Experiments on Relationship between Electromagnetic Noise and Surface Profile Change by Arc Discharge of Heterogeneous Material Contacts

Yasuo Ebara Toshiaki Koizumi Hideaki Sone Yoshiaki Nemoto
Graduate School of Information Science, Tohoku University
Sendai,980-8579 Japan

Abstract: The authors observed the relationship between waveform of electromagnetic noise and change of surface for arc discharge of opening Cu-C and Ag-Pd material electric contacts. In the case of Cu-C electrodes, the waveforms of electromagnetic noise and the changes of electrode surface are affected by electric current polarity. By the classification of noise waveform pattern, the authors showed a close relationship between noise and change of surface. The noise level of Pd(anode)–Ag(cathode) increases in the middle of arc duration, and decrease in the latter half. In conditions there exist the period of high noise level, the change of color on surfaces of both electrodes was found for Pd(anode)–Ag(cathode). Pattern of noise occurrence depends mainly on cathode material.

INTRODUCTION

Electric contacts in small electric appliances are considered as an electromagnetic noise source. It is necessary for noise control to investigate the relationship between arc discharge and electromagnetic noise generated from the electrodes. Traces of discharge on the electrode surface are formed by movement of the cathode spot and the anode spot of arc [1][2]. Intensive observation in relationship between burst noise and trace of discharge on the surface of electrode is effective in solving the noise control [3][4].

The authors have reported a correlation between electromagnetic noise by arc discharge and change of electrode surface for Cu-C electric contact as a simulation model of commutator motor[5]-[7].

In this paper, the authors observe Ag and Pd electrodes.

EXPERIMENTAL METHOD

The schematic diagram of measurement system is shown in **Fig.1**. It measures arc voltage and noise waveforms for an opening electric contact. The normal mode element of noise on the power line is detected by a choke coil, and measured as the output of spectrum analyzer(scan width 0[Hz]). Frequency f_c=5[MHz] is selected in this measurement, because the effect of propagating noise from electric contact on power line is great in range from 3MHz to 30MHz[8]. The characteristic of the choke coil is stable at this frequency. The time scale of the oscilloscope is 2[ms/div], and the resolution band width and video band width of the spectrum analyzer are set to 300[kHz] and 10[kHz]. The noise level is not calibrated, and it is referred as a relative value.

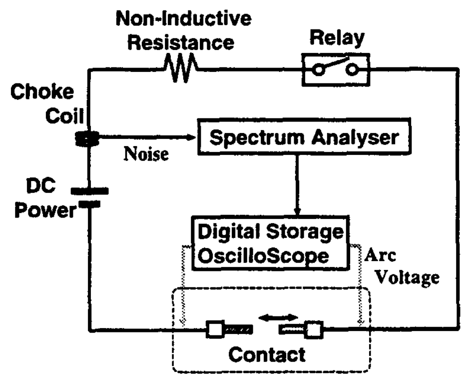

Figure 1. Schematic diagram of the measurement system

The microphotograph of the surfaces of both electrodes are taken after the first opening operation. The experimental condition is shown in **Table 1.**

EXPERIMENTAL RESULT AND DISCUSSION

Cu-C electrodes

In the case of Cu-C electrodes, the waveforms of electromagnetic noise and the change of electrode surface are affected by current polarity[5]-[7]. Classification of noise pattern showed a close relationship between noise and change of surface.

In the case of Cu(anode)-C(cathode), noise waveforms are classified into three categories by burst noise duration t_{na} which is observed at the beginning of the arc. One circular trace of discharge (area A in this paper) and shiny

Table 1. Experimental condition

Electrode	**Cu**(1mmϕ), **C**(6mm×7mm), **Ag**(1mmϕ), **Pd**(1mmϕ)
Electrode length	10mm
Circuit voltage	DC48V
Circuit current	1~4A
Circuit load	non-inductive film resistor
Opening speed	40mm/s
Opening number	1 time

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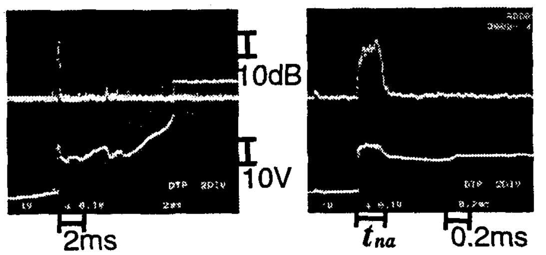
melted area (area B) exist on electrode surface. Relation between noise generation and the feature of surface change are shown in **Table 2** as observed frequencies of the patterns. Typical waveforms and microphotographs are shown in **Fig.2**. We can see that the area B corresponds to the generation of burst noise(**L** and **LC**), and the area A is formed during the steady arc.

