frequency bandwidth of the welding arc sound, bandwidth 707-2245 Hz is a remarkable one wherein such informations as arc voltage, shielding effect, electrode extension and others can be obtained.

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

1. Introduction

Soundly welded joint can be obtained only by operating with appropriate welding conditions and stable arcs. Hence, the welding conditions are established in accordance with overall observations on fluctuations in the arc current and voltage, generation of spatter and fume, bead shape or the like, and, usually, operation standards are settled. On the other hand, way of evaluating steadiness of the arc is not completely definite if the steadiness is not considered to be independent of establishing the welding conditions.

As a criterion for evaluating the stability of the arc, the arc sound has been drawing welding engineers' attention hitherto, and it is reported that the above is incorporated in an instructional film for the operators realizing some results[1]. Reports on the arc sound are very few, and its characteristic or just noticeable difference in physical function test, e.g., the discernment of the arc sound fluctuations due to change of the welding conditions, is also mostly indistinct.

Discernment and evaluation by hearing acuity as well as noisiness of the arc sound are herein reviewed and, continued from the preceding report[2], autocorrelation function and narrow band frequency spectrum analysis is carried out along with some examinations on its relation to the transferring of droplets for clarifying the characteristics of the arc sound.

2. Evaluation by Hearing Acuity of the Arc Sound

Steps of receiving and evaluating by the hearing acuity of the arc sound can be schematically shown as Fig. 1 (a). Assuming those to be a feedback control system, portion of analysis and evaluation is shown in detail in Fig. 1 (b);

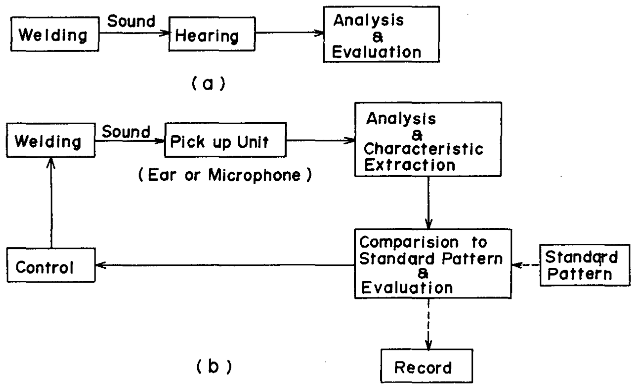

Fig. 1 Steps of receiving and evaluating by the hearing acuity of the arc sound.
(a) Feedforward,
(b) Feedback

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that is, sound wave passed through an operator's auris externa, tympanic membrane and auris media, is analysed by cochlea in the auris interna, then its characteristic is extracted in nervous system and is collated with "standard pattern" which has been individually memorized through sensation center.

In a feedback control system controlled variable of which is the arc sound, welding process is controlled with the arc voltage, for example, as manipulated variable after passing through such process as above. On this occasion, the operator's skillfulness is of great importance for the collation with "the standard pattern" and seems to have an influence upon the evaluation of informations obtained from the arc sound even if there is little difference between functions of individual hearing acuity which plays the role of a sensor. Further, said (b) of Fig. 1 can also be considered to describe a system wherein such apparatus as microphones and frequency spectrum analysers are used.

Weber - Fechner's low can rater exactly be applied to the function of hearing acuity of human being[3]; i,e., variation of stimulus ΔI, necessary for generating minimum sensation variation ΔL for discrimination, has a constant ratio to the total amount of stimulus I as shown by

$$\Delta L = C_1 \Delta I/I$$

Integrating both sides of the above equation, we obtain

$$L = C_2 \log I$$

thus, the sensation is blunted with the increase of the stimulus. C_1 and C_2 are the constants.

The function of the hearing acuity is influenced not only by personal difference, but also by acoustic environmental condition. Usually, audio frequency bandwidth of pure sound is from 20 Hz to 20 KHz, which difference limen D.L. (intensity difference between stimuli detectable with probability of 1/2) is, as for sound pressure level SPL, 1 dB when it is about 50 dB larger than threshold of audibility at 50 Hz to 10 KHz bandwidth, and, as to the frequency, for the SPL of 40 dB or more, D.L. is 3 Hz at 60 Hz to 500 Hz bandwidth and is 0.3% of frequency variation at 500 Hz or more bandwidth.

Equal loudness contours of Fletcher - Munson adopted in weight curve of sound level meter standardized in ASA and JIS, as well as said contour of Robinson and Dadson adopted in ISO standard are shown in Fig. 2. Although considerable gaps are found between both curves at bandwidth of less than 1 KHz, it is clear that the function of hearing acuity is shown best for the sound at 1 KHz to 4 KHz bandwidth and blunted at low frequency range.

If the sound pressure perceivable by the hearing acuity, the frequency bandwidth and the D.L. are known, the maximum number of steps which may be analysed by the

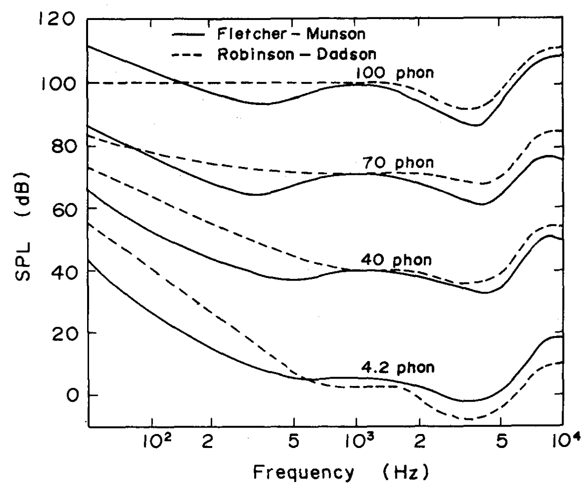

Fig. 2 Equal loudness contous of Fletcher - Munson and Robinson - Dadson.

hearing acuity on sound pressure and frequency is obtained by applicating Weber - Fechner's law. (Number of D.L. on the sound pressure: $N_p = 1/\Delta I \, dI$, Number of D.L. on the frequency: $N_f = 1/\Delta f \, df$, therfore, total number of steps detectable by the hearing acuity: $N_t = N_p \cdot N_f$).

Considering required time for discriminating a sound to be 1/5 to 1/4 second in average[4] together masking effect, information receiving capacity of the hearing acuity is effectively regarded as 8000 bits/sec approximately. The above is, however, applicable only to the pure sound which can not be identified with arc sound having spectrum components of a wide range and it just a criterion for the function of the hearing acuity.

Studied results on discernibility by the hearing acuity of the arc sound variations with the arc voltages varying so far as ±1.5 V and ±2.0 V within a reasonable range[2] are shown in Fig. 3. Each sample for this experiment is

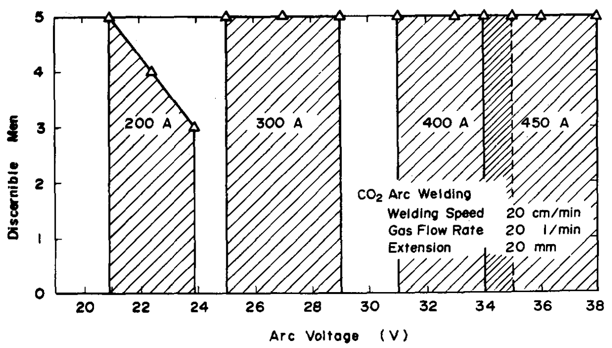

Fig. 3 Results on discernibility by the hearing acuity of the arc sound variations.

prepared by compiling the arc sounds collected by data recorder taking care not to spoil the objectivity. The test crew (5 Persons) consists of healthy men of 21 to 22 years having very little experiences in welding work and are facing to speaker at a distance of 3 m in a room having back ground noise of about 45 dB. As seen in the diagram, some replied impossible to discern in case of 200 A; however, the whole crew were discernible in case of 300 A, 400 A and 450 A. Octave band level of the arc sound analysed by octave band filter analyser is shown in Fig. 4