Typical waveforms and microphotographs of C(anode)-Cu(cathode) contacts are shown in **Fig.3**. A continuous burst noise generated over the period of arc discharge. When a discontinuous fluctuation of arc voltage occurs, the level of burst noise becomes high in that period. Circular traces of discharge(area α) and shiny melted area(area β) are observed on electrode surfaces. The feature of elctromagnetic noise are classified into four patterns as shown in **Table 3**, and their frequencies and the change of surface(area α, β) are shown in **Table 4**.

These results showed a close relationship between the pattern of noise and the change of surface in Cu-C electric contacts.

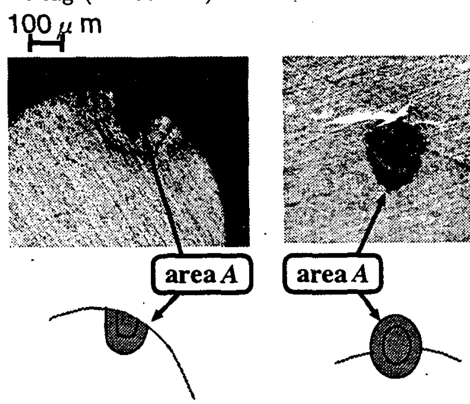
Table 2. Frequency of each pattern
[Cu(anode)-C(cathde)]

Noise	Trace of Dischage					Total
	Anode(Cu)		Cathode(C)			
	area A	area B	area A One	area A Multiple	area B	
S (t_{na}< 0.5[ms])	36	4	36	0	2	36
L (t_{na}> 0.5[ms])	26	26	26	0	23	26
LC(t_{na}> 0.5[ms] and multiple burst noise)	28	28	28	23	24	28



(i) Noise(the top) and arc voltage(the bottom)

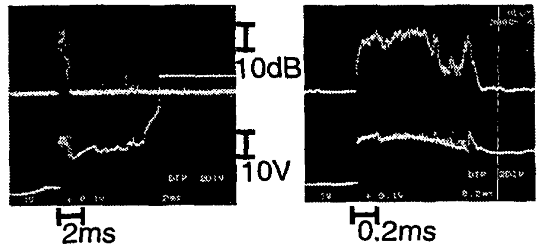
(ii) magnified waveforms



Cu(anode)

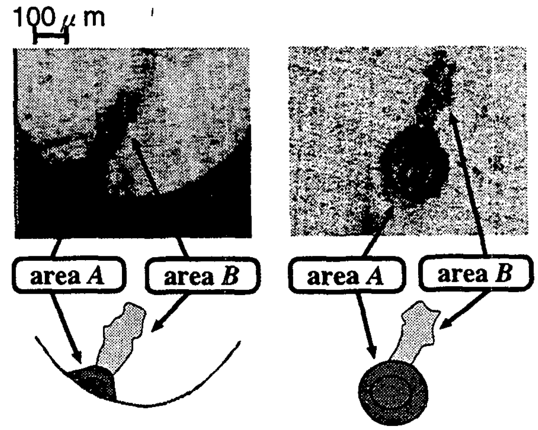
C(cathode)

(a)Pattern **S**



(i) Noise(the top) and arc voltage(the bottom)

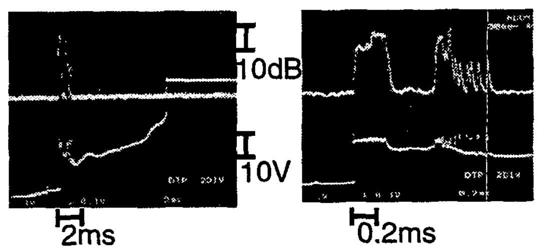
(ii) magnified waveforms



Cu(anode)