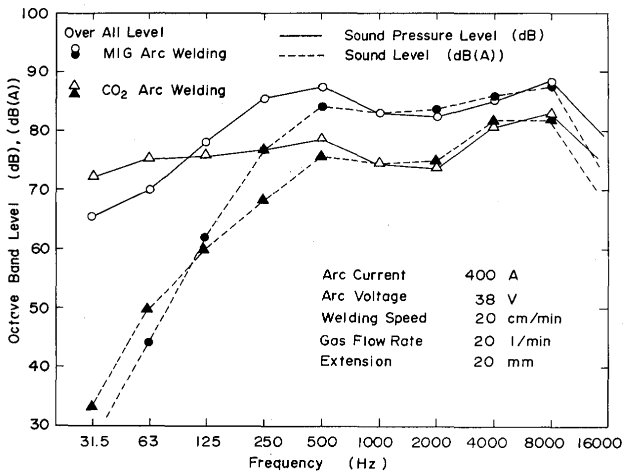

Fig. 4 Relation between the sound pressure level and sound pressure.

along with sound level obtained from the above by employing A characteristic correction value specified in JIS C 1502 to which auditory characteristic corresponds rater well; that is to say, the continuous line shows levels of the physical sounds, while the dotted line shows levels of the sounds perceived by the hearing acuity in this diagram. Remarkable difference between above both curves in found at the bandwidth of 500 Hz or less; however, the above can be easily foreseen from the auditory diagram in Fig. 2.

There is little difference between overall level of the sound pressure level and total level (L_T=10 log (log^{-1} $L_1/10$ + log^{-1} $L_2/10$ + . . . + log^{-1} $L_n/10$), where L_1, L_2, . . ., L_n is level of each band) of noise level; hence, both in CO_2 and MIG arc welding, it is known that the arc sound is mostly influenced by the sound at the higher frequency side. As abovementioned, the function of the hearing acuity does not have accuracy in physical meaning, but is very much sensitive for the discernment. Accordingly, introduction of the arc sound practice into the instruction of welding technicians is expected to make those education more effective for understanding of arcing phenomena including its stability.

3. Noisiness of the Arc Sound

Even when damping due to distance between sound source and the operator is taken into account, intensity of the arc sound sometimes reaches to 100 dB or more according to the welding method or welding condition. Just after loudly sounded, sensitivity of the hearing acuity decreases and both normal discernment and evaluation becomes difficult. Further, prolonged by noise starts, time causes temporary, sometimes dangerous permanent, hearing loss. (Hearing disease caused by noise starts, independently of its spectrum components, from bandwidth of 3 KHz to 4 KHz and becomes to cover conversational territory sometimes later).

There are many regulations on the noise established from standpoint of conservation of the hearing. ISO proposes Noise Rating Number, value N, concerning hearing disease, telephone conversational difficulty and noisiness. As for the hearing disease, according to this proposal, permissible limit of value N for continuous noise exposure of 5 hours or more per day is 85. Value N obtained from Fig. 4 is 78 in CO_2 arc welding and 85 in MIG arc welding, where the latter corresponds to the permissible limit. (Each value N is not corrected).

In some cases, the arc sound shoud be examined from standpoint of the conservation of the hearing as above and particular attention shoud be paid to high current arc welding, pulsed arc welding or the like. The other paper will report on the pulsed arc welding[5].

4. Analysis of the Welding Arc Sound

4.1 Autocorrelation function of the arc sound

A great portion of generating mechanism of the welding arc sound is unknown; however, in conclusion, existence of portion wherein the pressure is changing against the atmospheric pressure (pressure change due to vibrations or explosive phenomena) is the basis of the above. Arc sound observed in sound field is regarded as random signal following steady but irregular process, and its autocorrelation functionϕ_{pp} shows general dependence of data value at a time p(t) to value at the other time p(t + τ) and describes the secondary statistic of time series[2].

Arc sound pressure waveform portions of CO_2 arc welding (a), MIG arc welding (b) and TIG arc welding (c) are shown in Fig. 5 with corresponding autocorrelation function. From this diagram, (a) can be regarded as random signal at wide bandwidth, (b) can be regarded as a sum of random signal and sine wave signal and (c) can be regarded as almost singular sine wave signal. Fine variation of ϕ_{pp} at domains in (a) and (b) wherein τ is small is remarkable particularly in welding with consumable electrode and it shows fineness of construction of the arc sound. And, periodical component of ϕ_{pp} at domains mainly in (b) and (c) wherein τ is large corresponds to ripple frequency included in output of electric power

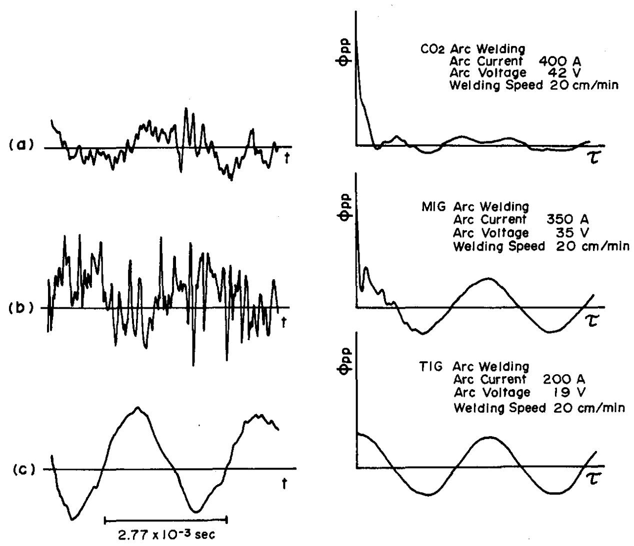

Fig. 5 Arc sound waveforms and autocorrelograms.

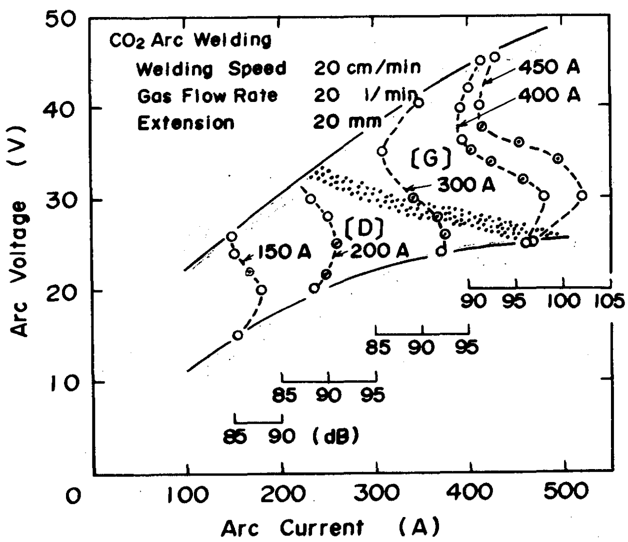

Fig. 6 Influence of welding conditions on the arc sound in CO_2 arc welding.

source for welding. Further, value of $\phi_{pp}(0)$ is total power of the overall spectrum of the arc sound. As mentioned above, characteristic of the arc sound in the time domain can be obtained by getting the autocorrelation function and by the analysis on real time, gaining of effective data for evaluation the discernment of the arc sound and the stability of the arc is considered to be possible.

4.2 Transferring form of droplet and arc sound

Influence of welding conditions (electric power supply for welding arc, welding speed, quantity of gas flow, electrode extension, etc.) on the arc sound is reviewed in the preceding report. Influence of the above on transferring form of droplet is herein reviewed further.

As well-known, transferring form of droplet changes from D type (Dip transfer) to G type (Globular transfer) in CO_2 arc welding, and changes from D to G type then to S type (Spray transfer) in MIG arc welding. Those variations also take place by increasing only arc voltage while keeping arc current. Varying domain of transferring form of droplet and SPL of the arc sound in each domain in CO_2 welding are shown in Fig. 6. Further, ○ mark in this diagram indicates SPL at reasonable arc voltage domain[2] which exists within reasonable arc voltage domain defined by T. Yamamoto[6]. As seen in this diagram, arc sound is very much sensitive to the variation of arc voltage, and its influence is noticed even to the variations in the reasonable domain. In those case, the arc sound is stable within considerably wide voltage domain including reasonable values and very much stable especially at higher voltage side of the domain. SPL becomes minimum where the voltage is slightly higher than the reasonable value; however, those are very natural since the reasonable value is defined considering increase of generated spatters with increase of the voltage, increase of generation of blow holes or the like. Several kinds of welding defects appear at the domain (hatched in the diagram) wherein the arc voltage is too high or too low, and especially when the arc voltage is too low, stabbing takes place and the arc sound becomes remarkably unstable.