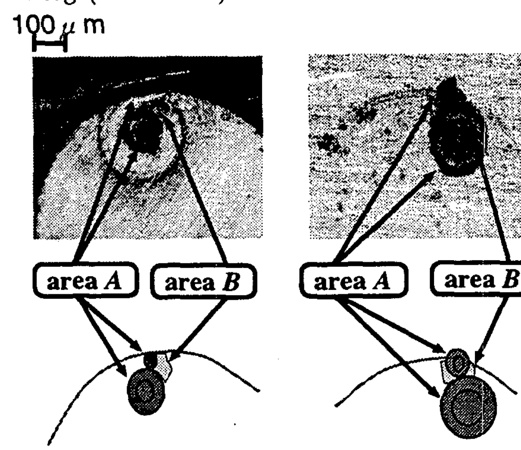
C(cathode)

(b)Pattern **L**



(i) Noise(the top) and arc voltage(the bottom)

(ii) Magnified waveforms

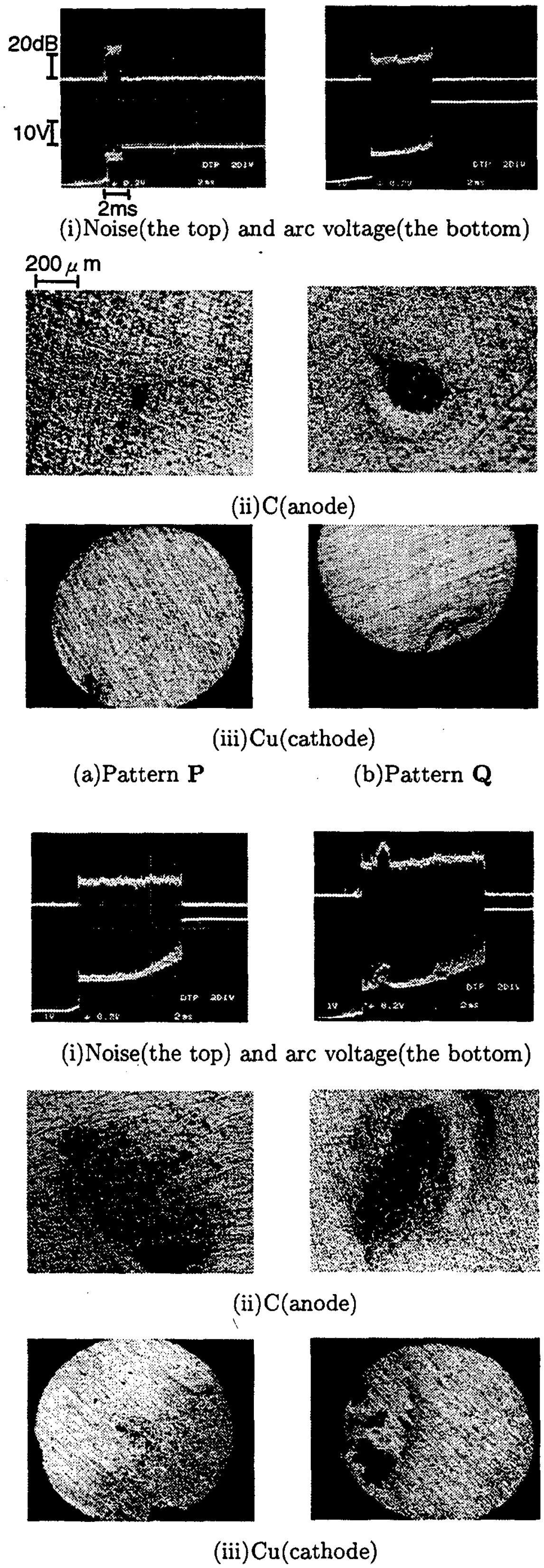


Cu(anode)

C(cathode)

(c)Pattern **LC**

Figure 2. The feature of each pattern
[Cu(anode)-C(cathode)]



(i)Noise(the top) and arc voltage(the bottom)

(ii)C(anode)

(iii)Cu(cathode)

(a)Pattern **P** (b)Pattern **Q**

(i)Noise(the top) and arc voltage(the bottom)

(ii)C(anode)

(iii)Cu(cathode)

(c)Pattern **R** (d)Pattern **S**

Figure 3. The feature of each pattern
[C(anode)-Cu(cathode)]