According to a reference data 1), optimum transferring form of droplet can be held from sound by adjusting wire feeding speed and arc voltage and, in most case, relatively good condition, though not the best, is located at the boundary of the transferring form of droplet, and, in the CO_2 gaseous atmosphere, it exists near the transferring point from D to G. This is quite similar to the case of 300 A of said Fig. 6.

Similar diagram for MIG arc welding is shown in Fig. 7,

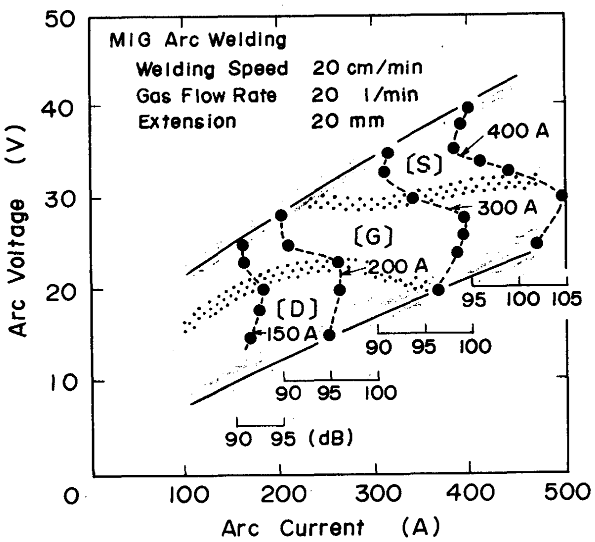

Fig. 7 Influence of welding conditions on the arc sound in MIG arc welding.

wherein variation of the SPL seems remarkable at the domain wherein the transferring form of the droplet transfers from D to G and from G to S.

4.3 Frequency spectrum of the welding arc sound

(Analysis of bandwidth wherein the hearing acuity is sensitive)

Since the arc sound generally has spectrum components of wide range, it is one of the problem which bandwidth is to be selected for the extraction of characteristic in the frequency domain. As abovementioned, the function of the hearing acuity is most sensitive at the bandwidth of 1 KHz to 4 KHz so that we herein aimed at the bandwidth of 707 Hz, wherein a peak is included in power spectrum up to 10 KHz and, supposing from the masking effect, the function of hearing acuity is expected to be active. Technique of frequency spectrum analysis is almost same as before and when defining the bandwidth, universal filter of 1/3 octave band is used.

Figure 8 shows an example of frequency spectrum

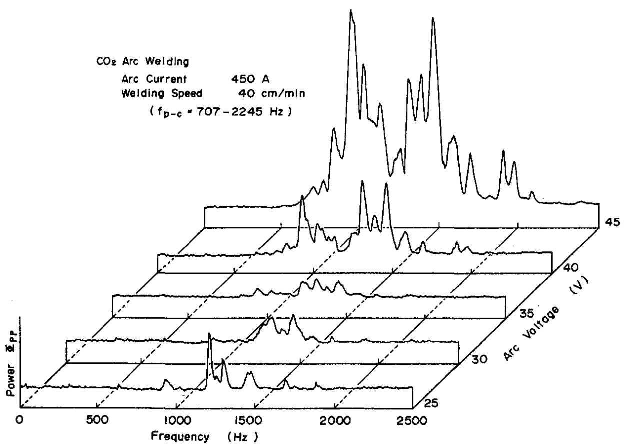

Fig. 8 Frequency spectrum of the arc sound at the bandwidth of 707 Hz-2245 Hz with various arc voltage.

analysis at the said bandwidth in CO_2 arc welding, wherein the arc current is kept constant at 450 A, while varying only the arc voltage. Although reasonable range of voltage for 450 A is 34 V to 38 V, variation of power is clearly noticed by comparing it with the case wherein the arc voltage is too low or too high. Further, the test crew could completely discern variation of the arc sound at this bandwidth by their hearing acuity.