Table 3. The feature of noise waveform

Group	Duration	Fluctuation	
		Start	End
P	short	low	low
Q	short	low	high
R	long	low	high
S	long	high	high

Table 4. Frequency of each pattern
[C(anode)-Cu(cathode)]

Noise	Trace of Dischage						Total
	Anode(C)		Cathode(Cu)				
	area α		area α		area β		
	small	large	small	large	small	large	
P	60	1	61	0	3	0	61
Q	35	8	40	3	34	6	43
R	36	3	38	1	12	27	39
S	2	72	6	68	22	51	74

Ag-Pd electrodes

Overview of electromagnetic noise and change of surface

Measurement result at 4[A] for (a)Ag(anode)-Pd(cathode) and (b)Pd(anode)-Ag(cathode) are shown in **Fig.4**. In both current polarity, continuous burst noise was observed over the period of arc discharge. Though the fluctuation of voltage is large in the middle part in the both cases, the change of noise level is small in (a), and the level becomes higher in (b). In both cases, noise level decreases in later half.

The microphotographs of electrodes for the measurement of **Fig.4** are shown in **Fig.5** along with schematic illustrations. In Fig.5(a), areas of orange(ⓐ) and blue (ⓑ) are observed on Ag(anode) surface as well as melted parts(ⓧ) within area ⓐ(area ⓩ). Light brown object distributed widely on surface(area ⓨ) of Pd(cathode). In Fig.5(b), areas ⓐ and ⓑ are distributed widely on Pd(anode) electrode and areaⓧ has clear outline and small expanse. Areas ⓐ and ⓑ are seen in a part of area ⓨ in Ag(cathode).

Relationship between electromagnetic noise waveform and change of surface

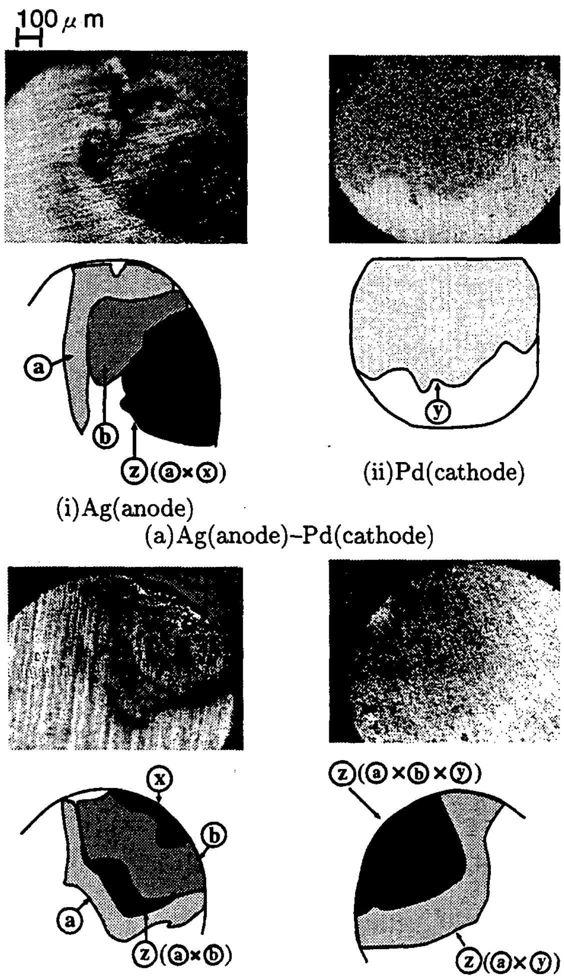
(1)Features of arc voltage and noise waveforms

In **Fig.6**, the feature of arc voltage waveform are classified for (a)Ag(anode)-Pd(cathode) and (b)Pd(anode)-Ag(cathode). The duration is divided into three parts based on fluctuation of voltage waveforms and they are defined as period **I** which the fluctuation is small, period **II** with large fluctuation. and period **III** which the voltage rises.

In Ag(anode)-Pd(cathode), noise level is stable and become lower in period **III**. In Pd(anode)-Ag(cathode), it is higher in period **II** than other periods.

(a)Ag(anode)–Pd(cathode) (b)Pd(anode)–Ag(cathode)

Figure 4. Noise(the top) and arc voltage(the bottom)



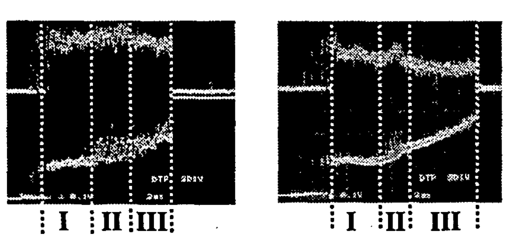
(i)Ag(anode) (ii)Pd(cathode)

(a)Ag(anode)–Pd(cathode)

(i)Pd(anode) (ii)Ag(cathode)

(b)Pd(anode)–Ag(cathode)

Figure 5. The microphotograph of electrode surface

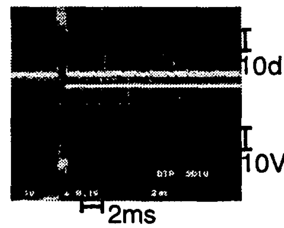


(a) Ag(anode)-Pd(cathode) (b)Pd(anode)-Ag(cathode)

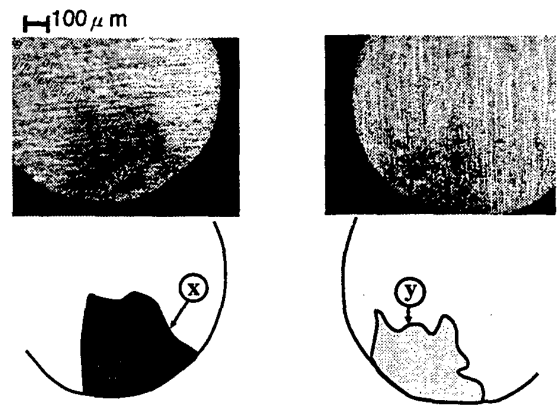
Figure 6. Classification of noise periods

(2)Ag(anode)–Pd(cathode)

Observed arc voltage waveforms for several current conditions are shown in **Fig.7**. Figures 7(a),(b) and (c) are for the cases when the waveforms are observed for the periods **I**(1.5[A]), **I+II**(3[A]), and **I+II+III**(4[A]), respectively. Occurrence frequency of each area is shown in **Table 5**. On Ag(anode) surface, only area ⓧ exist in case (a) accompanying a brown material. In case (b), areas ⓐ and ⓑ are distributed as well as ⓧ. It is considered that area

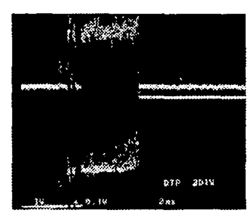


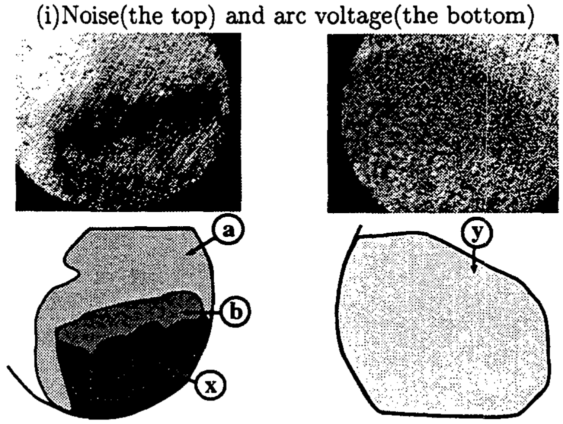
(i)Noise(the top) and arc voltage(the bottom)



(ii)Ag(anode) (iii)Pd(cathode)

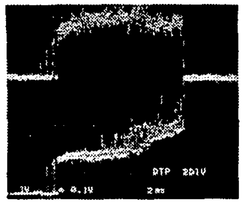
(a)Period **I**


(i)Noise(the top) and arc voltage(the bottom)