Figure 9 similarly shows the influence of shielding gas flow rate. Though increase of power is noticed when the gas is not supplied at all, variation of said power is very little when the gas flow rate is 5 l/min or more. Above tendency is similar to the variation of the SPL[2]. The minimum required gas flow rate under said welding condi-

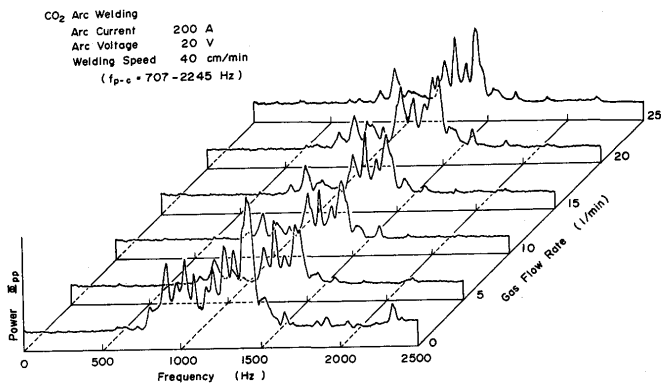

Fig. 9 Frequency spectrum of the arc sound at the bandwidth of 707 Hz-2245 Hz with various shielding gas flow rate.

tion ranges between 5 l/min and 10 l/min, and in case of higher current, above values will increase; however, in case of 400 A, difference of power spectrum according to the degree of shield effect is observed at the said bandwidth. And, the discernment by the hearing acuity is possible in the each case.

Influences of various electrode extension on the arc sound at a banwidth of 707 Hz to 2245 Hz and another bandwidth of 5660 Hz to 7120 Hz similarly having peak resulted from the frequency analysis at over all bandwidth, are shown in Fig. 10.

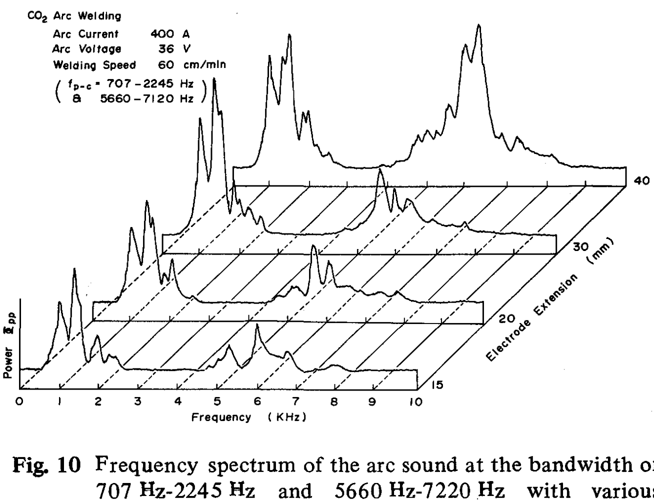

Fig. 10 Frequency spectrum of the arc sound at the bandwidth of 707 Hz-2245 Hz and 5660 Hz-7220 Hz with various electrode extension.

Difference of the influence between a case having normal electrode extension of 15 mm and 20 mm and the other case having excessive electrode extension of 30 mm and 40 mm is noticed at every bandwidth. Said difference can be discerned by hearing acuity, however, taking account of the function of hearing acuity, the sound of 5660 Hz to 7120 Hz is prospected to be masked by the sound of 707 Hz to 2245 Hz.

5. Conclusion

Discernment and evaluation by hearing acuity of arc sound and noisiness are reviewed and characteristic of the arc sound is also reviewed. The results are summarized as follows:

1) The discernment by hearing acuity of arc sound is satisfactory even when arc voltage varies in its reasonable domain.
2) when arc current is 400 A at 38 V, the Noise Rating Number is 78 in CO_2 arc welding and 85 in MIG arc welding, the latter therefore corresponds to the permissible limit of the number for the hearing disease.
3) The arc sound is composed of random component of wide bandwidth and sine wave component corresponding to ripple frequency included in output of electric power source for welding, and said sine wave component is emphasized especially along with increase of arc voltage at the domain wherein the transferring form of droplet is G type and S type.
4) The arc sound reveals a remarkable change near the transition point of the transferring form of droplet. The arc sound is stable at wider domain including reasonable arc voltage domain; however, the sound pressure level becomes minimum when the voltage is slightly higher than the reasonable domain.
5) One of the noticeable bandwidth in the frequency domain of the arc sound is, within the bandwidth wherein the hearing acuity is very sensitive, bandwidth of 707 Hz to 2245 Hz wherein the influences of arc voltage, shield effect, electrode extension and etc. can be observed.

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