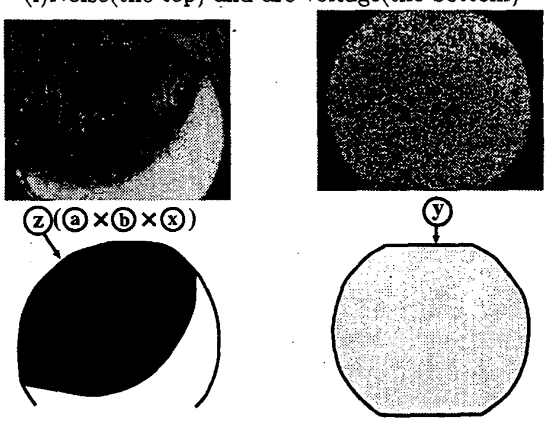


(ii)Ag(anode) (iii)Pd(cathode)

(b)Period **I+II**



(i)Noise(the top) and arc voltage(the bottom)



(ii)Ag(anode) (iii)Pd(cathode)

(c)Period **I+II+III**

Figure 7. The examples of each case
[Ag(anode)-Pd(cathode)]

Table 5. Pattern frequency of each case
[Ag(anode)-Pd(cathode)]

Noise		Feature of each Surfaces							
		Anode(Ag)				Cathode(Pd)			
		ⓧ	ⓐ	ⓑ	ⓩ	ⓨ	ⓐ	ⓑ	ⓩ
I	21	21	8	1	0	21	0	0	0
I+II	26	26	26	26	11	26	0	0	0
I+II+III	40	40	38	40	36	40	0	0	0

ⓐ and ⓑ are formed in the period **II**. Similarly, areas ⓐ and ⓑ are seen in case (c), and a black area(area ⓩ) distributed widely. Areas ⓐ and ⓑ became greater in period **III**, and it is considered that decrease of noise level in that period is related to these change on surface.

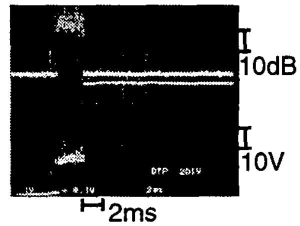
In Pd(cathode) electrode, only area ⓨ exist at all cases.

(3)Pd(anode)–Ag(cathode)

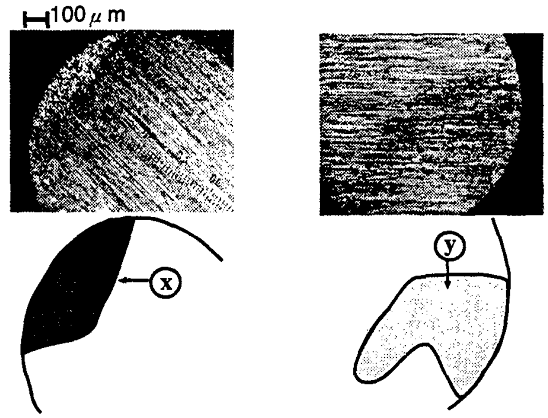
Observed arc voltage waveforms for several current conditions are shown in **Fig.8**. Figures 8(a) and (b) are for the cases period **I**(1.5[A]) and **I+II**(1.5[A]). Occurrence frequency of each area are shown in **Table 6**. (c) is for the case when the arc voltage continues until period **III**(4[A]).

On Pd(anode) surface, in case (a), area ⓧ is seen, and melted part exists with brown material mixed in this area. In case (b), areas ⓐ and ⓑ are distributed as well as area ⓧ. It is considered that areas ⓐ and ⓑ generated in period **II**. Increase of noise level during period **II** has a relationship with the generation of areas ⓐ and ⓑ. By making clear the mechanism of this relationship, it may be possible to find a new approach of noise control. In case (c), occurrence rate of area ⓩ is high.

In Ag(cathode) surface, only area ⓨ is seen in cases (a) and (b). In case (c), area ⓨ is covered with areas ⓐ and ⓑ, which becomes area ⓩ which looks to be created during period **III**. Noise level decreases in period **III**. Identically with the Ag(anode)-Pd(cathode), it is considered that the noise level is related to the changes of electrode surface, especially generation of area ⓐ and ⓑ in anode.

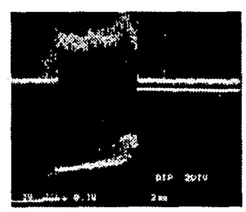


(i)Noise(the top) and arc voltage(the bottom)

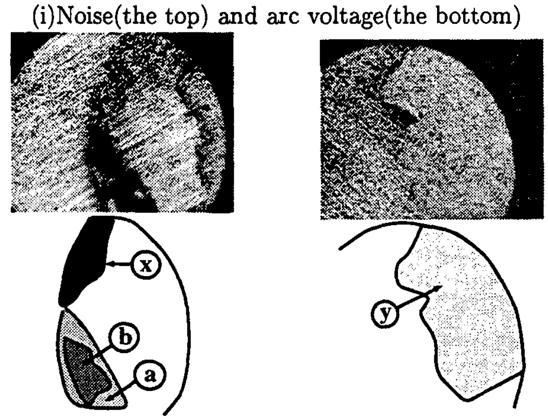


(ii)Pd(anode) (iii)Ag(cathode)

(a)Period **I**

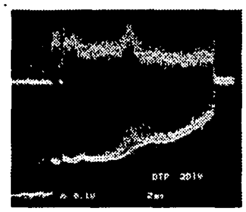


(i)Noise(the top) and arc voltage(the bottom)

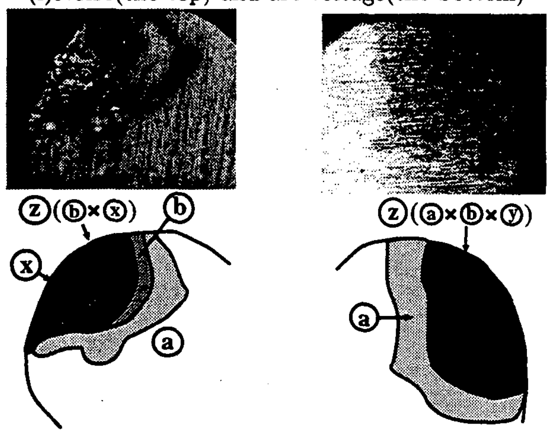


(ii)Pd(anode) (iii)Ag(cathode)

(b)Period **I+II**



(i)Noise(the top) and arc voltage(the bottom)



(ii)Pd(anode) (iii)Ag(cathode)

(b)Period I+II+III

Figure 8. The examples of each case [Pd(anode)-Ag(cathode)]

Table 6. Pattern frequency of each case [Pd(anode)-Ag(cathode)]

Noise		Feature of each Surfaces							
		Anode(Pd)				Cathode(Ag)			
		ⓧ	ⓐ	ⓑ	ⓩ	ⓨ	ⓐ	ⓑ	ⓩ
I	6	6	1	0	0	6	0	0	0
I+II	9	9	9	9	0	9	1	0	0
I+II+III	73	73	73	72	29	69	70	35	16

Table 7. Pattern frequency of each case [Ag-Ag and Pd-Pd]

Noise		Feature of each Surfaces							
		Anode(Pd)				Cathode(Pd)			
		ⓧ	ⓐ	ⓑ	ⓩ	ⓨ	ⓐ	ⓑ	ⓩ
I+II	3	3	3	1	2	3	0	0	0
I+II+III	6	6	6	6	2	6	0	0	0
		Anode(Ag)				Cathode(Ag)			
I+II+III	7	7	7	7	1	7	7	1	0

(4)Electrodes of same material

Similar measurement was done for Pd-Pd and Ag-Ag contacts. Measured frequencies of the electrode surface pattern are shown in **Table 7**. Pd-Pd and Ag-Ag have the similar tendency with Ag(anode)-Pd(cathode) and Pd(anode)-Ag(cathode), respectively. We can conclude that pattern of noise occurrence depends mainly on cathode material in this experimental conditions.

CONCLUSION

The authors observed the relationship between electromagnetic noise and the change of surface for arc discharge of opening heterogeneous material contacts. The following conclusions have been obtained from the experimental result.

(1) In the case of Cu-C electrodes, the waveforms of electromagnetic noise and the change of electrode surface depend on electric current polarity. By the classification of noise pattern, the authors showed close relationship between noise and change of surface.

(2) In the case of Pd-Ag electrodes, a continuous noise generated all over the period of arc discharge in both current polarities. In Pd(anode)–Ag(cathode), the fluctuation of voltage is large in the middle and the noise level is high. The noise level have a tendency to decrease in latter half. A close relationship was observed between occurrence of the period with high noise level and the change of color on electrode surface.

(3) Pattern of noise occurrence depends mainly on cathode material.

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